Erosional Velocity Limit

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Introduction

For two phase flow pipes, API 14E is one of the widely referenced standards in the oil and gas industries that specifies the velocity limit beyond which the erosion of pipe material is a concern. It introduces the erosion velocity limit as the basis for sizing two phase flow lines and provides a very simple equation to calculate it. Despite being a simple approach which is often appreciated by the industry, many believe that this method is highly conservative resulting in overestimated pipe sizes.

Besides, some have simply used the lower side of the API recommended range (for conservatism) without considering the nature of fluid, the system metallurgy, the corrosion protection method and more importantly failed to explain the reason for that. This has caused sort loss of confidence in the API recommended method among the standard users and questions on the basis and applicability of this method.

Furthermore, in the absence of any standard to specify the erosional velocity limit for single phase (gas or liquid) lines, there have been lots of debates on whether there is any limitation on the velocity of single phase flow in a process pipe due to erosion problem and if there is how to specify this limit.

This paper reviews the API 14E recommendations, its background and application as well as the single phase flow lines erosional velocity limit and the reason for some of the debates and confusions around this subject.

Two-phase Flow Lines (API 14E)

API 14E states that flowlines, production manifolds, process headers and other lines transporting gas and liquid in two-phase flow should be sized primarily on the basis of flow velocity. Experience has shown that loss of wall thickness occurs by a process of erosion/corrosion. This process is accelerated by high fluid velocities, presence of sand, corrosive contaminants such as SO_2 and H_2S, and fittings which disturb the flow path such as elbows.

The following procedure for establishing an erosional velocity can be used where no specific information as to the erosive/corrosive properties of the fluid is available. The velocity above which erosion may occur can be determined by the following empirical equation:

$$V_e = \frac{C}{\sqrt{\rho_m}} \qquad (1)$$

Where V_e and ρ_m are respectively the erosional velocity in ft/sec and mixture density in lb/ft^3.

Where	
$\rho_m = \dfrac{m_L + m_g}{\dfrac{m_L}{\rho_L} + \dfrac{m_g}{\rho_g}}$	m_L: Liquid mass flow rate, lb/hr m_g: Gas mass flow rate, lb/hr ρ_L: Liquid Density, lb/ft^3 ρ_g: Gas Density, lb/ft^3

Industry experience to date indicates that for solids-free fluids where corrosion is not anticipated or when corrosion is controlled by inhibition or by employing corrosion resistant alloys, values of C = 150 to 200 may be used for continuous service; values up to 250 have been used successfully for intermittent service. For solids-free fluids values of C = 100 for continuous service and C = 125 for intermittent service are conservative. If solids production is anticipated, fluid velocities should be significantly reduced. Different values of C may be used where specific application studies have shown them to be appropriate.

Where solids and/or corrosive contaminants are present or where C values higher than 100 for continuous service are used, periodic surveys to assess pipe wall thickness should be considered. The design of any piping system where solids are anticipated should consider the installation of sand probes, cushion flow tees, and a minimum of three feet of straight piping downstream of choke outlets.

Discussion on API 14E Recommendations

1. It is important to understand why the API 14E introduces the erosional velocity limit for two phase lines which is usually considered as the maximum permissible velocity and very undesirable conditions for a process line to operate at.
   This standard as its title implies provides the recommended practices for the design and installation of offshore production platform piping systems. In an offshore application, two phase flow lines mainly exist between the wellhead

and the production separator which includes flowlines, production manifolds and process headers. In one hand, the design pressures of these pipes are often extremely high. On the other hand, only limited numbers of line sizes are available in such high pressures. The following Table 1 shows the relation between the maximum allowable pressure of pipes at very high pressures and the pipe size. It shows that for example if the wellhead design condition is 400°F and 6000 psig, the line sizes larger than 3" are not suitable. This means that using the normal line sizing criteria in this particular application can impose a serious limitation on the design and extra burden on the cost of project. In other words, line sizing at high pressure application should consider the availability of line at the required design conditions, therefore approaching a high velocity limit such as erosional velocity can reduce the line size and improve the availability of pipe.

It should be noted that two phase production lines are usually short and their pressure drop does not matter much, therefore using a higher velocity limit results in a smaller line size that offers high mechanical strength at lower cost, weight and space that are extremely important in such a high pressure rating.

Table 1 – The Availability of Pipes at High Pressures

Nominal Size	**Maximum Standard Wall Thickness**	**Maximum Allowable Working Pressure (psig)**			
Inch	**Inch**	**-20 to 400 °F**	**401 to 500 °F**	**501 to 500 °F**	**601 to 650 °F**
2	0.436	6285	5939	5436	5342
2 ½	0.750	9772	9423	8625	8476
3	0.600	6090	5755	5268	5176
4	0.674	5307	5015	4591	4511
6*	0.864	4660	4404	4031	3961
8*	0.906	3700	3496	3200	3145
* All welds must be stress relieved.					

Unlike production applications, in a process plant the design pressure and temperature of two phase flow streams are not usually very high, therefore the design conditions do not restrict the selection of line size (large ones in particular). Furthermore, other considerations such as flow regime, pressure drop for relatively longer pipes and process equipment design and operation requirements usually dictate lower velocities for two phase flow lines.

In summary, considering the design and financial benefits of designing and running the pipe at such aggressive condition is often justified for (offshore or onshore) production pipes whereas in processing plants other design considerations usually govern the size of pipe. However, it is essential to check the velocity of two phase flow lines in the process plants to ensure it does not exceed this limit.

2. API 14E recommendations for two phase systems with presence of solid/sand is to use lower fluid velocities but the C factor is not discussed in this standard. This may create a wrong impression that the erosion rate as result of solid can be calculated by equation (1) whereas studies have shown that the mechanism of erosion/corrosion in the solid contaminated systems are too complicated to be predicated by such a simple model. The velocity limit for solid contaminated fluids is usually specified taking in to account the material of the system, flow regime, corrosion regime, the amount of solids and the allowable corrosion rate per year to meet the life cycle performance. Therefore, the API 14E line sizing guidelines remain applicable to the SOLID FREE TWO PHASE FLOW systems only.

3. API 14E does not specify how equation (1) has been derived but it is believed that the below formula which predicts the erosion rate of metal as a result of liquid droplet impingement is the origin of the equation.

$$V_e = \frac{Bh^{1/6}}{\sqrt{\rho_m}} \qquad (2)$$

B is a constant that depends on the target material hardness and critical strain to failure. Using B of 200 and allowing for a 10 mil per year erosion rate, equation (2) reduces to:

$$V_e = \frac{300}{\sqrt{\rho_m}} \qquad (3)$$

Abbreviation	
B	Equation 2 coefficient
C	Equation 1 coefficient
C1	Equation 4 coefficient
C2	Equation 4 coefficient
d	Pipe diameter, inch
h	Erosion rate, mil/year (1 mil = 0.0254 mm)
P	Hardness, psi
V	Velocity, ft/sec
V_e	Erosional velocity, ft/sec
W	sand flow rate, bbl/month, (bbl of sand ≈ 945 lb)
ρ_m	Gas-liquid mixture density lb/ft^3

Therefore, the API recommended C factor for the corrosion controlled two phase systems in the continuous operation is 35% to 50% lower than C factor suggested by equation (3) and hence conservative.
Using the C factor of 100 for corrosion controlled systems can result in highly conservative results. Therefore, it is essential to consult with the material/corrosion specialist and/or corrosion inhibitor vendor before selecting an appropriate C factor.

4. API 14E does not address the effect of two phase flow regime type (annular, slug, bubble, stratified, mist, etc.) on the erosion rate and C factor. Theoretically, the numbers of liquid droplets and their effect on the erosion is totally different in one flow regime than the other. For example, the erosion of pipe at bubble flow regime is expected to be lower than other flow regimes and relatively uniform for entire piping surface. In stratified and annular flow direct impingement on the pipe wall will be higher at bends. In slug flow the churning and breaking wave at the leading edge of a slug can give rise to perpendicular impacts on the bottom of straight horizontal pipe as well as at bends.
   However, it is very hard to quantify the effect of flow regime on the erosion rate. This considers the fact that flow regime changes with fluid properties (gas and liquid flow rates and densities), pipe orientation, size and type of fitting.

5. According to API 14E, a higher velocity can be used if the system is protected by use of the corrosion inhibitor. For these systems, it is essential to ensure that corrosion inhibitor offered by the vendor generates a stable film on the pipe surface that remains effective in all process conditions. This is because not all of the corrosion inhibitors work in two phase flow system. Otherwise, the system is practically in a "None" category and lower velocity limit (refer to Table 2) should be applied.
   Moreover, the highly agitated flow regime such as slug can make the corrosion inhibitor fully or partially ineffective by disturbing the chemical layer on the pipe surface and make the system in "None" category too.

6. API 14E does not discuss systems where the protection against corrosion is achieved by a corrosion protective layer (CPL). This passive film is nothing but corrosion reaction products which covers the pipe surface when material comes to a contact with the corrosive fluid. Table 2 specifies the same C factor range (150-200) for this category as other corrosion protection methods. The passive films on duplex stainless steels are stronger and more adherent than carbon steels; therefore the lower band of this range can be used for CS and higher values for SS.

7. API 14E introduces the "None" category with very low allowable velocity. It is hard to believe that a pipe in the corrosive service is considered without an appropriate corrosion protection method in the design phase. But if the corrosion protection is proved to be non-functional (for example, the corrosion inhibitor film fails in a certain condition, an inferior material has been used by mistake or corrosion inhibitor package is temporality out of service), the production rate should be reduced to meet the standard limit and prevent excessive corrosion/erosion of the pipe.

Table 2 – C Factor for Two Phase Flow

Service	Corrosion Protection	Continuous	Intermittent
Non-corrosive	---	150-200	250
Corrosive	Inhibitor	150-200	250
	CRA	150-200	250
	CPL	150-200	250
	None	100	125

8. Considering all above discussions, API 14E recommendations are summarized in the Table 2. In the presence of solid, the erosion starts at the lower fluid velocities than the liquid droplet impingement. The erosion due to solid particles is out of API 14E scope and discussed in the next section.

Solid Impingement Erosional Velocity

A very simple equation to predict the erosive damage of ductile metal due to solid particles' impingement was recommended by Rabinowicz;

$$h = 3.81\times10^{5}\ C_1 C_2 \frac{WV^2}{Pd^2} \qquad (4)$$

Where

- C_1 is the fraction of solid particles impinging the surface. 0.65 for two phase flow has been recommended.
- C_2 is the coefficient that depends on the impingement angle. It is 0.75 for elbow and 0.37 for pipe.
- V is the particle velocity that can be conservatively assumed to be equal to the mixture velocity.

According to equation (4) with fixed pipe diameter (which reflects the operating filed condition), erosion by solid is proportional to WV^2. Given that increase in the production rate can often increase the solid loading, then two times increase in production will approximately cause erosion rate (h) to increase up to ten times (if all else including corrosion, flow regime and gas-liquid ratio remain constant).
From the design perspective (with fixed production flow rate and sand concentration), since the fluid velocity (V) changes with $1/d^2$, the rate of erosion (h) by solid will be proportional to $1/d^6$. This means that reducing the pipe size from 3" to 2", the increase in the erosion rate will be more than ten times.
Substituting the value of 1.55 x 10^5 psi for steel (the variation of erosion resistance of different steel grades and alloys is not high) and assuming the acceptable erosion rate of 10mil/year, equation (4) for two phase flow line can be written as:

$$V_e = \frac{4d}{\sqrt{W}} \qquad (5)$$

When W approaches zero, the value of V_e is limited by equation (1), which is for solid-free system. Equation (5) is reasonably conservative and therefore in the absence of detailed erosion rate modelling can be used as a design criterion.

Single-phase Flow Lines

For non-corrosive solid-free single phase flow lines, there is no velocity limit requirement to avoid erosion damage.
For corrosive solid-free single phase flow lines also there is no velocity limit to prevent erosion. However, if corrosion inhibitor is used to control the corrosion, the fluid velocity shall be limited to the velocity required to ensure the stability of corrosion inhibitor film on the pipe surface. A typical example is Amine Solution with the velocity limits shown in Table 3 below. This velocity limit can be set in consultation with material specialist or corrosion inhibitor vendor.

If protection against corrosion is achieved by the protective corrosion-product layer, the fluid velocity shall be limited so that it cannot remove the corroded metal plaques from the surface of the pipe and expose the fresh metal to the corrosive fluid. This is much higher than the common velocity limits that are usually used for sizing a single phase line and hence in reality it is not practically considered to be a design limit.

Table 3 – Velocity limit for Amine Solution

Service	Velocity (m/sec)
Lean Amine Solution (CS pipe)	3.0
Rich Amine Solution (CS pipe)	1.0

If solid is present, the erosional velocity limit can be calculated by equation (4). However, the way solids erode the pipe wall in the gas is different than the liquid. The solid particles carried in the gas most probably hit pipe walls at the full gas velocity. In liquid flow, solid particles travelling at the liquid velocity will be significantly slowed by a liquid barrier layer on the pipe wall before striking the pipe material surface. In other words, most of the particles in the liquid will be carried in the stream in the center of the flow without impacting the pipe surface. In line with this observation, C_1 of 1.0 for gas and 0.3 for liquid have been recommended for equation (4).

Other Similar Criteria

There are other requirements that have been mixed up with the erosional velocity limit because of the similarity of terms or formulation. Some of the different cases at which ρV^2 has been commonly used as the design criteria are outlined below:

1. For the design of separator (inlet and outlet) nozzles. From process viewpoint, ρV^2 is:
   - The indication of stream momentum which is very important on the inlet side of the vessel to prevent liquid shattering and re-entrainment. On the gas outlet nozzle, ρV^2 is important to prevent localized high velocities in the mist extractor that can adversely affect the mist extractor performance. As discussed in "Three Phase Separator - Inlet Device", different ρV^2 limits is used for vessel nozzle sizing.
   - The sign of vibration. For example, ρV^2 of 6000Pa is usually used for the TEMA heat exchangers inlet and outlet nozzle sizing.
2. The calculation of force for piping support design is also related to ρV^2 as shown in the following formula. Flare header is one of the typical applications where ρV^2 (of typically less than 100000Pa) is used to limit the piping stress levels, vibration, fatigue, noise, etc.
   $F = \rho V^2 A$
   Where F and A are respectively force in Newton and the cross-sectional area of the pipe in m^2.
3. The preliminary line sizing. For example, the blowdown and relief valve outlet line in the gas service can be estimated based on $\rho V^2 < 150000$Pa.

Rearranging some of these relations to calculate the C factor may bring the erosional velocity limit to mind whereas they have been devised for reasons other than erosional velocity.

Contact

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