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Guidance on Practice for Erosion Control

GP 06-14

BP GROUP
ENGINEERING TECHNICAL PRACTICES

Foreword

This is the first issue of Engineering Technical Practice (ETP) BP GP 06-14. This Guidance on Practice (GP) is based on parts of heritage documents from the merged BP companies as follows:

British Petroleum

RP 32-4	Inspection and Testing of In-Service Civil and Mechanical Plant - Technical Guidance.
RP 14-2	Heating, Ventilating and Air Conditioning – Onshore.
RP 26-1	Heat Exchange Equipment.

Amoco

PTA PC-CVPR-00-G	Process Control—Control Valves and Pressure Regulators—Guide.
PTA FE-BLR-00-G	Fabricated Equipment—Boilers and Steam Generator—Guide.
PTA PN-NM-FRP-E	Piping—Nonmetallic Materials—Fiber Reinforced Plastic Pipe—Engineering Specification.

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Table of Contents

	Page
Foreword	2
1. Scope	5
2. Normative references.....	5
3. Symbols and abbreviations.....	6
4. Erosion	6
4.1. General.....	6
4.2. Liquid droplet erosion.....	7
4.3. Erosion-corrosion.....	7
4.4. Cavitation - erosion	7
4.5. Flow regime and its effect upon erosion.....	8
4.6. Why is erosion such an issue within BP?	10
5. BP approach to designing against erosion via erosion modelling.....	10
5.1. BP Erosion Model	10
5.2. Main erosion rate models.....	11
5.3. Accuracy of erosion models	16
5.4. Erosion modelling of flexible pipes/risers	17
5.5. Use of Computational Fluid Dynamics (CFD) to assess erosion	17
6. Existing standards for assessing/minimising erosion.....	18
6.1. API RP 14E (ISO 13703)	18
6.2. DNV's RP-O501.....	20
6.3. Other standards.....	20
7. Designing against erosion in refining operations.....	21
8. Material selection to minimise erosion and erosion-corrosion	22
8.1. General.....	22
8.2. Use of hard materials.....	23
8.3. Use of soft materials	24
8.4. Use of CRAs to avoid the corrosion element of erosion-corrosion.....	25
9. Equipment design to minimise erosion.....	25
9.1. Piping sizing, layout and routing.....	25
9.2. Piping bend points	25
9.3. Choke valves	27
9.4. Isolation (block) valves.....	30
10. Monitoring/assessment of erosion damage and/or solids production	30
10.1. General.....	30
10.2. Inspection	30
10.3. Sampling for solid particles	32
10.4. Solid particle detectors.....	33



10.5. Monitoring solid particle build-up in vessels	34
11. Existing guidance documents	34
11.1. In-house erosion guidelines and solid particle management guidelines	34
11.2. In-house guidance on erosion management	35
11.3. UK HSE guidelines	36
11.4. EEMUA guidelines	36
Annex A Informative Flow chart for assessment of erosion	37
Bibliography	38

List of Tables

Table 1 – Alternative material relative erosion resistance performance	23
Table 2 – Suggested maximum fluid velocities	35
Table 3 – Maximum flow velocities for FRP piping	36

List of Figures

Figure 1 – Typical two-phase flow patterns	9
Figure 2 – Comparison of API RP 14E threshold curves and 'failure' data	19
Figure 3 – Example of a flanged tee (flow tee with blind flange)	26
Figure 4 – Example of a capped tee (ordinary tee with weld cap)	26
Figure 5 – Lead-filled target blind flange	27
Figure 6 – Various designs of choke valve	28
Figure 7 – Potential erosion mechanism for the inside of elbows/bends	32



1. Scope

This GP provides guidance for modelling erosion, material selection and equipment design to minimise erosion, and monitoring of erosion damage.

2. Normative references

The following normative documents contain requirements that, through reference in this text, constitute requirements of this technical practice. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. However, parties to agreements based on this technical practice are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. For undated references, the latest edition of the normative document referred to applies.

BP

GP 14-??	Guidance on Practice for HVAC (RP 14-2).
GP 32-48	Guidance on Practice for In-service Inspection and Testing of Heat Exchangers (RP 32-4).
GP 42-??	Guidance on Practice for Non-metallic Piping [PTA PN-NM-FRP-E].
GP 56-??	Guidance on Practice for Boilers [PTA FE-BLR-00-G].
GP 62 01	Guidance on Practice for Valves.
GP 62-??	Guidance on Practice for Control Valves and Pressure Regulators [PTA PC-CVPR-00-G].
D/UTG/088/99	Adding Value with Sand Detection.
S/EPT/096/04	Erosion Guidelines Revision 3 (2004).
S/UTG/006/00	Living with Sand.
S/UTG/023/00	Guidelines for Selecting Downhole Tubular Materials for Oil & Gas Production Wells.

American Petroleum Institute API

API RP 14E	Recommended Practice for Design and Installation of Offshore Production Platform Piping Systems.
API RP 17B	Recommended Practice for Flexible Pipe.

Det Norske Veritas (DNV)

DNV RP-O501	Erosive Wear in Piping Systems.
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International Organization for Standardization (ISO)

ISO 10420	Petroleum and Natural Gas Industries - Flexible Pipe Systems for Sub-sea and Marine Riser Applications.
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Note: ISO 10420 is currently being revised and is due to be replaced by ISO/DIS 13628-2.

ISO 13703	Petroleum and Natural Gas Industries - Design and Installation of Piping Systems on Offshore Production Platforms.
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NORSOK

NORSOK Std L-002	Piping design, layout and stress analysis.
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UK Health and Safety Executive (UK HSE)

UK HSE RR115

Erosion in elbows in hydrocarbon production systems: Review document.

3. Symbols and abbreviations

For the purpose of this GP, the following symbols and abbreviations apply:

CFD	Computational fluid dynamics.
CRA	Corrosion resistant alloys.
CVD	Chemical vapour deposition.
DN	Nominal diameter.
FRP	Fiber reinforced plastic.
GRP	Glass reinforced plastic.
HVAC	Heating, ventilating, and air conditioning.
JIP	Joint industry project.
NEL	National engineering laboratory.
NPS	Nominal pipe size.
ToFD	Time of flight diffraction.

4. Erosion**4.1. General**

Erosion is the mechanical loss of material by the impact of solid particles and/or liquid droplets. For the purposes of this GP solid particles are defined as particulate inorganic matter that can cause erosion damage, examples include sand (silica), certain hard scales (e.g. magnetite, mill scale) proppants and catalysts.

Under certain flowing conditions, erosion damage can be very rapid. There have been countless examples of highly concentrated erosion damage of the topsides components of drilling rigs and offshore production platforms. Many of these failures have occurred over very short timescales, i.e. a few hours, e.g. during well clean-up operations.

Erosion failures are not new, the oil and gas industry continues to suffer from such failures – ‘erosion’ has accounted for nearly a third of the loss of containment incidents reported to the UK HSE over the past 10 years.

Many flow dependent wastage mechanisms are termed ‘erosion’. The majority of the reported ‘erosion’ failures can be sub-divided into one of the four main erosion mechanisms that may be encountered in produced fluids systems:

- *Erosion by non-corrosive fluids through liquid droplet impact.*
- *‘Pure’ solids erosion by non-corrosive fluids carrying solid particles.*
- *Erosion-corrosion by a corrosive medium in the absence of solids.*
- *Erosion-corrosion by a corrosive, solids-containing medium.*



4.2. Liquid droplet erosion

- a. This form of erosion is produced by the formation of very high pressures and shear stresses at the point where the liquid droplets contact the pipe wall.

Droplet impact is possible in annular mist flow, e.g. wet gas, but in general liquid droplet erosion is only considered to be a potential problem in very high velocity systems.

- b. Typically, for gas-condensate systems, a velocity of 70 m/s (230 ft/s) should not be exceeded.

4.3. Erosion-corrosion

- a. Erosion-corrosion occurs in environments that have the potential to be both erosive and corrosive. The erosion and corrosion can be either independent, in which case the total wastage is the wastage produced by each mechanism in isolation, or synergistic, in which case the total wastage is greater than the sum of the independent mechanisms of erosion and corrosion.

In solids-containing flows, the synergy between the erosion and corrosion rates, e.g. due to the removal of protective corrosion scales or inhibitor films, can be such that the resultant damage is enhanced. The most damaging situation occurs where any corrosion scale is only removed over a small area. Although solid particles may be implicated in the removal of the scale, this situation can occur without solids being present if the scale is not strongly adhered and flakes away from particular locations where the flow is disturbed, e.g. weld roots, flanges etc. Wall loss is likely to appear in the form of pitting corrosion. Under these conditions, the rate of wall loss in the location where the scale has been removed is dictated by the ratio of the scale-coated pipe wall to the area of the bare pipe wall. Erosion studies at Tulsa University have shown that where a protective iron carbonate scale is formed, but becomes damaged due to erosion, rapid, highly localised corrosion can result.

- b. Erosion-corrosion is not pure erosion and this GP does not address this phenomenon in detail. Nevertheless, potential interactions between the erosion and corrosion mechanisms shall be considered. Further guidance on dealing with erosion-corrosion is given in S/EPT/096/04.

The approach has been to set a maximum allowable erosion rate of 0,1mm/yr for materials that are prone to synergistic erosion-corrosion (i.e. carbon/low alloy steels and 13Cr steel). It is believed that as long as the erosion rate is maintained below this limit the risk of synergistic erosion-corrosion is acceptably low.

In the case of duplex stainless steel and higher CRAs (e.g. highly alloyed austenitic stainless steels, nickel alloys) no maximum allowable erosion rate has been set. Rather in these cases the maximum allowable erosion rate will be determined by the equipment design and the wastage tolerance available.

4.4. Cavitation - erosion

- a. If the potential for cavitation exists, control valve types which result in a high pressure recovery downstream (such as ball valves and butterfly valves) should be avoided as should piping features causing a high local pressure reduction (such as sharp bends). The use of multi-stage pressure drop devices and long radius bends etc. is recommended.

Cavitation is caused by the high energy collapse of vapour bubbles (or cavities) in a liquid flow stream as a result of pressure recovery following pressure reduction to a value below the vapour pressure of the liquid at the flowing temperature. Solid boundaries in the vicinity are likely to be eroded. This is a complex phenomenon and, like other forms of erosion, it can exacerbate corrosion effects if materials are susceptible. Cavitation erosion is not caused by the impact of solid particles or



liquid droplets, but by the impact of a very high velocity liquid pulse onto the solid boundary from a collapsing bubble. Cavitation emits a characteristic noise by which its presence and severity (incipient or full cavitation) can be recognised.

Cavitation may be caused by other features of the flow passage causing a sharp change in the flow direction e.g. a tight-radius (or no radius) 90-degree elbow, in which the pressure falls below the vapour pressure. Pump impellers may also initiate cavitation. Pipe fittings and valves can be allocated a "cavitation index" by the manufacturer which is a measure of their propensity to cause cavitation in a particular flow regime. Cavitation-erosion can also be caused by surface roughness, e.g. poor internal surface condition of a pipeline, and the damage often appears in the form of 'peening'.

- b. Appropriate erosion resistant materials (stellite, tungsten carbide, etc.) should be used locally in the area where cavitation is expected to occur.

Austenitic stainless steels, martensitic stainless steels, and nickel alloys are more resistant than carbon steel, but materials which are highly resistant to other forms of erosion, such as stellite, etc., are many times more resistant to damage.

- c. This GP does not provide any further guidance in evaluating the potential for, or extent of, cavitation erosion. If possible it should be avoided by appropriate design and equipment selection.

4.5. Flow regime and its effect upon erosion

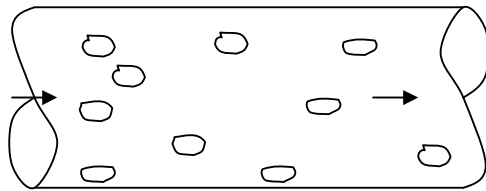
Flow regime is an important parameter in determining the erosion damage in a flow stream and this should be considered. Guidance on the consideration of flow regime is given in S/EPT/096/04.

One of the main difficulties of predicting the level of erosion damage in multiphase piping systems is due to the fact that numerous flow patterns of widely different geometry and mechanics can coexist. The flow patterns usually encountered in multiphase flow are usually referred to as:

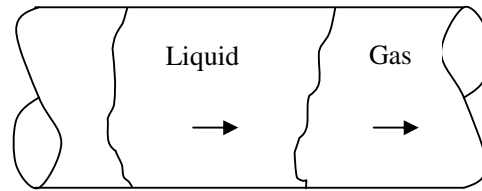
- *Bubble (or bubbly) flow.*
- *Plug flow.*
- *Stratified flow.*
- *Wave (or wavy) flow.*
- *Annular flow.*
- *Slug flow.*
- *Churn flow.*
- *Mist (or spray) flow.*

With the possible exception of stratified flow, these various flow patterns are common to horizontal, vertical, or inclined flow. Refer to Figure 1.

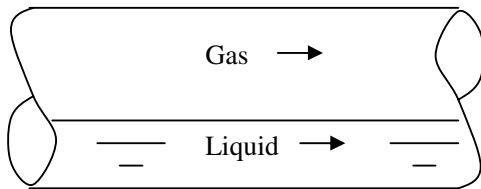


Figure 1 – Typical two-phase flow patterns

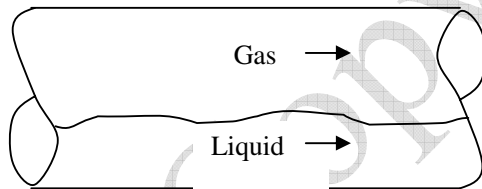
Bubble (or bubbly) flow



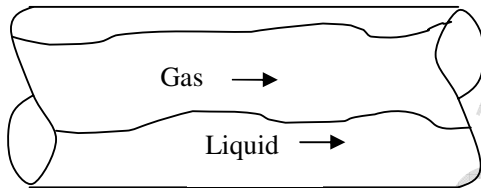
Plug flow



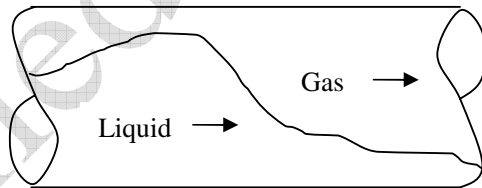
Stratified flow



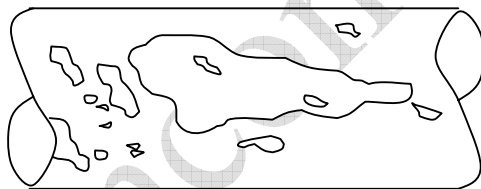
Wave (or wavy) flow



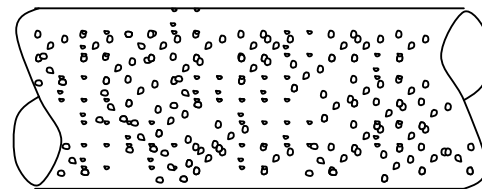
Annular flow



Slug flow



Churn flow



Mist (or spray) flow

The flow regime is very important in determining the erosion characteristics of multiphase flow, i.e. flow containing solid particles. The major factors that affect erosion in multiphase flows are: the phase the solid particles travel in; and how the phases are distributed in various geometries.

Due to the higher density and viscosity of the liquid compared with the gas phase, particles carried in the liquid phase follow the flow streamlines more closely and are less likely to impact the pipe wall if the fluid changes direction. Hence, for the same mixed phase velocities, flow regimes where the particles are carried in the gas exhibit higher erosion rates than flow regimes where the particles remain in the liquid.



In annular flow the particles are carried in both the liquid film and the gas core. The phase distribution in annular flow usually consists of a slow moving liquid film on the pipe wall and more rapidly flowing gas core containing liquid droplets.

In bubble (or bubbly) flow the low relative velocity between the gas and liquid phases means that there is very little entrainment of particles into the gas phase. This results in all of the particles being carried by the liquid phase. The liquid flows as a continuous phase with the gas fairly evenly distributed in it. As both gas and liquid flow at similar velocities the effects of bends and fitting on the phase distribution is much less pronounced than in annular flow.

As with bubble (or bubbly) flow, the relative velocities between the phases, in churn flow, is low. However, in churn flow, the large amount of mixing and generally random distribution of the phases could lead to a small proportion of the particles being transported in the gas phase.

4.6. Why is erosion such an issue within BP?

Any facility operated by or on behalf of BP that encounters the combination of flowing fluids and entrained solids and/or liquid droplets can be susceptible to erosion damage and the associated consequences of failure.

Erosion of components, e.g. valves, refractory linings, by catalysts is not uncommon in refinery operations, e.g. Fluidic Catalytic Cracking Units, and the pumping of slurries is not without its share of reported problems due to erosion.

Under aggressive operating conditions, velocity limits (and hence production limits) shall be set to avoid unacceptable levels of erosion. Guidance on evaluating the aggressivity of conditions in terms of erosion are given in S/EPT/094/04 and clause 5 of this document.

If these limits are overly conservative then BP loses production; if they are too optimistic then BP risks erosion damage and the loss of system integrity.

Erosion problems in the oil and gas industry are likely to increase in the future due to the changing nature of the produced fluids, e.g. increased levels of produced reservoir solid particle, and their method of production, e.g. increased use of multiphase flow.

5. BP approach to designing against erosion via erosion modelling

The risks posed by erosion damage are not new. In the 5½ years to 1997 the UK's HSE recorded 800 loss of containment incidents. 21% of these incidents were specifically identified as being attributable to either corrosion or erosion.

Accepting the reservations expressed on the API RP 14E methodology, there was a need to develop new methodologies, or models, to assess the erosion damage rate of plant components deemed to be the most susceptible to erosion.

Design against erosion should evaluate the likely erosion rate in the system using appropriate erosion model(s) and then determine whether the predicted levels of erosion are acceptable. The appropriateness of erosion models should be determined based on the following clauses 5.1 through 5.5.

5.1. BP Erosion Model

The BP Erosion Model should be used as a 'first pass' assessment tool to determine whether it is necessary to undertake a more thorough assessment using the Full Erosion Models, i.e. SPPS, Sandman, or DNV model and is intended to be used in place of the API RP 14E equation. It is not intended for use in detailed studies on the effects of various production parameters on erosion, etc. The BP Erosion Model is available in S/EPT/096/04.



The BP Erosion Model is based, in part, on a modified version of Salama's erosion model (refer to clause 7.2.5). These modifications deal with the over/under predictions of Salama's erosion model for certain multiphase flow conditions/regimes. As such, the BP Erosion Model provides for a 'smooth' transition between the liquid dominated and gas dominated threshold curves as presented in Figure 1 of this GP.

The BP Erosion Model is available as a spreadsheet and is capable of predicting the erosion rate (in mm/year) based upon input of:

- *Pipe internal diameter (assumed geometry is 1,5-D elbow).*
- *Superficial gas and liquid velocity.*
- *Gas and liquid density under process conditions.*
- *Process temperature and pressure.*
- *Solid particle size and content.*

The BP Erosion Model is a simplified erosion model compared with the 'full erosion rate models' (Sandman, SPPS, DNV model) and does not account for all the parameters known to affect the erosion rate, e.g. system geometry, flow regime, fluid viscosity. It has purposely been set toward the upper (conservative) end of the erosion rate prediction spectrum.

The BP erosion model should only be used for the following:

- a. Predicting solids erosion rate(it cannot predict droplet erosion damage levels).
- b. For solid particle sizes in the range 50 to 500 microns (2 to 20 mils).

The model should not be used for slug/churn flow. (It has been shown that the erosion rate under such circumstances can be 5 to 10 times higher than that predicted by the BP model.)

5.2. Main erosion rate models

5.2.1. General

During the last 10 –15 years, research groups in North America and Europe have conducted programmes of experimental and theoretical work to better understand the process of erosion (and erosion-corrosion), leading to the emergence of four recognised erosion models that are capable of predicting the erosion rate that should be expected under given flowing conditions.

- a. The four main erosion models that have been developed are:
 1. AEA Technology's Sandman (Sman39).
 2. University of Tulsa's (E/CRC) Sand Production Pipe Saver (SPPS).
 3. DNV's RP-O501.
 4. Salama's OTC 8898.

These erosion rate models quantify the erosion rate as a function of:

- *Flow (velocity, gas-liquid ratio).*
- *Fluids.*
- *Properties of the solid particles.*
- *Geometry of the piping components (radius of curvature, fitting type).*
- *Material of piping component.*

Each of the four models reduces to the following form of equation:



$$E = \int_0^n R \, dt$$

$$R = S \cdot P$$

$P = f(\text{flow-rates, fluid, particles, geometry and materials})$

where, E is the cumulative erosion damage through a field-life of n years, R is the rate of erosion damage (mm/yr), S is the solid particle flow-rate (tonne/yr) and P is the potential erosion rate (mm/te).

Models of this type enable one of the following quantities to be explored as a function of the other two:

- Erosion allowance.
- Component lifetime.
- Permissible flow conditions.

- b. It is important to be aware that limits of applicability exist for these models – mainly due to the fact that the experimental test work has been undertaken on small diameter pipework (typically DN 25 – DN 50 (NPS 1 – NPS 2)), with a limited range of solid particle size (typically 150 – 300 microns (6 – 12 mils), over a limited range of gas and liquid flow velocities using low cost fluids (air, N₂, water) and for low pressure operation (typically 1 – 10 bar (14.5 – 145 psi)). Each model, therefore, uses a set of equations to extrapolate from the limited set of test results to the process conditions for which the erosion rate is required.

Each of the four erosion models are briefly discussed below in terms of how they were developed, the principles that they are based upon, and the limitations to their use.

5.2.2. AEA Technology: Design procedure for erosion-corrosion in multiphase systems – ‘Sandman’

The ‘sandman’ erosion model was developed within the Critical Flow-rates Working Party Joint Industry Project (JIP) conducted between 1989 and 1997. The JIP was carried out in three stages and was funded by up to 10 major oil and gas operators (including BP) and the offshore division of the UK HSE. Stage 1 of the JIP investigated the validity of API RP 14E and provided improved guidelines, in the form of a design procedure, for determining the effect of erosion in production facilities. Stage 2 of the JIP investigated the interaction between erosion and CO₂ corrosion. Stage 3 of the JIP extended the investigation of erosion and CO₂ corrosion to address the effect of temperature and included modelling to understand the role of effects that were not studied as part of the experimental programme (pipe diameter, bend radius, effect of pressure, fluid properties and solid particle size).

The JIP included carrying out experimental work in a purpose-built test facility and also included modelling work, based on the use of particle trajectory analysis, to determine the effect on erosion of those parameters not specifically included in the experimental work. The experimental work investigated the erosion of four pipe geometries (constriction, 1.5 D elbow, 5 D bend, and a flanged equal tee – all based on 50 mm (2 in) nominal bore) and the erosion of commonly used steels ranging from carbon/low alloy steels, e.g. L80, to duplex stainless steel. Sand-laden, multiphase (N₂ and water) flow conditions operating at a maximum superficial gas velocity of 30 m/s (100 ft/s) and a maximum superficial liquid velocity of 15 m/s (50 ft/s) were facilitated by combining the flow of a liquid flow loop and the flow of a gas flow loop into a 10 m (33 ft) long vertical section within which the test components (geometries/materials) were mounted. One size of sand (150 microns

