Flow Assurance & Operability
Erosion due to sand production
Overview

1. What causes erosion?
2. Sand production and transport
3. Sand management
4. Instrumentation / monitoring of sand production
5. Guidelines and Sand erosion prediction models
What causes erosion?

Erosion can be generated by a number of phenomena:

- Particulate erosion
  - Solids produced
  - Proppants used for gravel pack or fracking the reservoir
- Liquid droplet erosion
  - Impingent of liquid droplets
- Cavitation
- Erosion corrosion

Particulate erosion by sand is most likely to cause erosive failures in oil and gas production systems.
What causes erosion – droplet erosion

- Confined to wet gas and multiphase flows in which droplets can form
- The erosion rate is dependent on a number of factors including the droplet size, impact velocity, impact frequency, and liquid and gas density and viscosity.
- Test have shown solid-free erosion only occurs at very high velocities:
  - Salama & Venkatesh $V = \frac{300}{\sqrt{\rho}}$
  - DNV-RP-O501: 70 – 80 m/s
  - Shinogaya: 80 – 110 m/s depending on type of metal in piping
  - Svedeman & Arnold: 30 m/s
What causes erosion – cavitation

• When liquid passes through a restriction low pressure areas can be generated. If the pressure is reduced below the vapour pressure of the liquid, bubbles are formed. These bubbles then collapse generating shock waves. These shock waves can be of sufficient amplitude to damage pipework.

• Occurs rarely in oil and gas production systems as the operating pressures are well above vapour pressure.

• Seen in chokes, control valves and pump impellers.
What causes erosion – erosion corrosion

- Erosion-corrosion is the combined effect of particulate erosion and corrosion.
- The progression of the erosion-corrosion process depends on the balance between the erosion and corrosion processes:
  - In a purely corrosive flow new pipework components typically corrode very rapidly until a brittle scale develops on the surfaces exposed to the fluid. This scale layer forms a barrier between the metal and the fluid that substantially reduces the penetration rate.
  - In highly erosive flows, in which corrosion is also occurring, the erosion process predominates and scale is scoured from exposed surfaces before it can influence the penetration rate.
  - At intermediate conditions erosion and corrosion mechanisms can interact. In this case scale can form and then be periodically removed by the erosive particles.
Sand production and transport

• Production of sand
  – New wells typically produce a large amount of sand and proppant as they “clean up”. Sand production then stabilises at a relatively low level before increasing again as the well ages and the reservoir formation deteriorates.
  – Sand concentration typically ranges from 1 to 50 parts per million by mass.

• Gas systems generally has higher velocities than liquid systems; making them more prone to erosion

• Concerns:
  – Erosion due to sand production
  – Transportation of sand; avoid accumulation of sand
Particle trajectories

a) Small particles (liquid)  
b) medium particles  
c) large particles (gas)

Drag forces on sand particles are different in liquids and gases. Erosion rates in gas flows are usually greater than in liquid flows operating at the same velocities. Also, the erosion scar position will be different.
Erosion due to sand production

Governing parameters

- Impact erosion model

\[ E = AV_p^n F(\alpha) \]

Here:

- \( E \) is the erosion rate (kg of material removed/kg of erodant)
- \( V_p \) is the particle impact velocity
- \( A \) is a constant depending on the material being eroded and other factors.
- \( \alpha \) is the particle impact angle
- \( F(\alpha) \) is a material dependent function of the impact angle between 0 and 1
- \( n \) is a material dependent index
Sand management

• Downhole completion of well
  – Sand screen, gravel pack, …

• Design of pipework
  – Minimize flow velocity
  – Avoid sudden changes in flow direction
  – Use full bore valves
  – Blind tees in place of elbows may reduce erosion problems
  – Avoid slugging
  – Erosion resistance material (NB avoid coating by brittle material!)

• Monitoring of sand production
  – Produced sand in separators (topside)
  – Accoustic sand detectors
  – Intrusive sand erosion probes
  – Wall thickness measurements: UTM, CEM

• Choke back/reduce production rate
Instrumentation – clamp on accoustic sand detector
Instrumentation – Corrosion Erosion Monitor

Monitors the average wall thickness of pipes
Instrumentation – intrusive erosion probe

Measure the change in electrical resistance of two to four independent, sensing elements as they are eroded by sand.
Guidelines and sand erosion prediction methods

- **API 14E** *(DO NOT USE FOR SAND EROSION!)*
  - Acceptable velocity: \( V = \frac{c}{\sqrt{\rho}} \) (\( C = 100, 150, 200 \) ?)
  - Often applied although it is widely accepted to be misleading or incorrect. It does not account for the physical phenomena governing the erosion process and its origins are obscure.
  - The recommendations given in API 14E are highly conservative for liquid flows and under estimate the potential for erosion in gas flows.

- **DNV-RP-O501**
  - Design guidelines for straight pipes, welded joints, reducers, elbows and blind tees
Guidelines and sand erosion prediction methods

- DNV-RP-O501 – Erosive Wear in Piping Systems is widely used as a guideline and for predicting erosion due to sand production in subsea production systems.

- The recommended practice includes an impact erosion model and empirical models for calculating erosion in common piping components such as:
  - Straight pipes
  - Welded joints
  - Reducers
  - Elbows
  - Blind tees
  - Intrusive sand sensors

- For multiphase flow, DNV GL uses mixture velocities and mixture density and viscosity as input to the flow/particle calculations.

- These empirical models have proved useful in estimating erosion due to sand production and aiding in the design and line sizing of subsea systems.
DNV-RP-O501 empirical models – limitations

• Assumes sand uniformly distributed across pipe cross section

• Does not take into account any upstream flow effects when calculating erosion rates due to sand production.

• Erosion models are developed based on tests with angular particles representative for particles produced in the North Sea.
  – Erosion is dependent on the shape of the particles. Sharp/very angular particles may typically give 2-3 the erosion rate as for angular particles, while rounded particles may give 2-3 times less erosion than angular particles.
DNV-RP-O501 particle impact erosion model

• The particle impact erosion model

\[ \dot{E} = K \cdot m \cdot V_p^n F(\alpha) \]

• Mass of particles impacting on the surface is denoted \( m \)
• Resulting wall material loss is denoted \( \dot{E} \)
• The wall material grade is characterized by the material constant \( K \) and \( n \) and a material response function \( F(\alpha) \). These material parameters are determined by testing.

• For steel: \( K = 2 \times 10^{-9} \text{ (m/s)}^{-n} \) and \( n=2.6 \).
• For WC: \( K=1.1 \times 10^{-10} \) to \( 3.2 \times 10^{-10} \text{ (m/s)}^{-n} \) depending of type and \( n = 2.2 \).
DNV-RP-O501 particle impact erosion model

- The shape of the material function $F(\alpha)$ depends on the type wall material used
CFD erosion simulations

- For complex geometries or if more detailed analysis is required, CFD is required to determine the particle trajectories and particle impact characteristics.
- Contribution to local pipe wall erosion is calculated by adding up contributions for each particle impact on the wall using the DNV GL particle impact erosion model.
Sand erosion prediction methods - accuracy

• Erosion calculations are not exact and will only provide indicative results:
  – The DNV-RP-O501 empirical models have an expected accuracy within a factor of 2 – 3
  – Computational Fluid Dynamics (CFD) erosion simulations have an expected accuracy within a factor of 2.
Flow Assurance and sand erosion

- Install downhole completion in well to reduce amount and size of sand being produced
- Optimize piping desing to reduce erosion due to sand production
  - Reduce velocity by increasing pipe size
  - Optimize routing of piping
- Allow for erosion wear in the design
- Monitor sand production
  - Sand detection, wall thickness measurements, record produced sand in separators
- Create steering criteria for production