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Review of corrosion and abrasion in iron-ore slurry steel pipelines

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Review of Corrosion and Abrasion in Iron-ore Slurry Steel Pipelines

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Revisão de Corrosão e Abrasão em Minerodutos de Aço-carbono

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Agenda

- Overview of slurry pipeline and iron-ore slurry
- Wear caused by slurry
- Corrosion and wear
- Dependences on particle and on slurry characteristics
- Corrosion and wear on corrosion coupons installed in a slurry pipeline
- Corrosive wear mitigation

Overview - Slurry Pipeline

- Minas-Rio iron-ore slurry pipeline is 529 km extension
- Steel pipes API 5L-X70, 24” and 26”


Iron-ore mine


Processing facilities


Iron-ore slurry Pipeline

Overview - Slurry Pipeline

- 11 directional holes and 21 above ground positions
  - At least, 31 changes in the flow direction

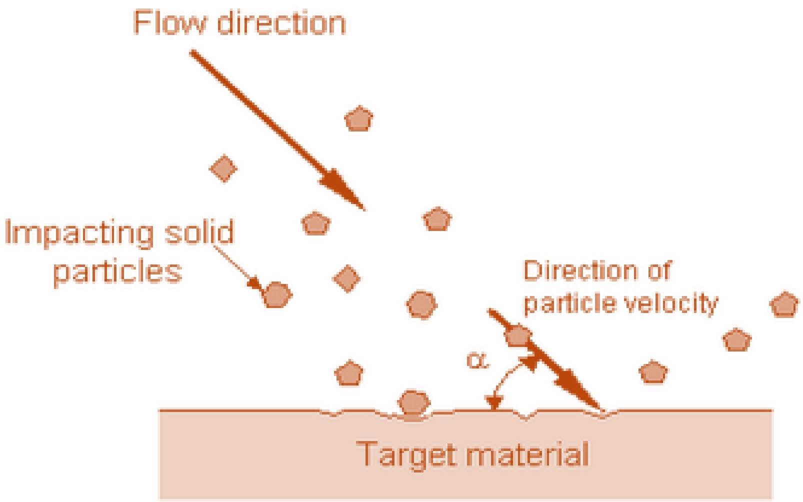
- Maximum flow for slurry transportation: 2105 m^3/h
- Pressures of 18 MPa (pump station 1) and 20 MPa (pump station 2)
- Minimum slurry speed to avoid settling: 1.6 m/s
- 43,774 joints welds made for the pipeline

Iron-ore Slurry

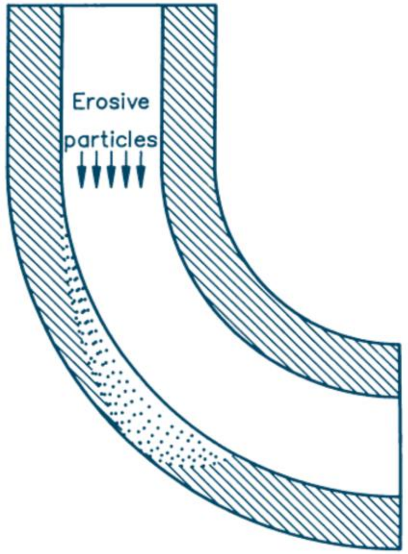
- SLURRY can be described as a mixture of solid particles in a liquid (usually water) of such a consistency that it can be readily pumped
- Slurry composition: hematite (Fe_2O_3), magnetite (Fe_3O_4), silicon dioxide (SiO_2)
- Iron-ore slurry = water + 68 % solids
- Use of alkaline additives (circa pH 12) for corrosion control

Slurry Wear

- **Erosion**: a process of wear which is defined as the progressive loss, fracture or displacement of material under the repeated impingement of solid particles on a solid surface
  - The largest share of the total wear and material removal
  - The contact time between the erodent and the eroded surface is much shorter than in abrasion



V. Javaheri et al. *Wear 408–409 (2018) 248–273*

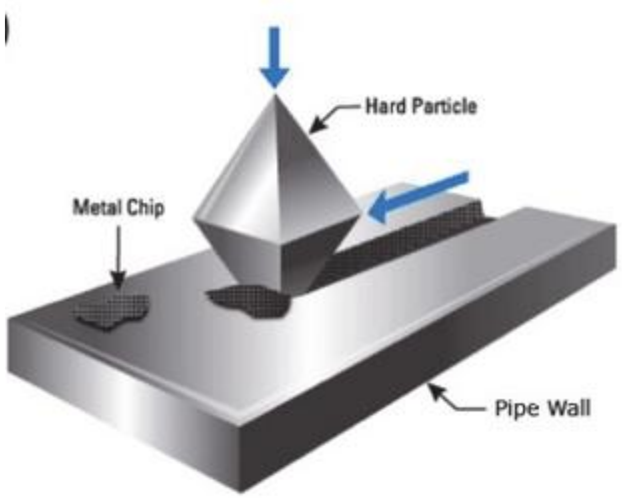


ASM Handbook vol. 18

Slurry Wear

Abrasion: wear is caused by the hard protrusion of one surface on the other.

- The particle needs to be 1.3 harder than the surface been abraded



V. Javaheri et al. *Wear 408–409 (2018) 248–273*

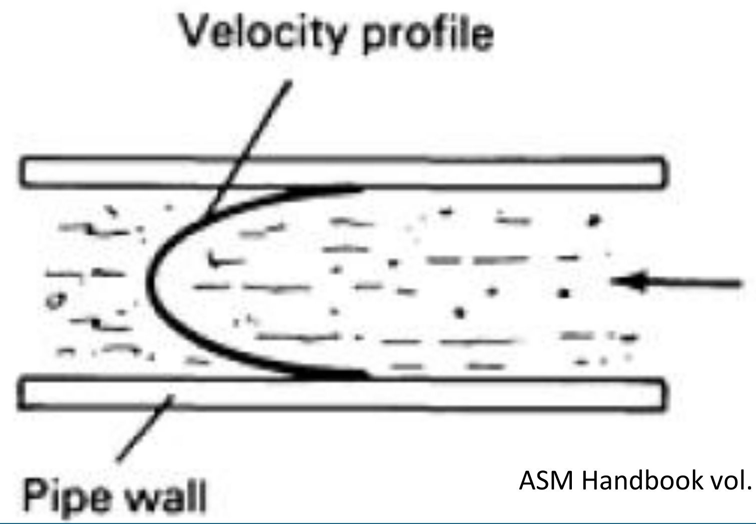
Vickers Hardness

- API 5L-X70: (200 to 250) HV
- Hematite or magnetite : (300 to 800) HV
- Silica (SiO_2): (1040 to 1300) HV

https://didatico.igc.usp.br/minerais/oxidos-hidroxidos

Slurry Wear and Corrosion

Slurry wear mode



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In a pipeline with laminar flow, the velocity profile (in the shape of a parabola) is such that the velocity near the wall of the pipe is nearly zero, and minimum wear takes place

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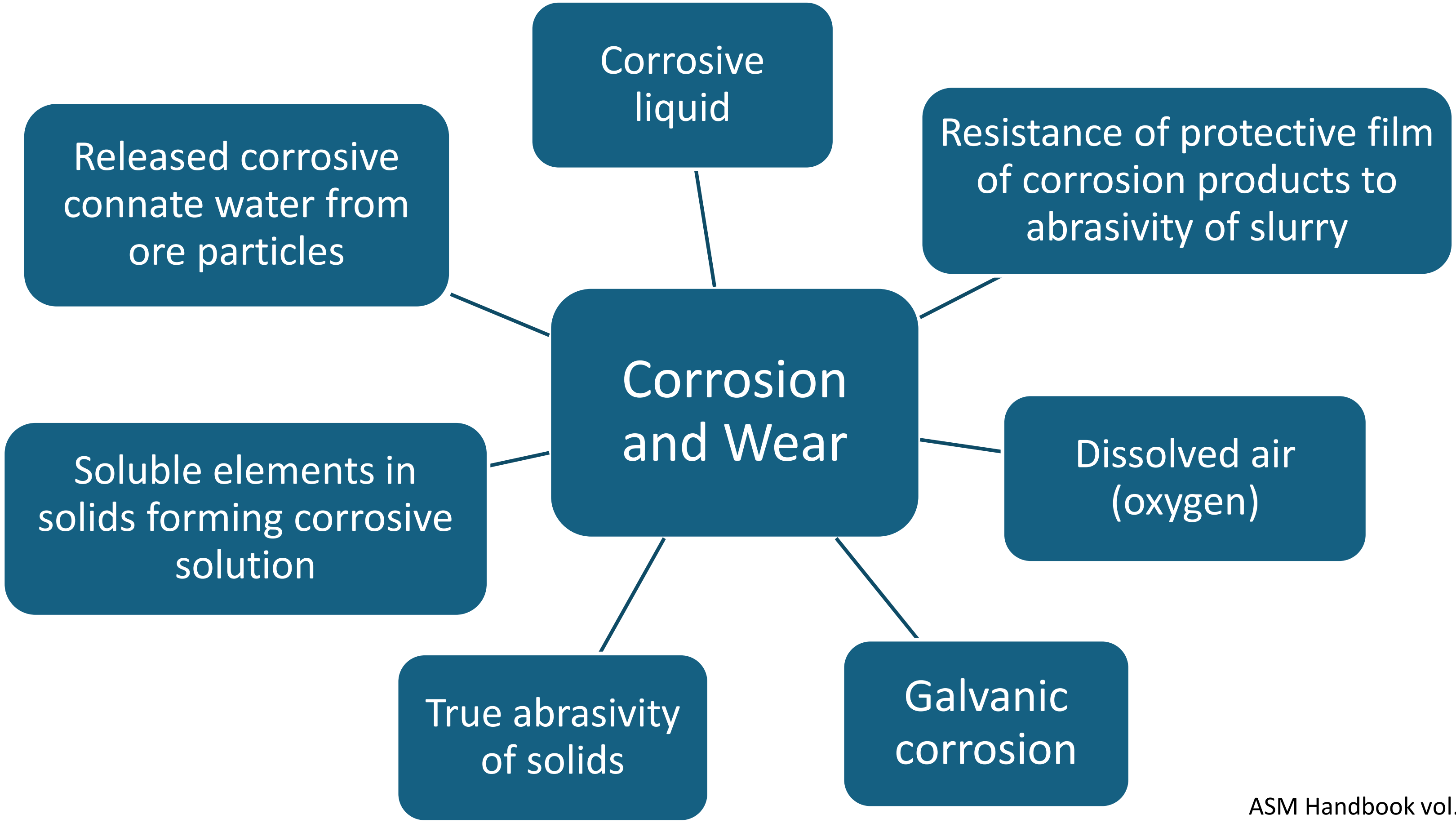
Slurry Wear and Corrosion

Complexity of the corrosion and wear phenomenum



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Corrosive Wear

- CORROSIVE WEAR is the degradation of materials in which both corrosion and wear mechanisms are involved

- The combined effects of wear (*W*) and corrosion (*C*) can result in total material losses that are much greater than the additive effects of each process taken alone, which indicates synergism (*S*) between the two processes

$$T = W_0 + C_0 + S$$

Corrosion and Wear

- The synergistic term (*S*) is defined as the sum of the change in corrosion rate due to wear (wear-accelerated corrosion, ΔC_w) and the change in wear rate due to corrosion (corrosion-accelerated wear, ΔW_c)

$$S = \Delta C_w + \Delta W_c$$

Erosion dominated regime: $\Delta C_w / \Delta W_c < 0.1$

Erosion-corrosion regime: $0.1 \leq \Delta C_w / \Delta W_c < 1$

Corrosion-erosion regime: $1 \leq \Delta C_w / \Delta W_c < 10$

Corrosion dominated regime: $\Delta C_w / \Delta W_c \geq 10$

ASTM INTERNATIONAL
Designation: G119 – 09 (Reapproved 2021)

Standard Guide for
Determining Synergism Between Wear and Corrosion[1]

Landolt and Mischler, 2011

Particle Dependences

- **Shape**: angularity of the slurry abrasives was important in determining the wear rate of materials where corrosion was not dominant. Recycle of slurry can reduce material loss due to rounding of the particles

- **Density**: for a particle of a given angularity, the denser the particle, the more likely it is to cause either deformation or cutting wear on impact. This is a consequence of the dissipation of more energy in the same volume

- **Size**: larger particles have a higher collision efficiency and a higher impact velocity

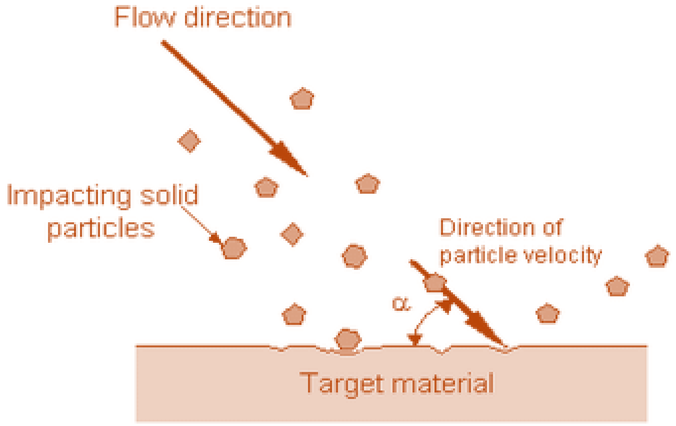
- **Hardness**: the wear of materials has been shown to dramatically increase when the slurry particles are harder than the material being worn. However, above a critical hardness value, it do not appreciably increase the wear rate.

Slurry Dependences

Velocity of the slurry: The wear rate is an exponential function of velocity

Angle of attack:

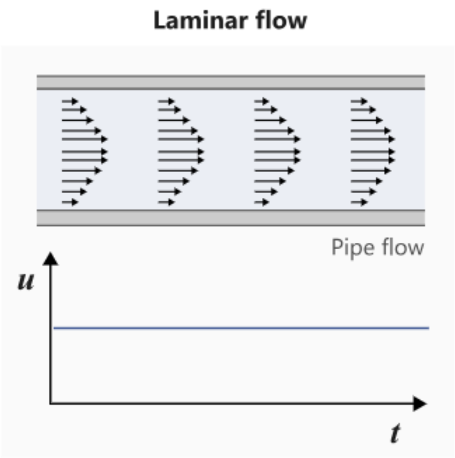
- in straight pipelines, little damage to the underlying metal results from direct contact between the abrasive and alloy. The abrasives and the solution serve to remove corrosion products and enhance the corrosion rat.
- when the pipe is curve, the slurry particles tend to wear the pipe. The slurry particles directly impart mechanical wear damage to the alloy. If the alloy passivates, the abrasive can continually remove the protective film and allow corrosion to proceed at a much higher rate

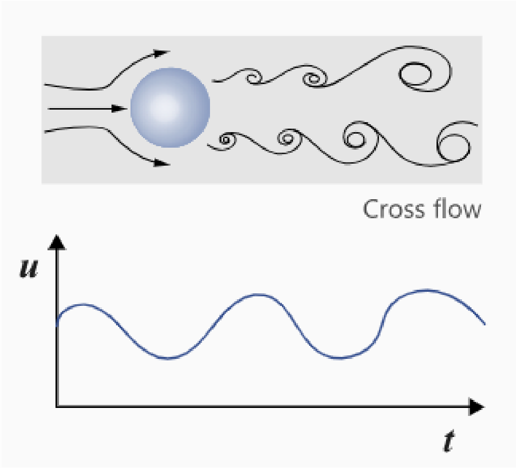


V. Javaheri et al. *Wear 408–409 (2018) 248–273*

Slurry Dependences

- **Solids concentration:** increasing the solids concentration in a slurry generally increases the wear rate. The increase is only proportional to the solids concentration for dilute slurries. For denser slurries, particle-particle interaction tends to decrease the dependence of the wear rate on slurry density
- **Dependence on hydrodynamics:** Flow-dependent corrosive wear typically occurs at geometrical irregularities, such as fittings, valves, and weld beads, where the flow separates from the wall of the containment vessel. Flow separation and reattachment produces high turbulence intensity and particle-wall interactions that lead to high corrosive wear rates





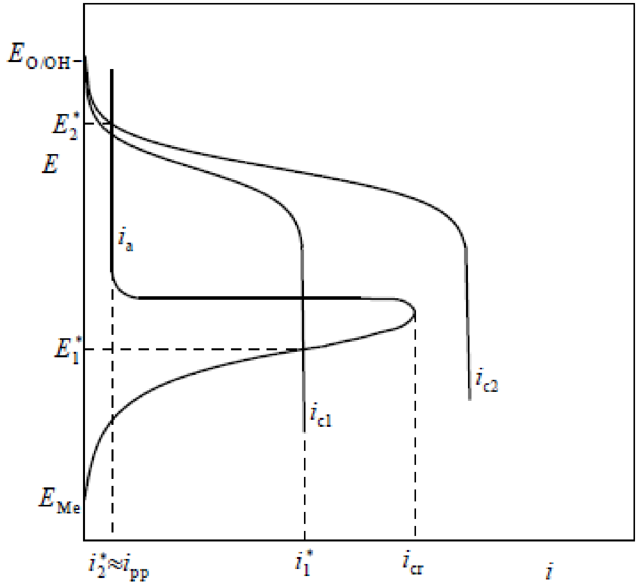
https://help.altair.com/hwcfdsolvers/acusolve/topics/acusolve/training_manual/turb_flow_vs_lam_flow_r.htm

Slurry Dependences

- **Corrosion products and the mass transfer of oxygen:** play an important role in the total material losses encountered in straight sections of a carbon steel pipeline

- Literature indicated material loss rate is under oxygen mass transfer control, with corrosion being the dominant mode of metal loss
  - The magnitude of the erosion-corrosion can be estimated using well-established mass transfer correlations for oxygen diffusion

Wolynec, 2003

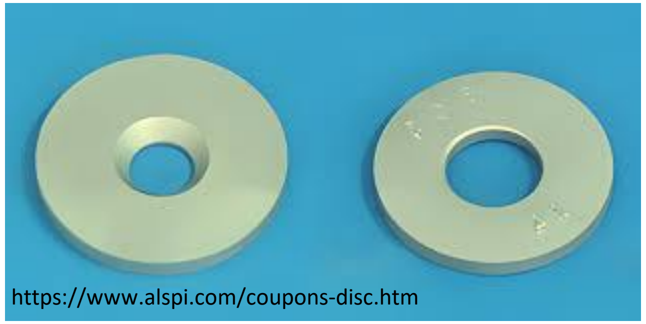


- Carbon steel passivates in alkaline medium, passive films may be fragile or porous
- Repassivation depends on kinetics and solution chemistry

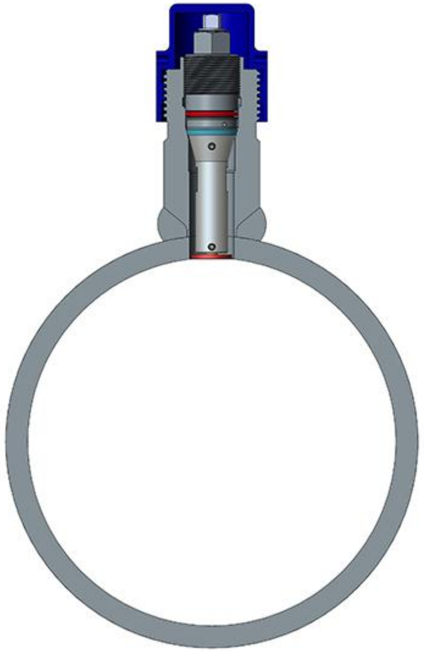
Corrosion and wear on corrosion coupons installed in a slurry pipeline

Corrosion monitoring and wear influences

- Corrosion monitoring in pipelines with flush-disc coupons



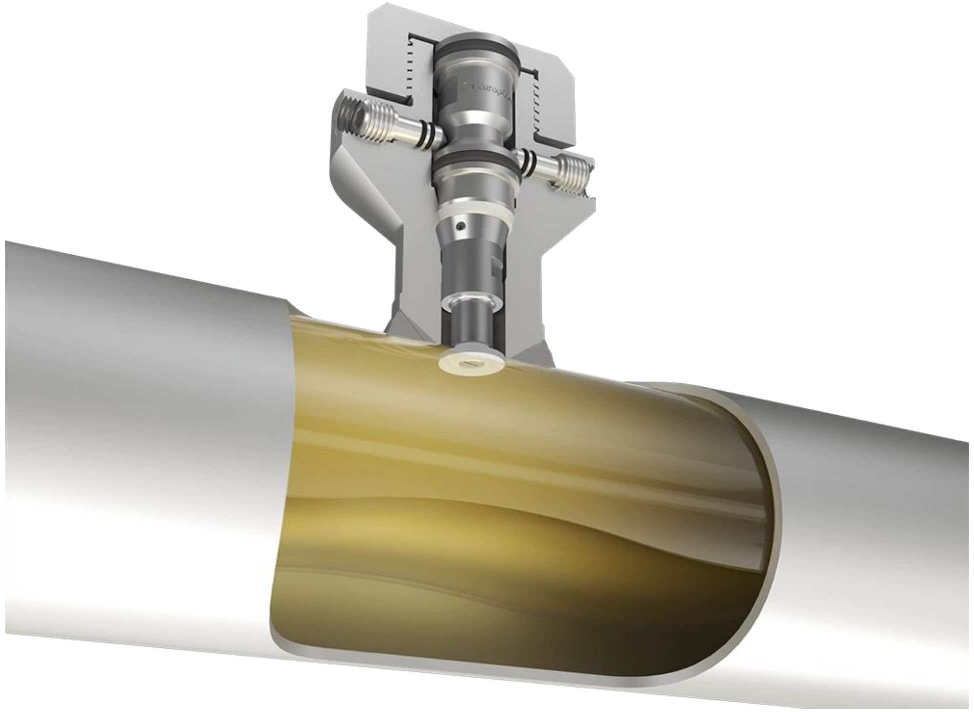
Flush Disc

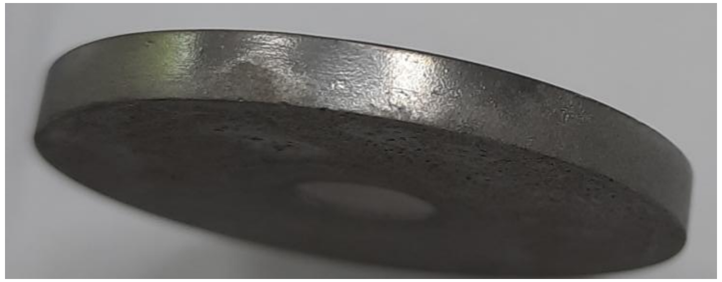


https://www.alspi.com/holdershp.htm

Corrosion monitoring and wear influences

- Coupon not flush with the pipe surface (out of the point of access)

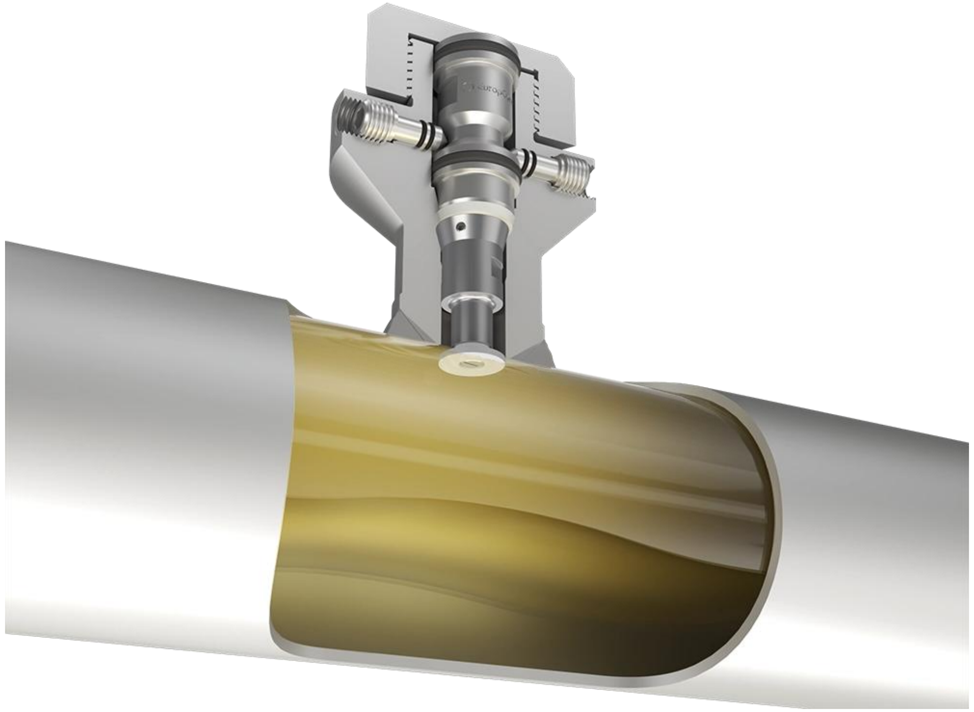




Localized brighter surface and rounded corner

Corrosion monitoring and wear influences

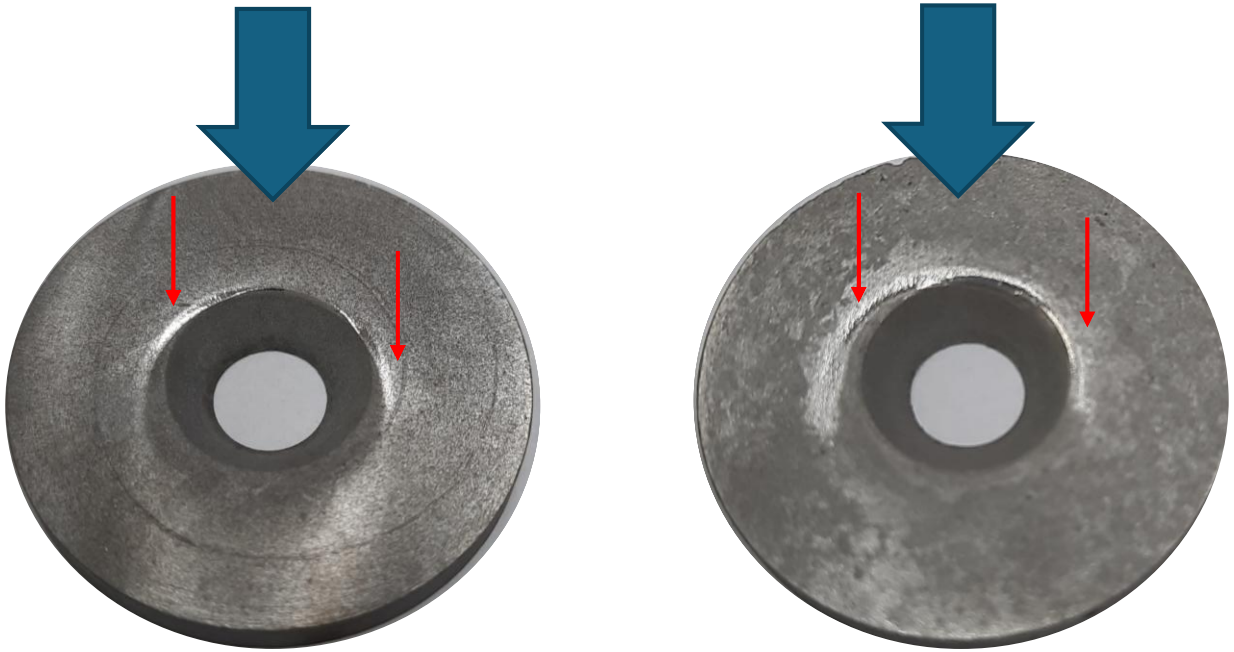
- Coupon not flush with the pipe surface (inside the access point)



Incrustation of slurry on the surface of the coupons

Corrosion monitoring and wear influences

- Screw not flush with the coupon surface



Intense localized mass loss!

Corrosion monitoring and wear influences

- The corrosion rate obtained through mass loss in a condition where corrosion and wear are present includes the losses due to the wear phenomenum

- The wear occurence should be visually identified from the observation of changes in the surface aspect ratio, such as roughness or localized erosion close to the screw position or irregularities

Mitigating Corrosive Wear

- **Materials Selection:** the selection of the right material for a particular corrosive wear environment can lead to extended life of component parts, less costly downtime, and other economic advantages

- **Surface Treatment:** addressed to situations where corrosion dominates metal loss, claddings and surface treatments such as hard facings and patching with welds, or replaceable liners can be used

- **Modification of the Materials Handling Environment:** solution conditioning, such as adjusting the pH and deaeration, can reduce the amount of material losses in a corrosive-wear environment

- **Use of Corrosion Inhibitors:** oxidizing inhibitors, such as chromates and nitrites, have been used to raise the potential of an alloy into passive regions and to lower their corrosion rates

Mitigating Corrosive Wear

Slurry Parameters:

- Reduction of the slurry velocity is a major factor in controlling the rate of material losses if the mechanical wear is important, because the wear rate generally varies with the velocity raised to exponents of 2, 3, or 4

- Particle size can also be a factor in the wear of slurry handling equipment. The mechanical wear will not be a problem if the particle size is sufficiently reduced so that the particles are fine enough to follow the streamlines of the solution, rather than impact the walls of the containment part.

- <u>However, fine slurry particles and low velocities may result in conditions mild enough to permit the growth of rust films and scale, which can lead to localized corrosion</u>

thank you!

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