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Solving Erosion and Corrosion Problems in Jordanian-Potash Company

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Abstract
The amount of surface material eroded by solid particles in a fluid stream depends on the conditions of fluid flow and on the mechanism of material removal. The paper first analyses the mechanism of material removal for ductile and brittle materials. For ductile material, it is noted that erosion produced by particles striking the surface at shallow angles $(15^0 - 30^0)$ but the maximum erosion in brittle materials at perpendicular impact at (90^0). In this paper ductile materials (steel alloys) are studied, then the paper discussed some aspects of the fluid flow conditions which may lead to erosion. Kind of pipe which connect between pumps and factory in Potash Company-Jordan is a carbon steel pipe. Because of large pressure from pumps (10 bar) and huge mass flow rate (about 700(m3 /hr)), particles (KCl, NaCl, ,MgCl) will strike with inner of pipe, erosion will happen, so a pipe will destroyed after many years. This problem considered costly, where Arab Potash Company is changing this pipe every seven years.

Keywords: Erosion, Corrosion, Pipe System, Cracks, Fluid Flow, Steel Alloys, Brittle, Ductile.

1. Introduction

Loss of original material due to solid particle impact on the material surface is defined erosion and Loss of material or loss of material integrity due to chemical or electro-chemical reaction with surrounding environment is defined corrosion. Material degradation due to corrosion, erosion and/or erosion-corrosion, may gradually affect the integrity of the piping system. Material degradation will generally depend on the production characteristics for the system; i.e. production rates, pressure and temperature, and the presence of corrosive components and erosive solid particles. The degradation may also be strongly dependant on the pipe material. Material degradation can, in most cases, not be fully avoided. However, by proper dimensioning, selection of suitable materials, use of inhibitors or other corrosion/erosion reducing measures and/or by application of corrosion/erosion allowance, a system which fulfils the requirements can generally be achieved. Selection of such measures may, however, be associated with high cost. A Life Cycle Cost Analysis should preferably be carried out in order to obtain an optimized solution. Sand particles and/or other solids will, in many applications, be present in the liquid, and may result in erosive wear of the pipe components; i.e. in the pipes, in pipe bends, blinded tees, connections etc. Many researches had been carried out such problems. Cheng-Hsun H., 2005, investigated the influence of different hard coatings (PVD-TiN and PVD-TiAlN) on the erosion and corrosion properties of ADI. Also, the coating structure and property were analyzed by using XRD, Rockwell C tester and SEM. The results showed that TiN and TiAlN films identified by XRD could be well deposited on the ADI substrate by the PVD method of cathodic arc evaporation (CAE). Adhesion between coating-layer and ADI substrate was better than that between coating-layer and DI substrate. It was found that the initial source of coated layer peeled for the both substrates occurred at the graphitic sites. The depositing rate of TiAlN was rapider than that of TiN, but it also resulted in the thicker coating thickness and rougher surface for the specimen coated with TiAlN film. After slurry erosion test, the result revealed that erosion resistance of coated specimens was better than that of uncoated specimen. In 3.5 mass% NaCl aqueous for polarization curve test, corrosion current of TiAlN film was smaller than that of TiN film. In 10 vol% HCl solution for immersion test, both TiN and TiAlN coatings could raise the corrosion resistance for ADI material, [6]. Rihan O. 2006, A novel apparatus, high-pressure/high-temperature nickel flow loop, was constructed to study the effect of the flow on the rate of erosion–corrosion of mild steel in hot caustic. It has been successfully used to measure the corrosion rate of 1020 steel in 2.75 MNaOH solution at a temperature of 160 _C and velocities of 0.32 and 2.5 m/s. In situ electrochemical methods were used to measure the corrosion rate such as the potentiodynamic sweep, the polarization resistance method, and electrochemical impedance spectroscopy (EIS). Also used were the weight-loss method and scanning electron microscopy (SEM). Eight electrodes/coupons were used to monitor the metal loss rate, four were placed at the low velocity section, while the other four were placed in the high velocity section. The first three coupons in each section were placed within the disturbed flow region, while the fourth was placed in a fully developed flow region.[7]

The corrosion rate of the coupons in the high velocity section was generally higher than that of the coupons in the low velocity section. One coupon in the disturbed flow region had a significantly higher corrosion rate than the others.[1,2,3].

This paper provides guidelines for the assessment of erosive wear in piping systems associated with production and transportation of Dead Sea water and injection of water into the reservoir in the potash company. The recommended calculation procedure is not applicable to certain components with highly complicated flow geometry; including manifolds and chokes. I.e. the models do not take into account upstream history effects and the document does not address corrosion, erosion-corrosion or inhibitor selection and performance. A general method developed to perform erosion calculations in arbitrary geometries is developed based on flow and particle track calculations performed with a standard Computational Fluid Dynamics (CFD) package. In this paper steel alloys are taking the dominant part in the piping systems for sea water.

In this paper lifetime of pipe is calculated using the erosion rate on the pipe and the paper examine reliability in piping systems for sea water. This paper contains practical information from Potash Company and it is discuss practical problems in this company.

Problem definition

In many applications a surface is attacked by solid particles entrained in a fluid stream. This type of wear is generally described as erosion. Probably the most important erosion problems which occur in industry are those connected with the equipment used in the catalytic cracking of fluid. However, erosion is also a continuing problem in such units as steam turbines and coal hydrogenation equipment. While usually considered undesirable, erosion has useful application in such processes as sand blasting, abrasive debarring and the erosive drilling of hard materials.

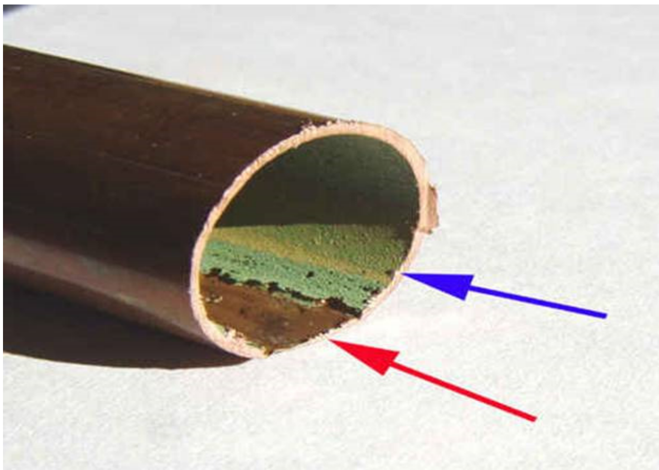

Fig.1: Erosion problem in pipe

It is known that piping system includes pipes for transportation of fluids and associated pipe bends , joints, valves and chokes. The general term covers tubing , flow lines for transportation of processed and un-processed hydrocarbons and piping downstream of first stage separator. It seems clear that an understanding of erosion may be divided into two major parts. The first part involves a determination from the fluid flow conditions of the number , direction , and velocity of the particles striking the surface. With such information available , the second part of the problem is a calculation of the amount of surface material removed. The first part of the problem is, basically, one of fluid mechanics, and its detailed treatment lies outside the scope of this. However, some aspect of the particle motion in the fluid will be mentioned. In particular, the problem of predicting particle velocities in erosion tests will be considered. The Arab Potash Company was established on July 7th, 1956 and in 1958 an exclusive concession was granted by the Jordanian Government for one hundred years. After which, the ownership of the factory is transferred to the government of the Kingdom of Jordan. The objectives of the company are to exploit, manufacture and market the minerals and salts of the Dead Sea. The main activities of the company and its subsidiaries are to produce and sell potash and potassium nitrate and other related products. The Arab potash company has huge centrifugal pumps which had put on Dead Sea, these pumps have a pressure about (10 bar), and the external shape of pumping station is shown in figure 2.

Fig.2: Pumping Station in The Arab potash Company

The main goal of these pumps is sending water to the factory to treatment and elicitation salts and potash components. Dead Sea water contain with mainly a following chemical compounds:Potassium Chloride (KCl) : with 85% from solution, Sodium Chloride (NaCl) :with 10% from solution, and Magnesium Chloride (MgCl) : with 5% from solution The density of this solution about 1.7(Kg/L) and the hardness of carnalities is 2.5 (MOH)

Erosion problem:

Kind of pipes which connect between pumps and factory is a carbon steel pipe. Because of large pressure from pumps (10 bar) and huge mass flow rate (about 700(m^3/hr)) , particles (KCl, NaCl, ,MgCl) will strike with inner of pipe , erosion will happen , so a pipe will destroyed after many years. This problem considers a costly with money, where Arab Potash Company is changing this pipe every six year. It is noted that Carbon steel has a varied kinds so we will study kind of carbon steel and we will study erosion on carbon steel pipe. Corrosion is the destructive attack of a metal by chemical or electrochemical reaction with its environment. Deterioration by physical causes is not called corrosion, but is described as erosion, galling, or wear. In some instances, chemical attack accompanies physical deterioration, as described by the following terms: Corrosion – erosion, corrosive wear, or fretting corrosion and Nonmetals are not included in this definition of corrosion. Plastics may swell or crack, wood may split or decay, granite may erode, and Portland cement may leach away, but the term corrosion, in this paper , is restricted to chemical attack of metals. "Rusting" applies to the corrosion of iron or iron - base alloys with formation of corrosion products consisting largely of hydrous ferric oxides. Nonferrous metals, therefore, corrode, but do not rust.

Corrosion Science and Corrosion Engineering

Since corrosion involves chemical change, we must be familiar with principles of chemistry in order to understand corrosion reactions. Because corrosion processes are mostly electrochemical, an understanding of electrochemistry is also important. Furthermore, since structure and composition of a metal often determine corrosion behavior, we should be familiar with the fundamentals of physical metallurgy as well.

The corrosion scientist studies corrosion mechanisms to improve: The understanding of the causes of corrosion, and The ways to prevent or at least minimize damage caused by corrosion. The change in Gibbs free energy and the Pilling – Bed worth ratio.

Pilling–Bed worth Ratio

Although many factors control the oxidation rate of a metal, the Pilling –Bed worth ratio is a parameter that can be used to predict the extent to which oxidation may occur. The Pilling – Bed worth ratio is (Md / nmD), where (M)and (D) are the molecular weight and density, respectively, of the corrosion product scale that forms on the metal surface during oxidation;

(m and d) are the atomic weight and density, respectively, of the metal, and n is the number of metal atoms in molecular formula of scale; for example, for (Al_2O_3), n = 2.

The Pilling – Bed worth ratio indicates whether the volume of the corrosion product is greater or less than the volume of the metal from which the corrosion product formed.

If Md / nmD <1, the volume of the corrosion product is less than the volume of the metal from which the product formed.

A film of such a corrosion product would be expected to contain cracks and pores and be relative lynon protective. On the other hand,

if(Md / nmD)>1, the volume of the corrosion product scale is greater than the volume of the metal from which the scale formed, so that the scale is in compression, protective of the underlying metal. Appalling – Bed worth ratio greater than 1 is not sufficient to predict corrosion resistance.

If Md / nmD >> 1, the scale that forms may buckle and detach from the surface because of the higher stresses that develop. For aluminum, which forms a protective oxide and corrodes very slowly in most environments, the Pilling –Bed worth ratio is 1.3, whereas for magnesium, which tends to form a non protective oxide, the ratio is 0.8. Nevertheless, there are exceptions and limitations to the predictions of the Pilling – Bed worth ratio.[4,5,7].

Corrosion in carbon steel pipes in Potash Company:

The effect of corrosion in carbon steel pipes in the Potash Company can be neglected because of: Properties of Dead Sea water, which in the following form, Potassium Chloride (KCl) : with 85% from solution, Sodium Chloride (NaCl) :with 10% from solution, Magnesium Chloride (MgCl) : with 5% from solution , and the density of this solution about 1.7(Kg/L).

From that it can be noticed that the solution has reached almost saturation limit, which means there is no dissolved oxygen, which eliminates almost the impact of dissolved oxygen. The effect of dissolved Salts can be neglected because of the concentration ratios for each. Type of pumping pipe which connect between centrifugal pump and factory in Potash Company is a (medium carbon steel pipe), a commercial name for this pipe in (ASTM) is (A 106) and it is shown in figure 3.

Fig.3: Commercial Name of Carbon Steel Pipe in Potash Company

The general properties of this pipe shown in table 1, also this table gives a design specification for countries: Germany, Japan, United Kingdom and United State.

Table 1. properties of pipes

Element	Weight %
C	0.37-0.44
Mn	0.60-0.90
P	0.04 (max)
S	0.05 (max)

Thermal Properties

Properties		Conditions	
		T (°C)	Treatment
Thermal Expansion (10^{-6}/ºC)	13.6	20-1000 more	annealed

Electric Properties

Properties		Conditions	
		T (°C)	Treatment
Electric Resistivity (10^{-9} -m)	171	20 more	

Mechanical Properties

Properties		Conditions	
		T (°C)	Treatment
Density (×1000 kg/m^3)	7.845	25	
Poisson's Ratio	0.27-0.30	25	
Elastic Modulus (GPa)	190-210	25	
Tensile Strength (Mpa)	518.8	25	annealed at 790°C more
Yield Strength (Mpa)	353.4		
Elongation (%)	30.2		
Reduction in Area (%)	57.2		
Hardness (HB)	149	25	annealed at 790°C more

Results and Calculations

The procedure is developed based on numerical simulations, model equations and experimental investigations. The procedure is intended to give conservative estimates for the erosion attacks in order to avoid excessive erosion in the system during operation. The terms erosive wear and erosion are, in the present document, defined as material loss resulting from impact of solid/sand particles on the material surface. Erosive wear can be estimated from the following general relation, provided impact velocities and angles are known for the particles hitting the target surface.

$$\dot{E} \sim \dot{m}_P . K . U_P^n . F(\alpha) \tag{1}$$

where: *E:* Erosion rate referred to depth (mm / year), $\dot{m}_p$: Mass flow rate of particles (kg/s), *K* : Material constant. [(m/s)$^{-n}$] , $U_p{}^n$: Particle impact velocity (equal to the fluid velocity). (m/s), *F* (α): Function characterizing ductility of the material (-), *(α)*: Impact angle of particles hitting the wall.

The function *F(α)* characterizes the ductility of the target material, see Figure 4. Ductile materials attain maximum erosion attacks for impact angles in the range (15^0– 30^0). Brittle materials attain maximum erosion attacks at normal impact angle. Steel grades are generally regarded as ductile, while cermets like tungsten carbides with a metallic binder phase are defined as brittle.

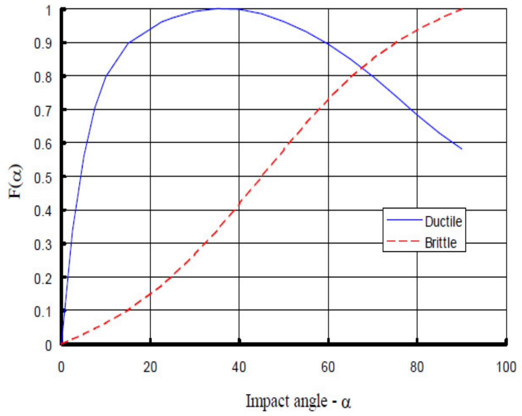

Fig.4: Function F (α) for typical 'ductile' and 'brittle' materials

The function *F(α)* for steel grades is given by the following relation:

$$F(\alpha) = \sum (-1)^{(i+1)} A_i \left(\frac{\alpha.\pi}{180}\right)_i \tag{2}$$

Or

$$F(\alpha) = A_1.\left(\frac{\alpha.\pi}{180}\right) - A_2.\left(\frac{\alpha.\pi}{180}\right)^2 + A_3.\left(\frac{\alpha.\pi}{180}\right)^3 - A_4.\left(\frac{\alpha.\pi}{180}\right)^4 + A_5.\left(\frac{\alpha.\pi}{180}\right)^5 - A_6.\left(\frac{\alpha.\pi}{180}\right)^6 + A_7.\left(\frac{\alpha.\pi}{180}\right)^7 - A_8.\left(\frac{\alpha.\pi}{180}\right)^8 \tag{3}$$

Where the Ai's are constants given in Table 2 for steel grades.

Table 2 Constants to be used in Equation (3)

A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
9.370	42.295	110.864	175.804	170.137	98.398	31.211	4.170

The material 'constants' *K* and *n* have to be determined by experimental investigations; Table 3 gives recommended values for various pipe materials.

Table 3: Recommended values for material constants to be applied in Equation (1) and density of actual pipe materials

Material	K $(m/s)^{-n}$	n (-)	Density (kg/m^3)
Steel grades	$2.0 \cdot 10^{-9}$	2.6	7800
Titanium grades	$2.0 \cdot 10^{-9}$	2.6	4500
GRP/Epoxy	$0.3 \cdot 10^{-9}$	3.6	1800
GRP/Vinyl Ester	$0.6 \cdot 10^{-9}$	3.6	1800

Equation (1) is used as a basis for an estimation of erosion rates. The equation requires input of particle impact velocity, particle impact angle and mass of sand impacting on the target area. If these parameters are known, the resulting erosion rates can be calculated from the following relation:

$$\dot{E}_L = \frac{\dot{m}_P.K.U_P^n.F(\alpha)}{\rho_t.A_t}.C_{unit} = \frac{\dot{E_m}}{\rho_t.A_t}.10^3[mm/yr], C_{unit} = 3.15E10 \qquad (4)$$

where: E_L: Erosion rate referred to depth. [mm/year], $\dot{m}_p$: Mass flow rate of particles. [Kg/s], K : Material constant. $[(m/s)^{-n}]$, U_p: Particle impact velocity (equal to the fluid velocity). [m/s], $F(\alpha)$: Function characterizing ductility of the material. [-], (α): Impact angle of particles hitting the wall, ρ_t: Density of target material. [kg/m3], A_t: Area exposed to erosion. [m^2], C_{unit}: Unit conversion factor (m/s → mm/year). [-] . Impact angles, impact velocities and the amount of sand hitting a surface are dependent on the multi-phase flow characteristics, the grain size distribution and component geometry. In the calculation procedure, these effects are accounted for by model/geometry factors applied to Equation (4). The model/geometry factors account for multiple impact of the sand particles, concentration of sand particles due to component geometry and model uncertainty. In the procedure, impact velocity is, if not otherwise defined, determined by the relation:

$$U_P = V_l^s + V_g^s = V_P \qquad (5)$$

Where: V_g^s : Superficial velocity of gas phase in piping. [m/s], V_l^S: Superficial velocity of liquid phase in piping. [m/s], V_p: Particle impact velocity (equal to the fluid velocity). [m/s]

Physical properties of the fluids are described as mixture properties and are determined by the measure experimentally. If the particles content is given as 'part per million values' (ppm), the resulting particles flow rate can be calculated according to the following relations:

-For ppm given on mass basis (ppmW):

$$\dot{m}_P = \dot{M}_m.ppmW.10^{-6} \qquad (6)$$

Where: $\dot{m}_p$: Mass flow rate of particles [kg/s], $\dot{M}_m$: Mass flow rate of mixture [kg/s] *ppmW*: Part per million

The following data are taken from Potash Company, which will be used in the final results: Flow rate(Q) = 700 (m^3/hr), Diameter of pipe(D) = 12(in) = 0.3048(m), The average length of pipe(L_{avg})= 11(km), The density of mixture(ρ_m)= 1.7(kg/L), Thickness of pipe(t)= 10 (mm), Hardness of Carnalities = 2.5 (MOH)

To obtain a measure of viscosity, we went to fluid mechanics lab in polytechnic to measure viscosity by ball experiment. We put the liquid that we want to obtain its viscosity in the falling sphere viscometer in a selected distance and we start to let the small spheres to have a free fall in it and we calculate the time toke by the sphere to reach the bottom of the viscometer and we calculate the velocity of the sphere to calculate the viscosity of the liquid, so viscosity from fluid mechanics studying is:

$$\mu = \frac{2}{9} r^2 g \frac{(\rho_s - \rho_l)}{u} \tag{7}$$

Where: (μ) : dynamic viscosity(pa/s), (r) : radius of ball(m), (g) : gravitational acceleration(m/s^2), (ρ_s) : density of ball(kg/m^3), (ρ_l) : density of liquid(kg/m^3), (u) : velocity of ball(m/s), R= 1.48(mm), ρ_s= 11164.69(kg/m^3), Time of falling$(\tau) = 0.67(s)$, Length of tube(L)= 0.5(m).

To find the friction factor of the pipes

1- Friction factor = $\frac{2d_{pipe}}{\rho_l V^2 * l} * \Delta P$
2- where: d_{pipe} : diameter of pipe(m), ρ_l : density of pipe(kg/m^3), V : velocity of liquid(m/s), ΔP : the drop pressure(kpa), l : length of pipe(m)

ΔP from potash company is 257 kpa and we compute for 1 (m) length of pipe

Friction factor = $\frac{2*0.3}{1700*2.75^2*1} * 257$= 0.01199 = 0.012

From moody chart, the flow is laminar, so it is not effect by increase erosion.

Erosion calculation for straight pipe

Figure 5 showing the Relative Erosion Factor (REF), for some standard steel grades tested at various impact conditions. REF is defined as:

REF = Volume loss of material / Volume loss of C-steel grade typical for piping systems

If REF < 1; material has better erosion resistance than C-steel , If REF > 1; material has poorer erosion resistance than C-steel

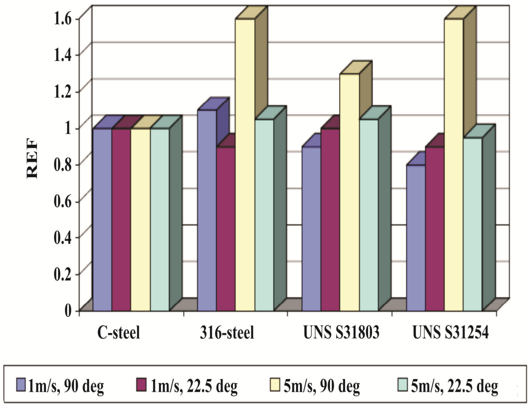

Fig.5: Relative erosion resistance for some steel grades. C-steel is used as a reference material

From figure (5):

1- (316 steel),(UNS S31803)and (UNS S31254) have a good erosion resistance at (2.5m/s,22.5^0) comparative with (C-steel).

2- (316 steel) not have a good erosion resistance comparative with (C-steel) at (2.5m/s, 90^0) but (UNS S31803) and (UNS S31254) have a good erosion resistance at this condition.

3- (316 steel),(UNS S31803)and (UNS S31254) not have a good erosion resistance at (5m/s,22.5^0) and(5m/s, 90^0) comparative with (C-steel).

The erosion for these materials will be computed and compared to select the better material

-Erosion calculation for carbon steel:

$$\dot{E}_L = \frac{\dot{m}_P.K.U_P^n.F(\alpha)}{\rho_t.A_t}.C_{unit} \tag{8}$$

$$F(\alpha) = A_1.\left(\frac{\alpha.\pi}{180}\right) - A_2.\left(\frac{\alpha.\pi}{180}\right)^2 + A_3.\left(\frac{\alpha.\pi}{180}\right)^3 - A_4.\left(\frac{\alpha.\pi}{180}\right)^4 + A_5.\left(\frac{\alpha.\pi}{180}\right)^5 - A_6.\left(\frac{\alpha.\pi}{180}\right)^6 + A_7.\left(\frac{\alpha.\pi}{180}\right)^7 - A_8.\left(\frac{\alpha.\pi}{180}\right)^8 \tag{9}$$

It noted that, erosion will be maximum when ($\alpha = (15^0 - 30^0)$) for carbon steel because carbon steel is ductile material, $F(\alpha) = 0.856$, from potash company:$ppmw_{KCl} = 8250$, $ppmw_{NaCl} = 2363$, and $ppmw_{MgCl} = 2040$

So, $ppmw_{Net} = 8250 + 2363 + 2040 = 12653$, where (ppmw) value is from Potash Company$\dot{m}_P = \dot{M}_l.ppmW.10^{-6} = 330.555 * 12653 * 10^{-6} = 4.1828\,(kg/s)$

$$\dot{E}_L = \frac{\dot{m}_P.K.U_P^n.F(\alpha)}{\rho_t.A_t}.C_{unit} = \frac{4.182*2*10^{-9}*2.75*0.85*3.15*10^{10}}{7845*0.0706} = 1.12 \text{ mm/year}$$

After one year erosion equal 1.12 mm but thickness of pipe equal 10 mm and potash company remove a pipe when the thickness equal 2 mm so:

Lifetime of pipe = $\frac{10-2}{1.12} = 7.14\ year$

-Erosion calculation for 316 steel:

$(K_{316\ steel})$ Is decreasing with 10.2% comparative with carbon steel so:

$$K_{316\ steel} = 2 * 10^{-9} - 2 * 10^{-9} * 10.2\% = 1.796 * 10^{-9}$$

$$\dot{E}_L = \frac{\dot{m}_P.K.U_P^n.F(\alpha)}{\rho_t.A_t}.C_{unit} = \frac{4.1828*1.796*10^{-9}*2.75*0.856*3.15*10^{10}}{8000*0.0706} = 0.9866 \text{ mm/year}$$

Lifetime of pipe = $\frac{10-2}{0.9866} = 8.108\ year$

Lifetime of pipe made from 316 steel increased one year

-Erosion for UNS S31803:

$(K_{UNS\ S318031})$Is decreasing with 16.73% comparative with carbon steel so:

$$K_{UNS\ S318031} = 2 * 10^{-9} - 2 * 10^{-9} * 16.73\% = 1.665 * 10^{-9}$$

$$\dot{E}_L = \frac{\dot{m}_P.K.U_P^n.F(\alpha)}{\rho_t.A_t}.C_{unit} = \frac{4.1828*1.665*10^{-9}*2.75*0.856}{7800*0.0706} * 3.15 * 10^{10} = 0.938 \text{ mm/year}$$

where $\rho_t = 7800$ kg/m^3

Lifetime of pipe = $\frac{10-2}{0.938} = 8.528\ year$

- Erosion for UNS S31254:

$(K_{UNS\ S31254})$ Is decreasing with 19.22%comparative with carbon steel so:

$$K_{UNS\ S31254} = 2 * 10^{-9} - 2 * 10^{-9} * 19.22\% = 1.6155 * 10^{-9}$$

$$\dot{E}_L = \frac{\dot{m}_P.K.U_P^n.F(\alpha)}{\rho_t.A_t}.C_{unit}$$

$$= \frac{4.1828 * 1.6155 * 10^{-9} * 2.75 * 0.856}{8000 * 0.0706} * 3.15 * 10^{10}$$

$$= 0.8872$$

Where $\rho_t = 8000$ from appendix (A)

Lifetime of pipe = $\frac{10-2}{0.8872} = 9.017\ year$

It is noted that lowest erosion was in UNS S31254 so; it is the best pipe for decrease erosion.

-Erosion at bends

Pipe bends are usually one of the most erosion prone parts in a pipe system, and will, for conditions where erosion is the most critical degradation mechanism, be limiting both with respect to dimensioning of the piping system and the production rate. When the flow direction is changed in the bend, the particles do not follow the fluid but hit the bend wall as shown in Figure 6. The current bend model assumes a straight pipe section upstream the bend. Experience has shown that in case of complex isometric, both the location and maximum erosion rate may vary. This should be taken into account when imposing safety factors on the calculations.[5,6].

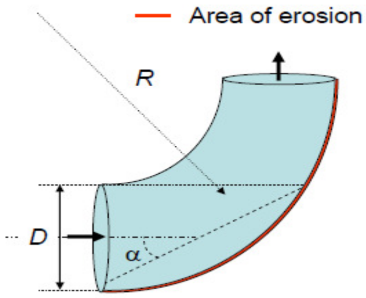

Fig.6: Impact angle, α, in bend. R is radius of curvature, Rcurvature=R/D (left).

Where Radius of curvature given as Number of Pipe Diameters. Reference of radius of curvature is centerline of pipe. Two different elbows geometries were tested with mainly:

1- 90^0 elbows with R/D = 1.5
2- 45^0 elbows with R/D = 1.2

-Calculate the characteristic impact angle, α, for the pipe bend geometry as shown in Figure 8, Note: Radius of curvature is given as the Number of Pipe Diameters:

$$\boldsymbol{\alpha = tan^{-1}(\frac{1}{\sqrt{2.R_{curvature}}})} \tag{10}$$

- dimensionless parameter group, A:

$$A = \frac{\rho_l^2.\tan(\alpha).U_p.D}{\rho_p.\mu_l} \tag{11}$$

- the critical particle diameter(γ_c):

$$\boldsymbol{\gamma_c = f(x) = \begin{cases} \frac{\rho_l}{\rho_p.[1.88.\ln(A)-6.04]} = \frac{1}{\beta.[1.88.\ln(A)-6.04]}, & \gamma_c < 0.1 \\ 0.1, & \gamma_c > 0.1 \; or \; \gamma_c \leq 0 \end{cases}}$$

Where $\boldsymbol{\beta}$is density relation and it is equal: $\boldsymbol{\beta = {}^{\rho_p}/_{\rho_l}}$

- the particle size correction function(*G*)by using the critical particle diameter

$$\boldsymbol{G = f(x) = \begin{cases} \frac{\gamma}{\gamma_c}, & \gamma < \gamma_c \\ 1, & \gamma \geq \gamma_c \end{cases}}$$

- characteristic pipe bend area exposed to erosion:

$$A_t = \frac{\pi D^2}{4.\sin(\alpha)} = \frac{A_{pipe}}{\sin(\alpha)}$$

- the value of the function *F(α)* by using the angle, α, found in step 1. *F (α)* can be found graphically from Figure

(4-2). The values for *F (α)* are in the range <0, 1>. The model/geometry factor, C_1, is set equal to , $C_1 = 52.6$ The model/geometry factor accounts for multiple impact of the sand particles, concentration of particles at the outer part of the bend and model uncertainty. The following unit conversion factor must be used (m/s → mm/year):

$$C_{unit} = 1000 * 3600 * 24 * 365 = 3.15 * 10^{10}$$

-The erosion rate is then found by applying all the calculated parameters into the basic erosion rate equation (8). The maximum erosion rate (mm/year) in the pipe bend is found by the following formula (all input values are given as SI-units):

$$\dot{E}_L = \frac{\dot{m}_P . K . U_P^n . F(\alpha) . \sin(\alpha)}{\rho_t . A_{pipe}} . C_{unit} . G . c_1$$

-Erosion elbows calculation for carbon steel:

erosion elbows from carbon steel is:

$$\dot{E}_L = \frac{\dot{m}_P . K . U_P^n . F(\alpha) . \sin(\alpha)}{\rho_t . A_{pipe}} . C_{unit} . G . C_1$$

Lifetime of pipe = $\frac{10-2}{2.239} = 3.573\ year$

Figure 7 shows the erosion in pipe bends as a relation with pipe diameter and particles diameter.

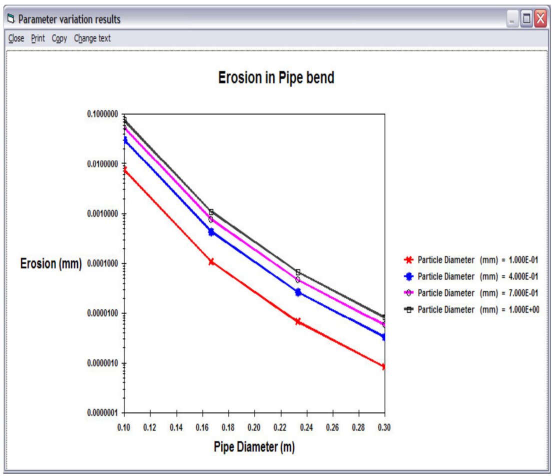

Fig.7: erosion in pipe bends

Conclusion

The wear of a surface due to solid particle erosion depends on the motion of the particles in the fluid as well as the behavior of the surface when struck by the particles. These two parts of the problem are related in that a surface, roughened by erosion, may increase the fluid turbulence and hence accelerate the rate of material removal. We have discussed the influence of the fluid motion on erosion rather briefly and have pointed out the difficulty in determining the conditions under which a particle strikes a surface. Ductile materials attain maximum erosion attacks for impact angles in the range $(15^0 - 30^0)$. Brittle materials attain maximum erosion attacks at normal impact angle (90^0). Steel grades are generally regarded as ductile. The Arab potash company has huge centrifugal pumps which had put on Dead Sea, these pumps have pressure about (10 bar a), the main goal of these pumps is sending water to the factory to treatment and elicitation salts and potash components.

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