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Evaluation of Wear Severity in Pipeline

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Abstract: The severity of wear occurrence in a pipeline was evaluated by applying the particle mass loading equation, stoke number and determining the mass transfer coefficient. These parameters examine the particle-particle and particle-pipe wall interaction pattern. Various laboratory experimental tests were done to determine the effect of particles on pipe walls and a range of values for the particle mass loading and stokes number were determined. These values became the interpretation criteria for analyzing results and suggesting recommendations. However, from this research result, the particle mass loading of 0.82, stokes number of 1.20 and mass transfer coefficient of 6.06 W m^{-2} °C were obtained. These values show that there was strong evidence of particle-wall interaction, which could have caused wear. When the pipe under study was cut into sections and visual examination was carried out, it was observed that cutting wear actually occurred in the internal geometry of the pipe. The severity of the wear is attributed to the small diameter of the pipeline under study; the size, coupled with the agglomerated stones is believed to have allowed for close particle wall interaction. From the findings, pipes whose depth of cut is high enough to significantly affect their load bearing capacity should be changed and sizable particles should be removed from the flow system to avoid wear.

Key words: Heat transfer coefficient, mass transfer coefficient, particle mass loading, pipeline, stoke, number, wear

INTRODUCTION

The integrity and lifespan of pipelines is very important in today's industrial environment. Pipes are usually subjected to hostile environments as most oil and other fluid transmission installations tend to be located in wilderness and untouched ecosystems. The performance, life and reliability of such pipelines is of great concern particularly to the environment. Therefore, research is carried out to enhance the quality of pipelines in order to prevent or reduce wear (Buchan and Spearing, 1994). Wear reduces the yield stress of the pipe, as a result, the pipe loses its ability to withstand the pressure exerted by turbulent flow and cracks appear, which cause leakages (Bajoraityte and Bogdevicius, 2002). Wear, which is the subject of this study is abrasive wear.

Abrasive wear is caused by hard particles (which have detached from the base material being an integral part of the fluid environment). These hard particles are trapped between either of two contacting surfaces; a particle-particle surface, or a particle pipeline surface. This abrasive contact induces the contacting surfaces to move contrary to each other and are consequentially forced to cut sharp scratches or grooves, damaging one or both of the surfaces (Ruiz and Koenigsberger, 1970).

Even though, abrasion in this environment acts on a micro dimension, it invariably leads to a general macro effect. The minutest changes within the pipeline can therefore, never be taken for granted. Several researchers have studied the severity of wear rate of mechanical materials (Lipson and Colwell, 1961; Bradley, 2002; Zughbi *et al.*, 1991) and have attributed the cause of wear particularly to suspended solids and as afore mentioned, these are coarse and hard particles in turbulent flow that occur in pipelines.

Hence in this research, the severity of wear occurrence in pipelines was evaluated by determining the particle mass loading, stokes number and mass transfer coefficient.

MATERIALS AND METHODS

The particle fluid behaviour: In this study, the particle fluid flow model generated by Brown (1999) was adapted but data interpretation was confined to test results determined experimentally. These model equations were used to determine particle mass loading β and stokes number, S_t.

Particle mass loading:

$$\beta = \frac{r_p \rho_p}{r_f \rho_f} \tag{1}$$

where:

r_p = The volume fraction of the particle
ρ_p = The particle density
r_f = The volume fraction of the fluid
ρ_f = The fluid density
$r_p\rho_p$ = Represents the particulate mass/unit volume of flow
$r_f\rho_f$ = Represents the fluid mass/unit volume of flow

Experimental data interpretation for β:

$$0.1 \le \beta \le 0.29$$

This shows that the particles are well diffused into the fluid and the flow is highly subject to inertia and negligible.

$$0.3 \le \beta \le 0.69$$

The particle-particle interaction is significant and remain suspended in the fluid, while the larger particles are acted upon by the force of gravity (tending to fall and settle within available crevices in the pipeline).

$$0.7 \le \beta \le 1.0$$

There is strong particle-particle interaction, particles are settling and forming aggregates. Fluid flow is heavily obstructed.

Stoke number: The stoke number shows the relationship between the particle motion and the fluid motion. This is defined as the ratio of the particle response time due to viscous drag to a characteristic turbulent eddy time in a carrier fluid (Brown, 1999). Stoke number is expressed in Eq. 2:

$$S_t = \frac{\rho_p d_p^2 V_s}{18\mu_f L_s} \quad (2)$$

where,

d_p = The particle diameter
μ_f = The dynamic viscosity of the carrier fluid
V_s and L_s = Characteristic velocity and length of scales in the flow

Experimental data interpretation for S_t:

$$0.001 \le S_t \le 0.05$$

indicates that there is uniform particle-particle distribution intermixed with the fluid and have negligible effect on the walls of the pipe.

$$0.05 \le S_t \le 0.1$$

There is the presenc in the mixture of small quantity of coarse particles and larger quantity of fine particles. At this stage particle-particle fluid interaction is not enough to cause significant impact on the walls of the pipe.

$$0.1 \le S_t \le 0.1$$

The particle-particle interaction is stronger. Some of which are acted upon by gravity and have sufficient interaction with the pipe walls to cause erosion wear. The range of stoke number here corresponded with the findings of Tu and Fletcher (1996).

$$S_t > 1.0$$

The effect of particle-particle interaction is dominant. The particle built up causes a constriction that forces particle-pipe wall interaction and in most cases, cutting wear occur.

Mass transfer coefficient: The convective heat transfer between the pipe and flowing particle-carrier fluid flow was characterized with a heat transfer coefficient, h_{pf} (Bang *et al*., 2002), determined by the dimensionless relation (Acadams, 1954). This relationship is modified to suit this research.

$$\frac{h_{pf} D}{K} = 0.32\left(\frac{(\rho_f + \rho_p) V_f D}{\mu_f}\right)^{0.06}\left(\frac{C_p \mu_f}{K}\right)^{0.04} \quad (3)$$

where,

D = The pipe diameter
V_f = The fluid velocity
μ_f = The viscosity of the fluid
h_{pf} = The heat transfer coefficient, between the pipe and fluid flow
ρ_f and ρ_p = The fluid and particle densities

RESULTS AND DISCUSSION

The values in Table 1 were used for the computation of the model results.

From Table 1, the particle mass loading was calculated to be 0.82 and the stokes number was 1.20. The measured fluid velocity was 8.75 m sec^{-1} while, the mass transfer coefficient was 6.06 W m^{-2} °C. These values show that there was significant presence of particle-wall interactions in a turbulent flow pipeline system. The average diameter of stone particles was 38 mm. From study, stones of this nature were found to have compressive and tensile strengths in the range of 200-1700 and 40-250 kg cm^{-2}, respectively and they are also hard and brittle. Upon continuous impact on the pipe walls, these properties could cause distortion of the microstructural arrangement of the pipe material, thereby inducing wear. On the other hand, the small diameter of the pipe would have contributed to the severity of the wear, for the reason that there was not enough space for adequate particle dispersion in the pipeline.

Table 1: Values used to determine particle fluid flow properties

Variables	Values
Density of particle (ρ)	2659 kg m^{-3}
Viscosity (μ)	35 Pa.s
Diameter of pipe (D)	0.5 m
Density of fluid (ρ_f)	852 kg m^3
Thermal conductivity of fluid (K)	3.54 W m^{-1}°C
Specific heat of fluid (C_p)	2245 J kg^{-1}°C
Length of pipe (L)	35 m
Length of scales in the flow (L_s)	44 mm
Particle volume fraction (r_p)	120 μm^3
Fluid volume fraction (r_f)	455 μm^3

CONCLUSION

The particle mass loading and stokes number equations as expressed by Brown (1999) has been applied in determining the severity of pipe wear. It was found that there was significant particle-wall interaction and that the high fluid flow velocity coupled with the size of the pipeline would have aided the high rate of wear that lead to oil leakages.

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