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Determination of particle impacts and impact energy in the erosion of X65 carbon steel using acoustic emission technique

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ABSTRACT

An *in-situ* acoustic emission (AE) monitoring technique has been implemented in a submerged jet impingement (SIJ) system in an effort to investigate the effect of sand particle impact on the degradation mechanism of X65 carbon steel pipeline material in erosion conditions.

A detailed analysis of the acoustic events' count rate enabled the number of impacts per second to be quantified for a range of flow velocities (7, 10, 15 m/s) and solid loadings (0, 50, 200, 500 mg/L) in a nitrogen-saturated solution at 50 °C. The number of impacts obtained from acoustic signals showed a strong agreement with theoretical prediction for flow velocities 7 and 10 m/s. A deviation between practical readings and theory is observed for flow velocity of 15 m/s which may be due to error from detected emissions of multiple rebounded particles.

Computational fluid dynamics (CFD) was used in conjunction with particle tracking to model the impingement system and predict the velocity and impact angle distribution on the surface of the sample. Data was used to predict the kinetic energy of the impacts and was correlated with the measured AE energy and material loss from gravimetric analysis. The results demonstrate that AE is a useful technique for quantifying and predicting the erosion damage of X65 pipeline material in an erosion–corrosion environment.

1. Introduction

In Oil and Gas production, sand particles may be present in hydrocarbon flow from reservoir formation due to increased use of proppants and reservoir fracturing techniques; dissolution of cementing materials, loss of capillary pressure after water-cut and well aging [1]. This can be a major threat to the integrity of the production facilities because the sand can cause erosion of flow-lines, chokes and valves which may lead to leakages, failures and harm to operators and environment. Erosion, especially in X65 carbon steel, can be very significant in the presence or absence of corrosion; it occurs as a result of mechanical interaction between the sand particles and the internal surfaces of pipeline. Different mechanisms of material removal during this erosion process have been suggested by different researchers. Hutchings [2] proposed that ductile materials tend to suffer most severe erosion at impact angles of 30° while brittle materials often suffer peak erosion for normal incidence. In view of this, various models have been proposed to explain the rate of material removal with consideration of several factors [3] affecting the process which can be categorised as operating conditions (particle velocity, hydrodynamics, impact angle, pH, and temperature); particle factors (concentration, size, shape and density) and material factors (elastic properties, hardness, and toughness of both particle and target). A comprehensive review of these models presented by Meng and Ludema [4] has revealed that particle impact velocity, erodent (particle loading, size and strength), type of material, and impact angle are the main factors affecting erosion rate.

Because of the complexity of the material degradation by the various factors involved in the erosion process, it is important to continuously monitor the flow stream so as to know the onset of sand production and predict the extent of damage to the material and possibly take action when excessive sand is noticed or damage becomes significant. Existing conventional techniques such radio-active probes, erodible resistance and optical measurements [5] use intrusive mechanisms to monitor the sand presence in flow streams and can be inefficient and cumbersome to maintain. These devices are always replaced after establishing the presence of sand. Also, sand control measures such as gravel packing, sand consolidation and controlled production have problems with practicality and success [6]. Acoustic emission (AE) technique which is non-intrusive, fast, cost effective, easily and cheaply maintained and can monitor large structures or pipelines from single sensor location may be applied in the monitoring of sand particles in the flow stream. Monitoring of particle impacts by acoustic emission is based on the theory that when a particle

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strikes a target, a fraction of the incident kinetic energy (KE) dissipates as elastic waves, which will propagate through the target material according to its geometry and elastic properties before being detected by a suitable AE sensor. In an effort to validate this theory using a single impact in dry environment, Hunter [7] determined the energy converted into elastic waves during normal elastic impact of a hard steel sphere on steel target to be less than 1% of the incident KE. His finding was lower than that of Reed [8] who suggested that the elastic wave energy was about 4.5% of the incident KE. Using a similar analysis, Hutchings [9] extended the study to plastic deformation of the target and proposed that 1–5% of the incident KE is radiated as elastic waves majorly in the form of Rayleigh waves, with 90% used up in plastic work while the remaining proportion goes into rebound KE. Using Finite Element simulation Wu et al. [10] observed that for elastic impact the energy dissipation due to elastic wave propagation is less than 1% of the total KE if there is more than one reflection during the contact which is in line with Hunter's analysis. If there is no reflection within the contact duration, a significant amount of KE is dissipated due to stress wave propagation, whereas for plastic impact, the energy loss due to elastic wave propagation becomes negligible and the KE is mainly dissipated due to plastic deformation. In a wet environment, Ferrer et al. [11] used glass beads in their single impact experiment on stainless steel and discovered that the proportion of KE radiated as elastic wave is below 1% and in the order of one part per 10,000. The very low energy dissipation could be attributed to effects of inertia, drag and hydrodynamic boundary layer deceleration of impacting bead in the flowing stream.

Based on this established theory, many researchers have applied acoustic emission (AE) in wear studies in both dry and wet conditions since the main cause of wear is energy transmitted from the impacting particles to the target [2]. Droubi et al. [12] have presented a detailed review on the application of AE in wear studies. They also investigated dry abrasive particle impacts on carbon steel by correlating AE energy with different particle diameters and velocities. They proposed that AE energy increases with the third power of particle diameter and the second power of the velocity. They maintained that the particle diameter exponent was only valid up to particle sizes of about 1.5 mm as a result of different energy dissipation mechanism with higher momentum, and that the velocity exponent and the general level of energy were lower for multiple impacts than for single impacts which were attributed to particle interactions in the guide tube and/or near the surface.

In this study, an AE technique has been implemented in a submerged impingement jet (SIJ) to quantify the number of particle impacts per second using the AE event count rate which is verified with theoretical predictions. Particle impact energy calculated from CFD in conjunction with particle tracking code was correlated with measured AE energy per second of the impacts to ascertain the dependence of AE energy on the impact energy. The AE event count rate was also correlated with the material degradation rate expressed as mass loss with a view to establishing a guide that can be used in monitoring and predicting erosion damage of pipeline material (X65) in service.

2. Experimental set-up, materials and procedures

2.1. Experimental set-up

The experimental set-up used in all the tests is a 50-l capacity submerged impingement jet (SIJ) rig coupled with AE devices as shown in Fig. 1. The rig is a re-circulating system controlled by a variable speed centrifugal pump that provided the required flow velocity, mixing and recirculation of the liquid–solid mixture. The mixture was delivered through a double nozzle (4 mm diameter) system impinging onto a circular flat specimen (5 mm stand-off distance) at 90° impingement angle with 50 °C constant temperature maintained by a heater and thermocouple sensor. The AE devices include a wideband piezoelectric ceramic acoustic emission sensor (VS900-M with microdot connector, 100–900 kHz frequency range, operating at 350 kHz peak frequency and temperature range of −50 to 100 °C), preamplifier, data acquisition system (AMSY-6) and software for data capturing and signal analysis which were supplied by Vallen [13]. The sensor calibration was performed using pencil lead technique [14] to confirm that it conforms to manufacturer's specification and was coupled to the back of the specimen by means of vacuum grease (to avoid AE signal attenuation).

2.2. Materials

2.2.1. Erosion material

The test specimen material is X65 carbon steel which was cut into circular discs of 25 mm diameter and 10 mm thick. The material Brinell Hardness number is 217 HB 10/3000/30 which means that a Brinell Hardness (denoted HB) of 217 was obtained

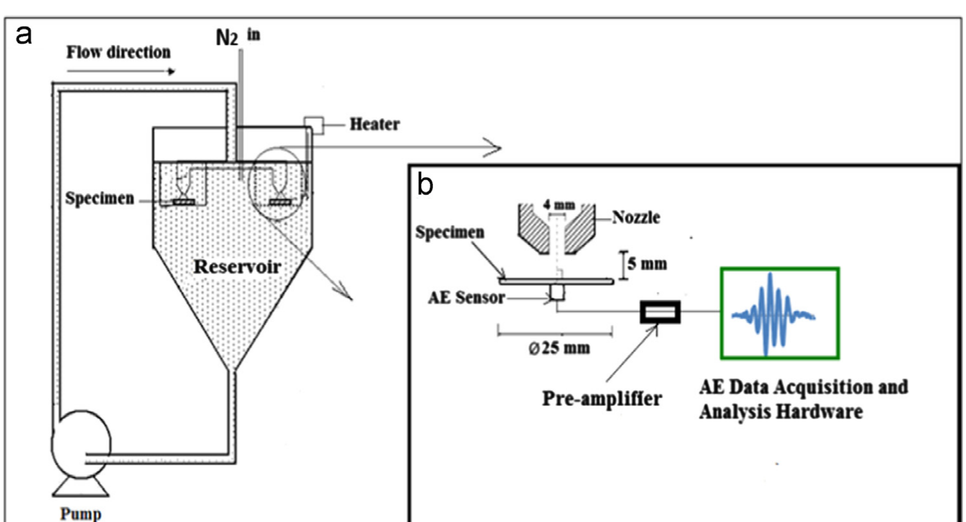

Fig. 1. (a) Schematic illustration of experimental rig set-up (b) AE analysis hardware.