Viscosity impact investigation on erosion of carbon steel in sand-mixed-polivinyl alcohol

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Abstract. Erosion in oil and gas production sector is predominantly caused by fine particles’ migration into the processing facilities. Fine particles are mostly transported to the facilities via carrier fluid. Other than sand, the viscosity of the carrier fluid also contributes to the sand erosion phenomenon. However, the impact of viscosity on sand erosion is not fully discovered by previous researchers. Therefore, this paper investigated the impact of fluid viscosity on erosion of the carbon steel surface. In the presented work, an experimental rig was fabricated and tested for the study of impact of fluid viscosity on erosion of the carbon steel by considering the water mixed-polyvinyl alcohol as a carrier fluid. The metal coupons were impacted with sand slurries of different viscosities. Scanning electron microscopy along with energy dispersive spectroscopy and Universal scanning probe microscopy were used to analyse the centred and adjunct areas of the coupons. These analyses revealed that the viscous slurry is least effective in removal of metal surface in comparison with the pitting erosion. The obtained results reflected a decrease in erosion rate as the fluid viscosity upsurges and the type of metal surface erosion changes from uniform erosion to pitting erosion by fluid viscosity increment.

1. Introduction

Erosion is one of the most usual problems in oil and gas industry. The problems caused by sand increases as the wells and pipelines get older and more sand is produced. In addition to the environmental concerns and restrictions, the sand creates a variety of problems for the oil and gas industry such as solid particles interfere with control and instruments, reducing the reliability of the system significantly [1, 2]. The possibility to remove sand in a controlled and automated manner can grant the process systems with better control and safety. It can increase the lifetime of the equipment by allowing more sand to enter the production train and speed up the production rate [3].

Many sand management systems have been implemented over a period of time to exclude sand and its source down hole of the well [4]. These sand exclusion techniques involve gravel packing at the well head and/or using screens to exclude sand from entering the pipeline [5]. The sand exclusion methods along with continuous sand monitoring and control have been successful in cutting down the production of sand in pipelines to a large extent and are extensively used in oil and gas production wells. In spite of these measures, based on the geography of the well location, fine sands (less than 50-75 microns) find its way to the sand exclusion system and travels along with the fluid through the pipeline causing erosion and damage to the piping components [6]. In erosion phenomenon, tiny solid particles are carried through the pipelines of production well. Many parameters can exacerbate the
erosion rate such as sand particle shape and size, impact angle, flow rate and fluid properties (viscosity and density) [7, 8]. It is beneficial to have clear understanding of how great the impact of each of these parameters on sand erosion; this understanding will lead us to have a better analysis and evaluation of how each of these parameters contribute to the magnitude of the sand erosion phenomenon.

Fluid properties such as density and viscosity play considerable role in the sand erosion rate and consequently damaging pipelines and other processing facilities [9]. The impact of fluid viscosity on erosion rate is not fully understood and still in its infancy [10]. However, significant research has been made to investigate the erosion phenomenon and to develop erosion models for predicting the erosion rate in various pipelines and different production situations [11, 12].

The effect of viscosity on the local thickness loss and total erosion ratio is crucial [9]. Sand particles are carried via fluid through the pipeline; the velocity of the flow in the pipeline will determine how big the erosion will be if the particle size assumed to be constant. It is well known that viscous fluids have lower rate of flow in comparison with fluid with lower viscosity. For many existing fields, the erosion potential of solid particles exists in any production well that involves the motion of solid particles within the carrier fluid. Erosion rate in processing facilities is highly related to several parameters such as fluid properties, flow rate, sand size and rate, material type, geometry as well as many others [11]. However, trying to isolate the effect of one parameter and evaluating its role in the erosion phenomenon can help to bring out a better understanding of each parameter status and parameter that should be given main consideration in analysis.

2. Materials and methods
The used sand was sandstone: fine sand matching the reservoir dimensions that can be a good representative of the real conditions. The carbon steel plates were used as erosion sample for representing the inner surface of the production line that was eroded by fine sand produced from the oil reservoir. A two-phase pump was utilized to pump the polymer-sand mixture from the container to hit the carbon plate. A metal container was used as a reservoir having a mixture of 12 litres and 750 g of water and sand, respectively. A stand was used to hold the carbon steel plate in the top of the container, so it can be exposed to the fluid flow, as shown in figure 1.

![Figure 1. Schematic of fluid flow loop setup.](image)

Polyvinyl alcohol was used as a viscosity increasing agent. Different amounts of polymer were added to the water-sand. These concentrations provided 1cP, 7 cP, 13 cP and 19 cP viscosity values to the fluid. Dry sieving method was used to characterise the sand particles. Sieve analysis is classic laboratory work implementation on a formation sand sample to determine grain/particle size distribution for sand control applications. The analysis was done by using a series of mesh having gradually decreasing screen sizes. The formation sample was placed on the top of the mesh series and seeped through the screens until it faces the screen which has smaller openings than the size of the grains. This method will used to obtain fine sands with dimension below 75 µm for the experiment.
Initially, 750 g of fine sand, with dimensions below 75 µm, was mixed in 12 l of tap water. This water to sand ratio remained constant for all experiments. The mixture of water and sand was pumped through a PVC pipe for duration of 8 hours and impinged onto the carbon steel plate. In the subsequent experiments, the water-sand mixture viscosity was increased by adding the polymer. Polyvinyl alcohol was used as the viscosity increasing agent and the effect of viscosity alteration on sand erosion phenomenon was measured using Universal scanning probe microscopy (USPM), energy dispersive spectrum (EDS), and scanning electron microscopy (SEM).

3. Results and discussion

The carbon steel coupons, eroded during the present experimental work, were analysed through USPM, EDS, and SEM tools. For each experiment, two areas of interest were analysed in the treated sample, the area directly exposed to fluid flow and its adjunct area, which has not been directly eroded.

3.1. USPM analysis

After erosion experiments, the samples were washed and cleaned for topography analysis. The treated surfaces were scanned with a USPM probe to identify interactions in near-field regions. USPM analysis provided three dimensional (3D) models of the eroded plates plus erosion profile of the samples. The 3D models of directly eroded spots (central area) and the corresponding erosion profiles are shown in figure 2.

![Figure 2](image)

Figure 2. 3D models and corresponding erosion profiles of directly eroded coupons with: (a) 1cP solution, (b) 7 cP solution, (c) 13 cP solution and (d) 19 cP solution.

The results from 3D model show that the erosion severity decreases as the value of viscosity increases and the metal surface tend to be more uniform. This is thought to be due to the high drag force and low fluid flow turbulence as the fluid viscosity increases [10]. Moreover, it can be observed from the erosion profile that although the severity of the sand erosion decreases, deep penetration by...
the sand occurs on the metal surface which indicates that the type of erosion is changing from uniform surface erosion to pitting erosion.

The 3D models and corresponding erosion profiles of the adjunct areas are shown in figure 3. The analysis of USPM results related to the adjunct areas show that as it was expected, the erosion rate in the adjunct areas is lower than the directly eroded areas since the 3D models are showing a more homogeneous surface as the viscosity number increases. Moreover, the same phenomenon of erosion, as in case of directly eroded areas, was observed with an increase in viscosity of the fluid. The erosion was changing from uniform to pitting as the viscosity value increases. The number of deeper holes, resulted from pitting erosion, was higher in high viscosity values.

Figure 3. 3D models and corresponding erosion profiles of indirectly eroded coupons with: (a) 1cP solution, (b) 7 cP solution, (c) 13 cP solution and (d) 19 cP solution.

3.2. SEM analysis

SEM and EDS were used for surface and elemental analysis of the metal surface. For directly eroded spots, SEM results are shown in figure 4. Moreover, table 1 provides information regarding the detected iron and oxygen elements in the analysed spots. The pre-treatment samples were fine polished plates having no rough patches on the surface. However, after conducting sand erosion trials, the treated surface exhibited high degree of roughness. The viscosity of the carrier fluid governed the roughness of the eroded samples.

As the viscosity value increases, the congestion eroded area ratio to the not eroded one decreases since more untouched and untreated areas appear in samples treated in the experiment 3 and 4 with 13 cP and 19 cP solution viscosities. Moreover, it can be visually analysed that more dark holes were spotted in the SEM micrographs of the samples treated with high viscosity solutions. This can be a support to the earlier mentioned USPM analysis. Table 1 shows the percentage of iron and oxygen elements detected during the EDS analysis of the eroded samples. As it is tabulated, the percentage of detected iron is extremely higher in the samples treated with high viscosity solutions [7-10].
Figure 4. SEM illustration of eroded coupons with: (a) 1cP solution, (b) 7 cP solution, (c) 13 cP solution and (d) 19 cP solution.

Table 1. Iron and oxygen content of the eroded samples.

| Viscosity (cP) | Element | Weight (%) |
|----------------|---------|------------|
| 1              | Oxygen  | 19         |
|                | Iron    | 25.2       |
| 7              | Oxygen  | 33.1       |
|                | Iron    | 66.9       |
| 13             | Oxygen  | 0          |
|                | Iron    | 100        |
| 19             | Oxygen  | 0          |
|                | Iron    | 100        |

SEM of areas adjunct to the directly eroded spots are shown in figure 5. The erosion impact on the analysed surface starts to vanish after the second sample for viscosities higher than 7 cP. This observation is related to the higher viscosity values of the fluid, which resulted in less drag force and eventually less erosion values. The same analysis of the centred areas regarding the iron element percentage is valid for the adjunct areas. However, the iron percentage reduction in the centred areas as the value of viscosity increases remains lower than the iron percentage reduction in the adjunct areas. This behaviour evidently supports the conclusion made from the erosion profiles showing the uniform erosion in the adjunct areas which is more effective in surface metal removal in comparison with pitting erosion.
4. Conclusion

Erosion of metal surface was investigated at four different viscosity values, 1 cP, 7 cP, 13 cP, and 19 cP. It can be concluded that the erosion velocity is more sensitive to the viscosity values below 8 cP as the erosion velocity plunges from about 120 cm/s to 40 cm/s. However, the effect of viscosity on erosion velocity loses its significance impact for higher viscosity values as the slope of the graph becomes more tedious.

The second observation is related to the erosion type. Overall there are two types of erosion in metal surface, one is uniform erosion where causes a uniform metal loss from the surface and the second is pitting erosion which causes deep holes in the metal surface. It can be observed from the erosion profiles that although the severity of sand erosion decreases, deeper penetrations caused by sand occurs on the metal surface which indicates that the type of erosion is changing from uniform erosion to pitting erosion in the centred areas. However, the governing type of erosion remains the uniform erosion, but with very low impact on surface. The obtained 3D models and EDS analysis also support this observation.

The erosion severity is indicated by the percentage of metal loss from the surface. For this purpose, the EDS and SEM analysis were used to support the conclusion. As discussed earlier and tabulated in the element detection table of each sample, as the viscosity number of the carrier fluid raises, the percentage of the detected metal on the surface upsurges. This suggest that the erosion impact in terms of its severity is restrained as the viscosity increases which is thought to be due to the lower drag force of the fluid and its lower turbulence stream. However, it is recommended to examine more viscosity values such as, 50 cP and 60 cP to have a holistic range of data points so they can be a better representative of the mere viscosity impact in extreme viscous oils. Furthermore, rerunning the same experiment procedure utilizing different common viscosity agents such as hydrolysed polyacrylamide can be fruitful due to the catalyst component difference of each polymer.
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