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Surface erosion behavior of an intrusive probe in pipe flow

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ABSTRACT

Unconsolidated sandstone reservoirs in northwestern China exhibit high sand production rates. This extreme working condition causes unusual erosion behaviors of ER (electrical resistance) probes. To describe the erosion behavior of an ER probe in this extreme condition, an intrusive probe is mounted in a pipeline in the same manner as an ER probe. The sand production rates are adjusted to simulate the working conditions of an unconsolidated sandstone gas field. Factors, including the evolution of the surface profile, unstable sand production rate and probe materials, are studied for erosion behaviors. The results show that the peak values of the sand production rate substantially affect the erosion progress. Different wear mechanisms were discovered for different materials. Under a 250-kg sand load, the most seriously eroded upstream surface was the top of the probe at the beginning of the erosion test, but the erosion surface shifted to the bottom of the probe by the end of the experiment. The erosion angle α of the upstream surface is decided by the upstream edge angle θ. A model, modified to account for the evolution of the surface profile, is suggested and validated using experimental data, and the model had an average relative deviation of 9.9% for a 330-kg erosion and 12.6% for a 480-kg erosion. The limitations and applicable range of the modified model are listed. This study offers a numerical model for the research and development of a strong, flexible ER probe to be used for higher sand production rates.

1. Introduction

Unconsolidated sandstone reservoirs, such as the Sebei gas reservoir in northwestern China, exhibits high sand production rates (average 0.001 kg/s for a single well). According to a field investigation of the sand signal via an acoustic detector installed in the wellhead, the sand bursts out intermittently and randomly, as shown in Fig. 1. The intermittent peak values of the high sand production rate (averaging approximately 0.016 kg/s and lasting for 10 min) contributed substantially to sand erosion during an operational period greater than 1 year. Therefore, in laboratory studies, it is essential to understand the erosion behaviors that occur during peak sand production periods.

ER (electrical resistance) probes are extensively used subsea and topside to continuously monitor sand erosion rates. However, ER probes are not robust enough (the element is 1 mm thick) to be used in these extreme working conditions. Instead, intrusive probes (cubic columns) of different materials are used to study surface erosion behavior, as shown in Fig. 2. DNV RP O501 (DNV, 2007) provided an erosion model that used intrusive probes to evaluate the erosion rate; however, this model is only applicable to a sand content range of 1–50 ppm (equivalent to a mass flow rate of 1.7–84 mg/s in this study). This value is three to four orders of magnitudes smaller than the actual sand flow rate in an unconsolidated sandstone gas field. Thus, a higher sand production rate may reduce the reliability of DNV RP O501. An accurate erosion prediction for intrusive probes is unavailable.

For the erosion of higher sand production rates in a pipe flow, Chong et al. (2012) investigated an erosion model based on Chen's model (Chen et al., 2004) for flat surface erosion around a hole (at an air-sand flow rate 0.0285–0.0342 kg/s). They acknowledged that the evolution of the surface profile should be considered when predicting the sand erosion rate because the CFD (Computational Fluid Dynamics) method was not versatile enough to describe the erosion progress. Christopher et al. (2013) proposed a relationship

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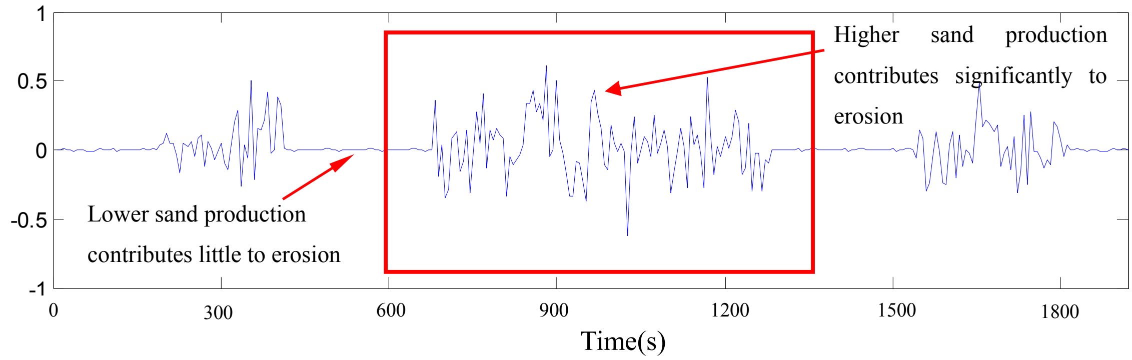

Fig. 1. Discontinuous and random (unstable) sand bursts recorded using a sand acoustic detector.

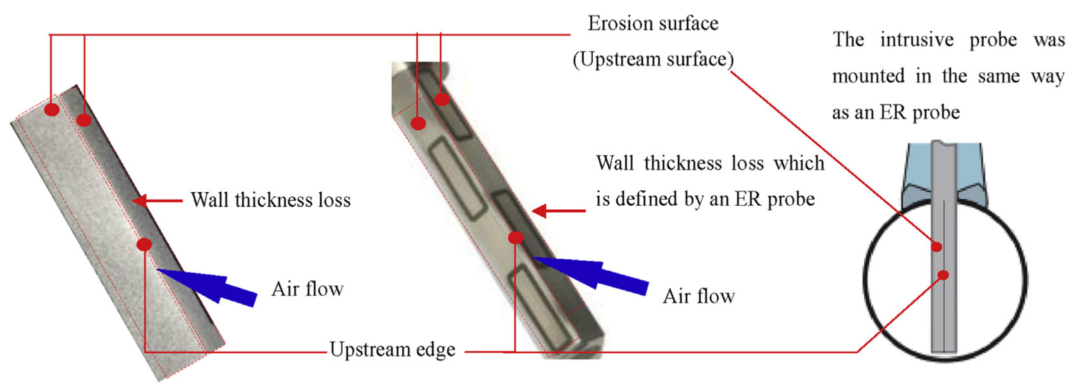

Fig. 2. An intrusive probe (cubic column), instead of an ER probe, is used to study the wall thickness loss under extreme working conditions.

between the particle size distribution and erosion angle (at an air-sand flow rate 0.013 ± 0.002–0.024 ± 0.002 kg/s) and proved that the Stokes number also had a strong influence on the progress of the erosion and the erosion model. Lester et al. (2010) suggested that the erosion model should be modified to include the geometry of the erosion specimen in the suspended loop flow (slug flow, sand content 7% by volume). Lester's model is a development of Finnie's erosion model (Finnie, 1960); however, the erosion evolution of the geometry was ignored in that study. The dynamic mesh of fluid-solid coupling was also proposed to be incorporated for investigating and evaluating the erosion rate (at a gas-sand flow rate 0.0019 kg/s) (Zhu et al., 2014). However, the rubbed-off parts could not be simulated because they were transformed rather than deformed.

Moreover, sand bursts from reservoirs always lead to unstable suspended flows in pipelines (Braaten et al., 1996). Odigie et al. (2012) simulated unstable sand flows using a sand injection test loop to modify the critical sand product velocity of API 14E (API 14 E, 1991). Sand was intermittently injected into the loop to simulate the working conditions in the field. This type of loop, with an acoustic sand detector, is used to simulate unstable erosion progress in this study.

The work presented in this study focuses on experimental and numerical studies of the surface erosion behaviors of intrusive probes exposed to high sand production rates. An erosion loop system was developed, and precise measurement instruments were used to investigate the wall thickness loss. A modified model that considers the erosion evolution and unstable sand production rate was proposed and validated using experimental results.

2. Experimental analysis of the test probe

2.1. Probe specimens

Three types of materials (i.e., Q235, Inconel625, and Monel400) were tested for the intrusive probe. The specimens were sent to a commercial lab to determine their elemental compositions (the results are shown in Table 1). The probes were nominally 45 mm long × 6 mm wide × 6 mm thick and mounted normal to the air stream in the vertical section of the test rig with a 45° windward edge. To facilitate access to the probe and to inspect the profile of the surface, the probe was placed into a 45° oblique square sharp slot on the loop surface and sealed with adhesive sealing tape to ensure that it was airtight.

Table 1
Properties of the test samples.

Material	Brinell hardness (HB)	Modulus of elasticity (GPa)	Density (kg/m^3)	Composition (%)
Q235	120	200	7858	C(0.2) + Si(0.3) + Mn(0.35) + P(0.045) + S(0.05)
Monel400	140	183	8800	C(0.29) + Mn(0.2) + Ni(65) + Si(0.5) + Fe(2.5) + S(0.024)+Cu(30)
Inconel625	220	205	8400	Ni(62) + Cr(23) + Mo(9)