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Pipeline failures due to lightning

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ABSTRACT

In the last thirty years lightning properties have been measured with a high degree of detail. Yet, the mechanisms by which lightning causes failure of buried structures are still not fully identified. This work addresses results from experimental studies and modeling of two lightning failures in buried natural gas pipelines. In both cases leaks followed by fire were caused by small punctures as a consequence of localized fusion of the pipe wall metal. Bolts hit the ground very close to the pipelines and produced the ionization of the soil in an area which was larger than their topsoil. Then, failures were caused by Joule effect, due to large currents generated by the establishment of arcs between the pipeline and the point of impact. Models to check the effect of the topsoil (burial) depth, the closeness of air-breaking metallic components and other construction characteristics on the probability of occurrence of these phenomena are reviewed. Ways to minimize the impact of this damage mechanism upon the integrity of buried pipelines are finally discussed.

1. Introduction

There are more than 2.5 million miles of oil and gas pipelines in the United States alone. Approximately 900 failures occurred on hazardous liquid pipelines from 2002 to 2003, 9% of these failures were attributed to natural force damages, which included lightning strikes, among other naturally occurring events [1]. The US Pipeline Hazardous Material Safety Administration (PHMSA) regulators require that pipelines with external coatings for which there is a threat of weather-related conditions such as lightning should be assessed by external-corrosion direct assessment (ECDA), in-line inspection (ILI), hydrostatic testing, or other methods to ensure integrity of the pipeline system. Removing this particular threat of outside force by lightning is required, but seldom accomplished. However, this threat which requires the need for sufficient historical data on the number or density of lightning strikes, condition of coating, distance from AC tower grounding, pipe investigations, etc., is justified where damage is anticipated or has occurred [2].

There is a recent history of damage to pipes and other buried structures, due to the incidence of lightning. On the Gulf coast of the United States, small blisters in the pipeline's coating were found in its top quadrant when dug up for inspection. Although in this case there was no leak, small burn marks were found in the steel after removing the coating [2].

In another case, lightning reached a pipe during pipeline laying, generating a small leak that was detected by ILI (in-line inspection). In a third case, lightning hit a power line close to a gas pipeline. AC accelerated corrosion was reported, which occurred in 15 s (3 cycles of 5 s each) and generated a 12.7 mm diameter hole in the tube wall. The coating showed little damage, except for the precise spot of the leak.

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In July 1994 in Cideville, France, a buried pipeline with 1.20 m topsoil was perforated because of lightning, creating a leak followed by fire. In this case, it was determined that the impact of the lightning occurred in a 1.5 m high wooden post buried to a depth of 0.5 m, that served as a landmark. The lightning caused 2 craters, separated by 110 mm, in which the coating completely disappeared and the pipe wall was perforated. A hole developed in one of the craters, and two holes were detected in the other. The radii of the elliptic holes varied from 1 to 13 mm in the outer radii (OD) [3].

In 2009, Alabama also recorded a failure caused by lightning in an inter-State pipeline, owned by BP. Metallographic analysis revealed that the most likely cause of failure was a shock caused by lightning striking at another location that caused the leak at the site of the electrical grounding.

More recently, Quickel et al. [1] provide a case history in which a failure analysis was applied to determine the metallurgical cause of a failure involving a polyethylene-coated hydrocarbon pipeline that leaked as a result of a lightning strike.

There are also records of damage buried electrical wires and cables due to the incidence of lightning, that include direct incidence of the thunderbolt in superficial nearby structures such as trees, buildings, etc. that generate a current distribution in the ground. Recorded cases in Thailand, for example, include a failure approximately every 15 years [4]. H.D. Campbell [5] also reported damage to buried telephone wires due to the fall of lightning in the vicinity.

This article presents experimental studies and conclusions from the analysis of two recent failures that occurred in buried pipelines for distribution of natural gas [6,7]. Both cases occurred in 2012 in Argentina, in steel pipelines with cathodic protection (CP) systems, in a case by sacrificial anodes and in the other with rectifiers and reference electrodes.

Both failures caused gas leaks followed by fire. Leaks were located at the top of the pipe. The first case (A) corresponds to a pipeline built with a 3 in. (75 mm) dia. SAW (submerged arc welded) seam tubes. The failure occurred on a plain about 3800 m above sea level. The second case refers to a 4 in. (102 mm) 3.2 mm thick pipeline, built with ERW (electric resistance weld) seam,

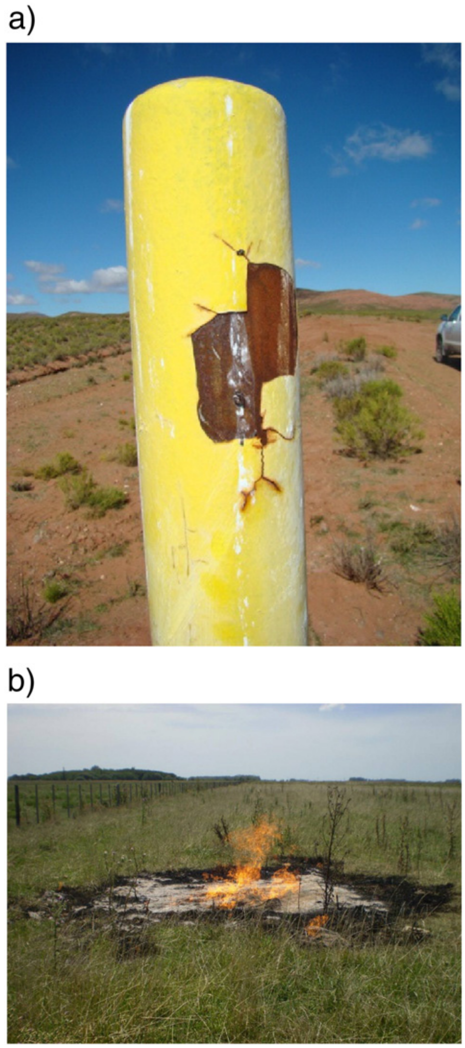

Fig. 1. a: Molten metal in CP post 30 m away from failure (A), in flat landscape. b: Small fire after failure (B), note flat landscape and nearby wire fence.