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SENSOR CABLE FOR DETECTION AND LOCATION OF OIL PIPELINE FAILURE CAUSED BY THIRD PARTIES

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ABSTRACT:

This work describes the results from the tests performed to a new sensor cable used for detecting and locating third party damages to any kind of buried pipelines, either by intention or accident. Additionally, the sensor cable has a potential application to oil pipelines transport exposed to illegal extractions as well as to high consequence zones. For instance, if someone tries to steal fuel from a pipeline or a pipeline is hit and a leak is caused, the hydrocarbon will get in contact with the sensor cable wall and the leak will be detected and located by measuring the cable resistance. This work makes reference to the advantages of the new sensor cable compared to cables with similar characteristics; such advantages, which have been proved through experiments, include: the response time is shorter; since it is made out of several wires, it avoids false alarms; since it is made out of steel mesh, it protects pipelines from electromagnetic interference, which would negatively affect their cathodic protection.

Keywords: Third party damages, leaks, electrical resistance, and pipeline.

1. INTRODUCTION:

Since every country considers having a reliable supply of oil and its derivatives very important, security has always been, and will continue to be, a priority matter for governments. To achieve an effective administration of pipeline integrity in terms of operation, it is recommended that pipelines are designed and manufactured including mechanical protection (coating) and cathodic protection systems against corrosion. Moreover, it is important that during their operation, pipelines have permanent monitoring systems as well as effective repair technologies. The foregoing brings about benefits such as the basis for the decision-making process with regard to preventive and corrective maintenance, and therefore an effective administration of pipeline integrity [1], [2].

The main purpose of a detection and location system regarding leaks in hydrocarbon transportation pipelines is that such detection takes place in real time and that even tiny leaks are detected. In other words, if such a system has these characteristics, no major leak will occur, and therefore no major damage will be suffered.
There are different tools available for pipeline inspection and leak detection, as well as for the identification of potential problems arising from leaks. The selection and use of these different tools and techniques are determined through the implementation of an integrity plan described in the referred standards and best practices [3], [4].

Through the application of standards and procedures oriented towards a reliable design of the installations, and with the personnel trained to react promptly and effectively in cases of emergencies, workers can be

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protected, as well as the installations used in hydrocarbon production, transportation, processing and distribution.

Pipeline protection against leaks represents the biggest challenge for operative areas. Many pipeline sections traverse distant land, where visual monitoring is difficult, or densely populated areas, where the consequences of a failure may be catastrophic. While certain inspection techniques may be used to identify the wear in hydrocarbon transportation pipelines, there are others that are not useful. This means that it is necessary to continue improving the existing inspection and monitoring technologies, as well as developing effective real time technologies [5], [6].

In the specific case of Mexico, illegal hydrocarbon extraction continues to occur in the National Pipeline Network. As of June 30, 2012, the estimated volume of extracted fuel amounted to 1,841,478 barrels, 18% higher than the calculated fuel extraction for the same period of last year, which amounted to 1,557,569 barrels. This increase in the estimated volume is due to the fact that pipeline systems are virtually controlled by the organized crime [7], [8]. In view of such scenario, the development of failure and leak detection technologies is crucial to reduce the economic losses in the transportation systems.

2. TECHNICAL BACKGROUND

There are several ways to detect leaks, such as airplane inspection, surveillance by foot, or reports from witnesses. In commercial terms, there are two types of detection systems --external or hardware based systems and internal or software based systems-- that monitor the internal parameters of a pipeline (pressure, flow, temperature, etc.) [9].

The selection of a determined leak detection method depends on a wide range of factors, such as the pipeline physical characteristics and the operation mode thereof, product properties, instrumentation and communication requirements as well as economic factors [10], [11].

Hardware Based Systems

- Acoustic Devices: Third party damages generate noise signal which can be picked up by acoustic sensors installed outside the pipeline.
- Sensor cables: These sensors use polymer materials that swell in the presence of hydrocarbon thus changing their electrical properties.
- Fiber Optic Sensors: Third party damage can be detected through the identification of temperature changes in the immediate surroundings using fiber optic cable, or through changes in the optical property of the cable itself induced by the presence of a third party damage.
- Soil Monitoring: Leaks caused by third party damages are detected by analyzing the concentration of the vapor phase or trace substances in the soil surrounding the pipeline.
- Ultrasonic Flow Meter (USFM): This uses a patented wide band technology to induce an axial sonic wave in the pipe wall for the detection of third party damages.
- Vapor Monitoring System: If the product inside a pipeline is highly volatile, this system sucks the vapors in a low-density polyethylene (LDPE) sensor tube and runs this gas stream past specialized sensors that can detect trace concentrations of specific hydrocarbon compounds [12], [13].

Software Based Systems

- Mass or Volume Balance: This method detects leaks by measuring the mass or volume at two sections of the pipeline.
- Real Time Transient Modeling (RTTM): This method mathematically models the fluid flow within a pipeline. The equations used to model the flow are conservation of mass, conservation of momentum, and equation of state for the fluid.
- Pressure Point Analysis: This method detects a leak by comparing the current pressure signal with

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the trend taken over a period of time. The patented software then performs a statistical analysis to determine whether there are any significant differences between the two signals, which would indicate third party damage.

In general, no perfect or universal method exists that could be used for every application; however the method to be selected should perform optimally in the detection of leaks in hydrocarbon transportation pipelines [12], [13], [14].

3. SENSOR CABLE OPERATION PRINCIPLE

This section describes the sensor cable operation principle used in experiments, where different scenarios of pipeline failure caused by third party damages are simulated. The failure location principle is also described [15].

Failure detection is based on electrical resistance measurements and its location is directly related to the distance, according to Ohm's law. The system operation principle is based on the electrical impedance (purely resistive) of a circuit [9], [16].

The current circulating through the sensor cable produces different voltages throughout the cable; such current is constant and known for each of the lines (wires) integrating the sensor cable, and is monitored constantly with reference to ground (see figure 1), to verify that the wires have not experienced any changes in their resistance values. Whenever an attack to a pipeline covered by the sensor cable is intended by third parties, a short circuit occurs in one or several lines, either among them or with respect to ground, and this resistance variation allows detecting and locating the pipeline attack. It is worth noting that the sensor with several lines allows confirming both the detection and location of pipeline failures so that false alarms are avoided. The foregoing is outlined in figure 1 with the two measurement variables [16], [17].

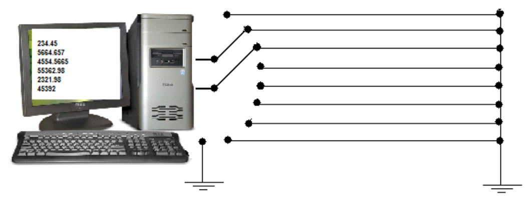

Figure 1 Sensor cable monitoring

4. EXPERIMENTAL:

Figure No. 2 shows an overview of the sensor cable, which consists of several 24-gauge wires (0.5100 mm) connected in a parallel array at a distance of 10 mm from one another, used to detect simultaneously different types of failures caused by third party damages, i. e., a multi-failure system, regardless of the phase of the product being carried by the pipeline; the cable resistance is accurately measured for every meter of the pipeline covered by the sensor cable; insulating material separates the wires from the steel mesh layer to provide the latter with flexibility and resistance; the mesh is connected to physical ground, i. e., with reference to voltage zero.

The wires and steel mesh are covered by two layers of polyethylene plastic film. It is worth mentioning that the plastic layers covering the sensor may present the shielding effect due to their high impedance, which is not a limiting factor, since these plastic layers can be replaced with others of low or minimal shielding properties, as is the case of Fusion Bond Epoxy material.

Figure No. 3 shows the disposition of the sensor cable in pipelines carrying fluids; such pipelines may be rigid of flexible. Pipelines are completely covered by the sensor cable. Any intention of attacks by third parties would cause a short circuit to several wires, which will allow detecting and locating the damage [15], [16], [17].

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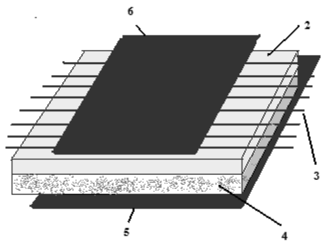

Figure 2 Sensor cable composition

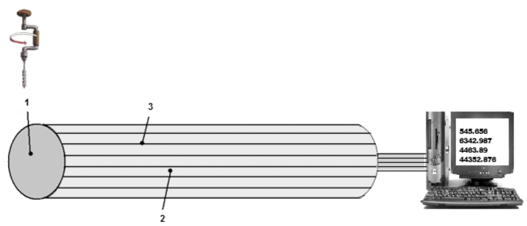

Figure 3 Disposition of the cable in the pipeline

1. - Pipeline
2. - Insulating material
3. - Parallel wires
4. - Steel mesh
5 and 6. - Polyethylene plastic film

In a practical application, the sensor to be used to cover a pipeline does not have to be mounted in the pipeline external wall; therefore the interconnection between the pipeline sections is highly practical.

To integrate the new sensor cable to old pipeline sections, old pipes must be replaced with pipes including the new sensor cable, so that the entire pipeline network can be monitored.

The sensing cable can be used in any kind of pipelines, but specifically in hydrocarbon transportation pipelines exposed to a great diversity of third party damages, either by accident or intention.

5. RESULTS AND DISCUSSION

Using a PVC pipeline of 4" (Approx.100 mm.) of diameter and 30 meters of length, we made 8 holes to the pipeline wall --simulating third party damages with drills having diameters of 1/8" (3.17 mm), 1/4" (6.35 mm), 3/8" (9.52 mm), ½" (12.7 mm), 5/8" (15.87 mm), 3/8" (19.05 mm), 7/8" (22.22 mm), and 1" (25.4 mm). The pipeline was sealed in one end and on the other end there was a small opening through which we poured pressured water. We conducted one test for each of the openings, while the rest of the openings were sealed. We measured the time in which the sensing cable was able to detect the damage [15], [16], [17].

The figure 5 show the response time of the sensor cable when it is tested to a constant pressure and we change the dimensions of drilled hole, that are simulated that it go from 1/8" (3.17 mm) with increments of 1/8" until 1" (25.4 mm), in the figure we can observe as the response time of the sensor cable with the simulated third party of 3/4" (19.05 mm) it is around the 50 seconds and with a simulated third party of 1" (25.4 mm), the time of response of the sensor cable is increased considerably around the 230 seconds.

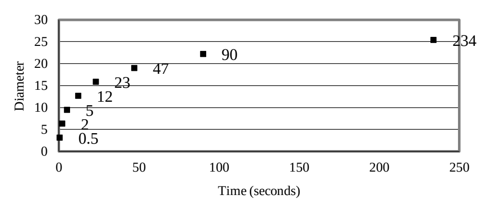

Fig. 5 Response time with a constant pressure of 100 psi

Table 1 shows the response time of the sensor cable under constant pressure and considering the different dimensions of the openings, which ranged from 1/8" with increases of 1/8" each time, to reach 1". The table also shows how the sensing cable response time remains virtually constant, which indicates that regardless of the size of the opening, or the rupture of the cable, the response is almost immediate.

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Diameter (cm)	Time (sec)
0.32	3.7
0.64	3.9
0.95	4.3
1.27	4.7
1.59	4.8
1.91	5.3
2.22	5.7
2.54	5.7

Table 1 Sensing cable response time

The transversal section area, A (cm^2), obtained for every test opening (diameter (cm) in table 1) is related to the response time (s) according to a power law of the form of equation 1:

$$t = a(1 + A)^b \qquad (1)$$

Where a, the scale factor, has a value of 3.701 and b, the exponent that gives form to the function, has a value of 0.261. The adjustment to the function was performed though a non-linear adjustment with the commercial program of origin 8.5 T.M.

Table 2 contains a comparison between the known locations where third party damages were simulated, and the locations calculated by the sensor cable.

Known location	Measured resistance	Calculated location
1 m	5.2 Ω	0.98 m
1.5 m	8.5 Ω	1.6 m
3 m	14.87 Ω	2.8 m
9 m	49.42 Ω	9.3 m
15 m	78.11 Ω	14.7 m
21 m	113.71 Ω	21.4 m
25.5 m	131.78 Ω	24.8 m
29.5 m	155.16 Ω	29.2 m

Table 2 Location of third party damages

6. CONCLUSIONS:

The new design of sensing cable for the detection and location of pipeline failure or leaks caused by third parties is based on existing systems, but some features have been improved to fulfill PEMEX's needs, such as:

a. - The response time to detect a deliberate or accidental damage is short regardless of the severity of the failure or damage, as observed during the tests (whose results have been included in the above tables).

b. - The accuracy in locating the failure is very high, as observed during the tests. It is worth noting that the tests were conducted in a very short pipeline section, but the forecast is very promising for the use of the sensing cable in real conditions.

c. - The structure of the steel mesh of which the sensor cable is made protects the pipeline from electromagnetic interference, which would damage the cathodic protection, reducing therefore the pipeline useful life.

d. - The fact that the sensor cable is made out of several wires provides it with robustness to avoid false alarms, since if a wire detects a disturbance, the rest of the wires must confirm that such a disturbance exists before the appropriate remedial actions are taken.

e.- The sensor cable plastic layers can be replaced with other layers not presenting the shielding effect, as is the case of the three-layer Fusion Bond Epoxy coating.

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