PIPELINE INSPECTION TECHNIQUES

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INTRODUCTION

Our society depends on the safe and efficient movement of energy and raw materials, without which, our daily routines would stop. These energy supplies need to be transported from fields to different locations throughout the country with a cost/efficient and secure system to cover large distances. While gas is primarily transported by pipelines on land and by ships on water, oil is transported through trucks, trains, ships, and pipelines.

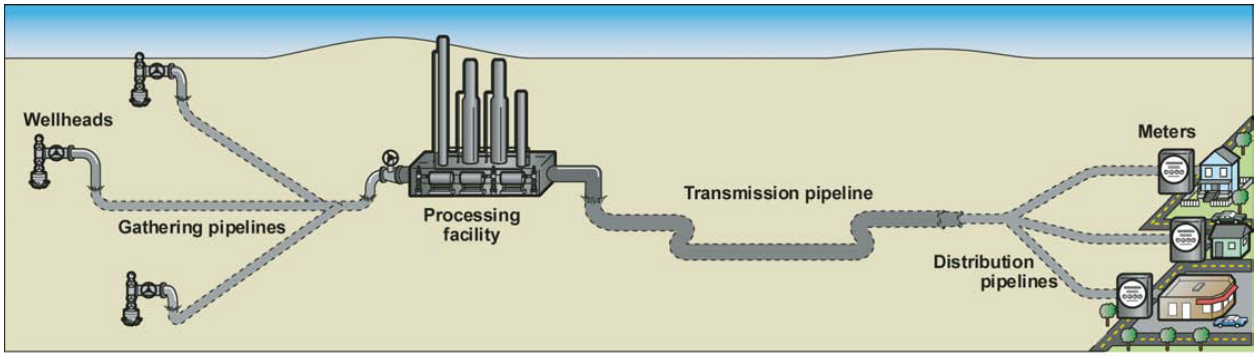
Overall, pipelines provide an alternative transport system that is less polluting and more economical compared to conventional vehicles. The main idea is to transport fluids through fixed structures that do not require, as in the case of oil tankers or trucks, gasoline or fuel to operate. Pipelines are the most efficient systems for the transportation of oil and natural gas.[1] It is a massive works of engineering that has to face and overcome complex construction problems first, and a high level of maintenance in the long term. Technology helps to increase and maximize safety. The current US pipe network, formed by 2.6 million miles of oil and gas pipelines, constitutes a real circulatory system (the largest in the world) that supplies energy to our civilization.

PIPELINES OVERVIEW

In 2015, pipelines delivered 76% of domestic crude oil (EIA data). Crude oil and gas are transported in gathering, transmission, and product lines. Gathering lines operate in oil fields; transmission lines are larger segments that carry crude oil to refineries; product lines carry refined products like gasoline, kerosene, & heating oil from refineries to

[1] For more information, see "Assessing America's Pipeline Infrastructure: Delivering on Energy Opportunities".
http://nouveaucorp.com/wp-content/uploads/2014/02/Pipeline-White-Paper-02.05.14.pdf?subject=whitepaper

market.



Source: PHMSA.

Currently, pipelines are under the media spotlight because these new infrastructure projects have raised the ire of environmental activists. President-Elected Donald Trump affirmed to support infrastructure expansion and development, including pipelines. For this reason, it is essential to understand the functioning and the management of these complex structures.

The first pipelines were made of wood which later gave way to cast iron. Although many iron pipelines are still in service, the preferred material since the 1950s is steel.[2] Pipe dimensions vary in relation to the amount of oil/gas that they carry. The speed of the fluid inside is on average of a few feet per second. It is, therefore, necessary that the transportation takes place in safe conditions, that materials are not deteriorated, and that there are no leaks along the line. While transmission lines tend to carry higher volumes at higher pressures, natural gas distribution lines in residential areas are often constructed from plastics and carry small volumes at very low pressures.

Thanks to modern technology and to periodic inspections, pipeline spills have decreased by 59% over the last 10 years, even as overall production has increased.[3] The Pipeline and Hazardous Material Safety Administration (PHMSA) is the government agency, under the U.S. Department of Transportation (USDOT), responsible for

[2] http://www.phmsa.dot.gov/pipeline/technical-resources/pipeline-materials
[3] For more information, see http://nouveaucorp.com/pipeline-safety-facts/

managing the transport of energy to ensure a safe, reliable, and modern network. Since The Pipeline Safety, Regulatory Certainty, and Job Creation Act of 2011, PHMSA's goal is to provide new safety regulations and standards, to include the use of technology to prevent leaks and to promote collaboration between government and private sector.

INSPECTION TECHNIQUES

As mentioned in the previous paragraph, safety is the ultimate goal. Pipelines construction follows strict regulations and material tests are conducted before they are deemed fit to be placed into service. PHMSA is in charge of monitoring the construction projects, while the operators oversee periodic inspections and maintenance.[4]

There are two main procedures to test the integrity and reliability of pipelines: destructive testing and non-destructive testing. The destructive testing procedure uses hydrostatic pressure to evaluate if the pipeline meets the safety standard for operation. The pressure method is based on the use of a series of pressure taps that pressurize water. The taps are placed at a predetermined distance along the pipe segments in order to monitor the trend of the pressure. Electronic equipment sends signals to the control panel and constantly checks the pipeline parameters. If a leak occurs there will be a deviation from the expected pressure, or a catastrophic failure will result in a dramatic loss of pressure. During this test, a "spike" test is usually employed which subjects a pipeline to pressures well beyond intended maximum operational pressure.[5] This method has to be used before placing a pipeline into service, although subsequent interval testing may also be required. Concerns raised with this traditional testing method include the possibility that the testing itself weakens the line and makes it possibly more prone to failure later in the pipeline lifecycle.

The non-destructive testing, primarily through the use of in-line inspection (ILI) tools can be generally categorized into magnetic flux leakage method and ultrasonic wave

[4] http://www.pipeline101.com/are-pipelines-safe/how-do-operators-keep-pipelines-safe
[5] Pipelines are genrally operated at 72% of their maximum design strength. Hydrostatic testing reaches pressures beyond 100% of specified minimum yield strength, commonly known as (SMYS)..

technique. It uses "sophisticated and sensitive" tools called "smart pigs" that "travel through the pipe and measure and record irregularities that may represent corrosion, cracks, laminations, deformations".[6]

The leakage monitoring made by ultrasonic detectors calculates the impact that a moving fluid has on a sound wave. The limits of such technique are again the unlikelihood to detect small leaks. A Magnetic Flux Leakage (MFL) tool involves the use of magnets along the pipeline. These will create a magnetic field with a homogeneous flux through the pipeline. "Anomalies result in a change in distribution of the magnetic flux, which, in a magnetically saturated pipe wall, leaks out of the pipe wall."[7]

Lines that are "non-piggable" are tested with a direct assessment (DA) technique that measures external corrosion, internal corrosion, and stress corrosion. DA is a controlled approach that does not prevent the pipeline to operate,[8] and literally involves excavating the areas around the pipeline in order to afford personnel direct access for testing and examination. Non-piggable refers to lines that are either too small in diameter for an ILI tool to pass, or lines which were placed into service before the use of such tools were mandated. In this latter case, valves or angular changes to the direction of the line have are not conducive for the passage of ILI devices.

Traditional monitoring techniques include both land-based patrols through the pipeline right-of-way or aerial inspections by helicopter or plane. Aircraft can be utilized to visually examine large areas in a relatively short period of time. Additionally, aircraft can be outfitted with leak detection instrumentation. These sensors can detect methane or hydrocarbon in the air, indicating the presence of a leak in the corresponding pipe's segment (identified through the aid of GPS). Overall, aerial inspections use non-contact or standoff detectors, where both the operators and equipment remain distanced from the sample. Standoff detection is almost always accomplished with methods involving

[6] https://primis.phmsa.dot.gov/comm/FactSheets/FSSmartPig.htm
[7] https://primis.phmsa.dot.gov/comm/FactSheets/FSSmartPig.htm
[8] http://pstrust.org/docs/direct_assessment.pdf

spectroscopic techniques[9] such as laser-induced fluorescence or infrared. high-altitude over flight allows to analyze a larger area but, at the same time, it results in a reduction of resolution. Helicopters can fly low altitudes and collect more precise data but they are more expensive to operate and they require more fuel for short distances.[10]

The oldest method is the visual inspection carried out by foot patrols. They are usually operator contractors that monitor predefined areas to detect leaks. The main limitation is that this visual/olfactory inspection may not be able to detect small leaks or internal problems. These inspections are performed according to a predetermined pattern and are mainly based on statistical analysis of segments that have a higher probability of leaks; consequently, there are areas that are never inspected.

Table 1. Inspection Techniques Summary

Destructive Testing	Non-destructive Testing	Direct Assessment (DA)	Traditional Techniques
When pipeline is not in service • Hydrostatic pressure testing	Smart pigs (in-line inspection or "ILI") • Dent (Deformation & Geometry) • Corrosion (Magnetic) • Crack (Ultrasonic / Transverse Field)	Gas and non-piggable oil pipelines. Corrosion tests • External • Internal • Stress	Aerial • Airplanes • Helicopters Ground • Vehicle • Foot patrols

[9] "Spectroscopy is the study of the interaction of electromagnetic radiation in all its forms with matter." Royal Society of Chemistry. http://www.rsc.org/learn-chemistry/collections/spectroscopy/introduction#Introduction
[10] http://aerofex.com/applications/aerial-pipeline-inspection/

Table 2. Leaks Detection Evaluation

Techniques	**Detection**			
	Constant	*Visible leaks*	*Non-visible leaks*	*Small leaks*
Pressure	X	X	X	
Smart Pigs	X	X	X	X
DA		X		
Conventional		X		

To conclude, there is not an optimum solution or a perfect inspection technique. The choice is based on a case evaluation, and every advantage or disadvantage is calculated taking into account several factors such as the price of operation, cost of equipment, time flexibility, and regulation requirements.

FUTURE SCENARIOS

Another technique that can bring considerable benefits, both in terms of viability and speed of operations, is the use of drones to monitor pipelines. Drones are used in the most diverse places on the planet and for countless purposes. In particular, drones are used by the military for image collection and real-time information. Drones are aircraft piloted by some operators placed at a considerable distance from the vehicle which generally operate at low altitudes. Operationally this technology may not possess the necessary instrumentation needed to effectively identify potential defects, but drones clearly offer enhanced surveillance when it comes to unauthorized activities on a pipeline right-of-way or larger spills which are more easily noticed by aerial observation.

The term drone it is not truly exact as it appears to be reductive and generalizing because it involves an amount of autonomy that these aircraft do not have. The United States Department of Defense (DoD) uses the term 'unmanned aircraft' (UA) to describe a vehicle that does not need a human pilot inside it to flight; while UAS is the system

(apparatuses, technological networks, and staffs) that is indispensable to guarantee the remote control of the vehicle. Other terms used to identify the same concept are Unmanned Aerial Vehicles (UAV) or Remotely Piloted Aircraft (RPA). Drones, UA, UAV, and RPA are all terms that describe the same type of technology.

One main advantage is the possibility of incorporating reliable and sensitive sensors to a small mass that can keep high endurance and safety, avoiding catastrophic impacts or flight accidents. Pipelines extend for several miles and they cross different type of lands, from rural areas to high mountains. The use of drones will overcome any visual or spatial limitation. Drones can collect and transmit images directly to a station, where a technician will interpret the data.

Overall, the important aspects to consider when choosing a detection instrument or inspection method are:

- Speed,
- Reliability,
- Selectivity (it refers to the extent to which a method can determine particular components in mixtures or matrices without interferences from other components.[11]),
- Sensitivity (measures the probability of detection without taking into account false alarms).[12]

Drone Inspections can be done using standoff and contact sensors overcoming the tradeoff between selectivity and sensitivity. Smaller drones have a small energy density, for this reason, all the instrument attached to the device should have a minimum mass. In fact, a smaller load is reflected in a reduction of the power required to fly a drone, which translated into a better life of the batteries and an increased speed.

[11] Jörgen Vessman et al. "Selectivity in analytical chemistry (IUPAC Recommendations 2001)." *Pure and Applied Chemistry* 73.8 (2001): 1381-1386.
[12] Singh "Sensors—an effective approach for the detection of explosives." 18.

Currently, engineers are trying to develop technologies that will increase benefits and reduce high costs. Drones can be the first step toward an automatized inspection phase, but the equipment is not enough advanced to assure detection and constant inspection at the same time. Furthermore, the Federal Aviation Administration (FAA) is still unsure on how to manage drones' legislation both in terms of flying zones and privacy. Cameras and sensors that are constantly flying and collecting data/images can interfere with the privacy of citizens living in the surrounding areas.

CONCLUSION

As of today technology has advanced significantly and has directly contributed to increased safety as well as the significant reduction in pipeline spills. While there remains however, no single ultimate solution to the pipeline leak detection issue, technological advances continue at an accelerated pace. Each analyzed inspection technique has inherent advantages and limitations that vary mainly depending on pipelines geographical position.

UAS technology has the potential to disrupt and revolutionize the future but remains constrained by regulations, limited payload capability, and endurance. Government policymakers must also ensure the rapid rise of technology is not thwarted by an outdated regulatory system which requires a significant amount of time to approve technology. Thus the most efficient solution is the use of multiple techniques and hybrid systems, as the presence of more sensors compensates for shortcomings. This combination of technology, known as sensor fusion, allows for multiple data points to be globally analyzed in order to achieve a certain degree of selectivity, sensitivity, and reliability of data.