‘Using canines to inspect for leaks in buried pipelines’

by

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ABSTRACT

Oil and gas transmission pipelines are long welded structures, operating at high pressures, delivering billions of dollars of energy every day of every year, to customers all over the world. These pipelines have an excellent safety record, but failures still occur, and it is important to detect any leaks in a pipeline before they can prevent significant damage.

Pipeline operators use on-line leak detection systems for continuous leak monitoring. But these on-line systems will only detect a small percentage of leaks on a pipeline; for example, they are unable to detect small leakages. Consequently, operators need to use complimentary leak detection methods, such as patrolling their pipeline route.

Animals, such as dogs, rats, and pigs, have an acute sense of smell, and can be trained to detect low concentrations of vapour; accordingly, animals offer a pipeline leak detection and location capability to pipeline operators.

Penspen Ltd, UK, and Newcastle University have been investigating the feasibility of implementing dogs as an additional leak detection tool to be used on onshore pipelines. Leak detection dogs were walked along a pipeline right of way, and also took part in extensive field trials on farm land. The right of way and farm land contained both buried and surface simulated leaks of jet fuel.

The results of this research have shown that dogs can detect leaks as small as 5 ml, up to depths of 800 mm below ground, with an 86% success rate. Larger volume leaks would be easily and consistently detected by dogs.

The research showed there is a 95% confidence that the dog would:

- find between 52% and 78% of extremely small leaks (~5 ml) on a pipeline;
- miss between 22% and 48% of these sizes of leaks on a pipeline; and,
- incorrectly identify the presence of these small leaks between 5% and 15% of his total indications.

The dogs would be particularly useful for:

- inspecting areas where deep corrosion has been identified by in-line inspection;
- where coating problems have been identified by above ground surveys;
- ‘un-piggable’ pipelines;
- locations with poor cathodic protection (CP) coverage;
- where there are suspected ‘illegal taps’; and,
- detecting leaks during a hydrotest (using scented water).

Using sniffer dogs, to survey areas like those mentioned above, can greatly increase the probability of finding any leaks. Also, it provides the operator with additional assurance if no leaks are found.

Finally, the dogs are not only reliable; they are also cost-effective, and environmentally-friendly.

AUTHOR DETAILS

Phil Hopkins (p.hopkins@penspen.com) is a Technical Director with Penspen Ltd., UK.
1. INTRODUCTION

Oil and gas transmission pipelines are long welded structures, operating at high pressures, delivering billions of dollars of energy every day of every year, all over the world, Figure 1. These pipelines carry hazardous products, and they are ageing, but they remain a safe form of energy transportation when compared to other forms of transportation such as highways or sea\(^1\), and failures of pipelines are decreasing\(^2\).

![Transmission Pipeline being Constructed.](image)

Figure 1. Transmission Pipeline being Constructed.

Pipeline failures still occur, and they can have deadly consequences (e.g., Reference 3), and pipeline operators are constantly improving methods to both protect their pipelines against damage and defects that can cause failures, and also detect problems in their pipelines before the problems create major failures.

1.1 What causes ‘leaks’ in pipelines?

Pipelines will leak\(^1\) product due to:

- corrosion;
- outside force damages (e.g., gouges);
- incorrect operation;
- defects from construction, line pipe, or manufacturing;
- natural forces such as landslides;
- etc..

We often define leaks in two categories\(^4\):

- incipient leaks (those just about to occur);
- actual leaks (product is lost from the line).

\(^{[1]}\) ‘Leaks’ are any type of product loss from the pipeline; hence, a leak could be a large ‘rupture’. One reference\(^6\) considers a ‘rupture’ a situation where the pipeline becomes inoperable, whereas a ‘leak’ is where operation of the pipeline and its facilities can continue operating as intended. Most loss of product incidents in liquid and gas pipelines are leaks\(^6\).
There are also degrees of actual leaks:

- ‘Large’ leaks will cause significant change in pressure gradient and differences in flowrates. These leaks should be easily and quickly detected.
- ‘Small’ leaks will cause small changes to the usual process measurements. These changes will be very small, and within the ‘noise’ levels of the equipment measuring flow, etc.. These leaks will be difficult to detect and locate.

1.2 Detecting failures during service

1.2.1 Control rooms

Pipeline systems are operated and controlled using remote ‘control centres’: these centres provide operators with complete operational information of the pipeline system in one location. The centres provide a centralised response-and-control base of operations to facilitate the coordination and response of abnormal or emergency situations.

They also provide a centralised base of operations for ongoing maintenance and other field activities occurring on the pipeline system; therefore, their main functions are4,5:

- planning and scheduling operations (e.g., matching supply with demand);
- monitoring (e.g., gas quality) and controlling the pipeline (e.g., pumps and compressors);
- responding to, and correcting, abnormal operations (e.g., performing a pressure test);
- managing alarms from unusual sources, such as from a leak in the pipeline;
- maintaining the control equipment.

Hence, the control room has a key role in detecting leaks in the pipeline. Most control rooms use ‘SCADA’ (supervisory control and data acquisition) to monitor the condition of their pipelines. Sensors (flow, pressure, etc.) are located along the pipeline: these sensors send data to the control room using SCADA. The control room can employ a real-time, on-line leak detection system (e.g., using pressure/flow monitoring) which makes use of the SCADA data.

Note that SCADA controls the pipeline operating parameters, but a leak detection system (LDS) using SCADA data is separate from SCADA: the leak detection system is focussing on detecting and locating a leak6.

1.2.2 Detecting leaks in pipelines

Control centres employ leak detection systems on pipelines, to automatically alert a pipeline operator when a leak occurs. The simplest leak detection system measures the product going into the pipeline (‘metered in’) with the product leaving the pipeline (‘metered out’), whereas other systems use sophisticated and complex computational monitoring systems which simultaneously monitor numerous operating conditions. Other methods fall somewhere between these two examples in their level of complexity. Obviously, operators can and do use other methods of leak detection, such as land-based surveillance.

We can group our leak detection methods into7:

- simple systems using flying, walking, or driving methods:
  - these allow leaks to be seen, smelled, etc..
- acoustic, thermal, or vibration sensors:
  - leaks can create vibrations, temperature changes, etc..
- flow balance:
• this means measuring the amount of product entering and leaving a pipeline: a loss may indicate a leak. This can be either measuring the volume of the product (this is more effective for incompressible fluids), or the mass of the product (this is better for fluids which are compressible).

- rate-of-change:
  o this method monitors key operating parameters at various locations along the pipeline, and detects when these variables change at an abnormal rate, or in some other unusual way.

- computational system modelling:
  o sensors along the pipeline monitor various parameters (pressure, temperature, flow, density, etc.) and compared the measurements to a computer model of the whole pipeline system. The theoretical performance of the system is compared to the actual performance delivered to the control room by the sensors along the pipeline: any differences can be analysed to determine if there is a leak.

Note that no single leak detection method can meet all leak detection criteria (detection speed, location accuracy, etc.) satisfactorily; hence, we use systematic approaches, using a number of the above systems.

1.2.3 Effectiveness of leak detection methods

There is much controversy surrounding leak detection methods used on pipelines, particularly those managed from the pipelines’ control rooms. A recent report stated:

‘… pipeline control rooms, which help monitor whether a line is functioning properly, identified leaks in hazardous liquid and gas transmission lines only 17 percent and 16 percent of the time.’

This quote is supported by other data presented in Table 1 to Table 4, which show that the general public (‘third party’, ‘public’, ‘passer-by’, ‘homeowner’, etc.) detect most of the leaks in both liquid and gas pipelines.

<table>
<thead>
<tr>
<th>Leak detected by</th>
<th>Number (average spill size, m³)</th>
<th>%</th>
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<tbody>
<tr>
<td>Right of way survey by operator</td>
<td>29 (229)</td>
<td>9</td>
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<tr>
<td>Automatic detection system</td>
<td>25 (188)</td>
<td>8</td>
</tr>
<tr>
<td>Third party passer-by</td>
<td>144 (120)</td>
<td>45</td>
</tr>
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<td>Routine monitoring by operator</td>
<td>64 (388)</td>
<td>20</td>
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</tr>
<tr>
<td>Contractor working on line</td>
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</tr>
<tr>
<td>Operator maintenance staff</td>
<td>13 (60)</td>
<td>4</td>
</tr>
<tr>
<td>Third party worker</td>
<td>20 (110)</td>
<td>6</td>
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<td>Internal inspection survey</td>
<td>3 (6)</td>
<td>1</td>
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</table>

Table 1. Leaks Detected in Onshore European Liquid Pipelines.

Leak detected by:  
<table>
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<tr>
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<tbody>
<tr>
<td>Local operating personnel, procedures, equipment</td>
<td>45</td>
</tr>
<tr>
<td>Third party (excavator, homeowner, etc)</td>
<td>27</td>
</tr>
<tr>
<td>Remote operating personnel including controllers</td>
<td>9</td>
</tr>
<tr>
<td>Computational Pipeline Monitoring / SCADA with leak detection system</td>
<td>8</td>
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<tr>
<td>Air patrol or ground surveillance</td>
<td>7</td>
</tr>
<tr>
<td>Other (including leak/pressure test)</td>
<td>5</td>
</tr>
</tbody>
</table>

Table 2. Leaks Detected in Onshore USA Liquid Pipelines\(^\text{10}\).

Detected by:  
<table>
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<th>%</th>
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<tr>
<td>Public</td>
<td>37</td>
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<tr>
<td>Patrol</td>
<td>17</td>
</tr>
<tr>
<td>Contractor</td>
<td>16</td>
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<tr>
<td>Unknown</td>
<td>8</td>
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<tr>
<td>Company staff</td>
<td>8</td>
</tr>
<tr>
<td>Distribution company</td>
<td>5</td>
</tr>
<tr>
<td>Landowner</td>
<td>5</td>
</tr>
<tr>
<td>Other</td>
<td>3</td>
</tr>
<tr>
<td>Client</td>
<td>2</td>
</tr>
<tr>
<td>On-line inspection</td>
<td>2</td>
</tr>
<tr>
<td>River police</td>
<td>&lt;1</td>
</tr>
<tr>
<td>Unknown</td>
<td>8</td>
</tr>
</tbody>
</table>

Table 3. Leaks Detected in Onshore European Gas Pipelines\(^\text{11}\).

<table>
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<tr>
<th>First to identify leak</th>
<th>Liquid (%)</th>
<th>Natural gas (%)</th>
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<td>Air Patrol</td>
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<td>3</td>
</tr>
<tr>
<td>Pipeline Controller</td>
<td>6</td>
<td>1</td>
</tr>
<tr>
<td>LDS or SCADA</td>
<td>15</td>
<td>18</td>
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<tr>
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<td>3</td>
<td>5</td>
</tr>
<tr>
<td>Local Operating Personnel</td>
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<td>27</td>
</tr>
<tr>
<td>Emergency Responder</td>
<td>9</td>
<td>3</td>
</tr>
<tr>
<td>Public</td>
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<td>26</td>
</tr>
<tr>
<td>Pressure Test</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>Other</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Third Party causing the release</td>
<td>-</td>
<td>10</td>
</tr>
</tbody>
</table>

Table 4. Leaks Detected in USA Pipelines\(^\text{6}\).
1.2.4 Problems with on-line leak detection systems

Above ground patrols can detect small leaks, but these patrols will be infrequent: aerial patrols are typically every two or four weeks, whereas walking patrols will be every several years. Therefore, pipeline operators have to rely on on-line leak detection systems for continuous leak monitoring. But these on-line systems will only detect a small percentage of leaks on a pipeline, Table 1 to Table 4. Why are pipeline operators not able to detect all leaks in their pipelines? Consider the following:

- ‘A leak becomes detectable when the volumetric leak rate exceeds the sum of uncertainties in flow measurement and line fill’\(^{12}\). All pipeline flow measurements will have uncertainties, due to measurement equipment tolerances, variables (e.g., temperature), customer demand variations (customers extracting more or less product), etc.

- Leak detection systems will detect leaks of 0.1% to 1% of product flow in liquid pipelines, within about 2.5 to 15 minutes, with an accuracy of ≥30 m\(^{13}\). This means that a leak of the order of 1,000 barrels of oil may not be detected on a 100,000 barrels/day pipeline\(^5\).

- The efficiency of a leak detection system will depend on: location of sensors; accuracy of sensors; and, size of leak. It is easier to detect and locate a leak if there are more sensors, the sensors have high accuracy, and the leak is large.

Clearly, it is not possible to remotely detect all leaks on a pipeline: small leaks will go undetected.

1.2.5 Using a variety of methods

Operators will continually strive to improve their leak detection systems, but most operators will use a variety of methods. A striking observation from Table 1 to Table 4 is the fact that above ground patrols, passers-by, etc., detect most leaks. This leads to the obvious conclusion that above ground surveillance, whether planned by the operator, or provided incidentally by the general public or third parties, is key to leak detection.

The data in Table 1 to Table 4 can be viewed positively: above ground surveillance is effective in detecting leaks, and is a key compliment to on-line leak detection systems. The large leaks should be quickly detected by the on-line leak detection systems, whereas the small leaks will need to be detected by other methods.

But the current above ground surveillance methods are not planned, structured, or calibrated for leak detection. This paper proposes the use of canines to help detect/locate leaks on pipelines.
2. USING DOGS FOR LEAK DETECTION

2.1 Animals and their sense of smell

Animals, such as dogs, rats, and pigs, have an acute sense of smell, and can be trained to detect low concentrations of vapour\(^{14}\). Accordingly, animals offer a pipeline leak location capability to pipeline operators\(^{15}\). Obviously, they cannot replace the continuous monitoring systems already available for leak detection and location, but they could be complementary.

The number of olfactory\(^{2}\) cells in an animal is partly dependant on the size of the animal's nose; therefore, animals with long snouts and/or large noses should be the most sensitive to scent\(^{16}\). We normally associate dogs with detecting scent, but researchers have trained rats, ferrets, and other animals to detect explosives and drugs, with success rates equal to that of dogs. Insects such as bees also have an exceptional sense of smell, and pigs are well known hunters of truffles.

2.2 Sniffer dogs

Dogs are preferred as ‘sniffer’ dogs, due to their ease of training and fondness of humans. The use of ‘sniffer’ dogs is well-established for law enforcement, mine detection, and cadaver search. The dogs require training, and will not be 100% reliable or accurate. For example, the beagles you see at airports, seeking meat and fruit in your suitcases, undergo a 10 week training course. A well-trained dog and accomplished handler can achieve an accuracy rate of about 95%: significantly better than any machine. However, if the dog is ill-trained, or the handler poor, this figure can drop to 60%\(^{17}\).

It takes around six months to train a sniffer dog, and around 2 weeks to change the ‘target scent’ that the dog seeks out. This could be from drugs to explosives, or from jet fuel to natural gas. It is possible to train the dogs to identify up to 10 different scents at any one time. In principle, a pipeline operator could send a sample of their product to allow the dogs to be trained and calibrated, by approved dog trainers, to detect that scent. The dogs’ accuracy and reliability can then be confirmed to the operator prior to the dog being taken to site.

2.3 Using dogs for leak detection on pipelines

Dogs can be used to detect and locate leaks on pipelines, and this ‘biological’ method has been used occasionally for a number of years\(^{18}\). Dogs are very reliable (>90%) at detecting leaks\(^{19}\):

- they can detect concentrations down to \(10^{-18}\) molar (1 in \(1,000,000,000,000,000,000,000\)).
- they have been shown to be able to detect leaks when the pipeline was 12 ft underground.

The dog searches for the scent of the leak by ‘quartering’ the search area, scanning the width of the pipeline’s right of way with their nose just above the ground ensuring that no smell is left un-sniffed. When the ‘target scent’ is detected the dog spirals into where he believes the source of the smell is located. The presence of a leak is identified by the dog using their indication technique (e.g., by digging): this technique will vary from dog to dog.

\(^{2}\) 'Olfaction' is the act or process of smelling.
3. RECENT RESEARCH INTO USING DOGS FOR PIPELINE LEAK DETECTION/LOCATION\textsuperscript{15,20,21}

Penspen Ltd, UK, and Newcastle University, UK, have been investigating the feasibility of implementing dogs as an additional leak detection tool to be used on onshore pipelines. A problem with using dogs is the absence of reported scientific data on a dog’s accuracy and reliability when used to detect leaks on a pipeline. Consequently, field trials\textsuperscript{15,20,21} were carried out in 2007, 2008, 2009, and 2011, to assess a dog’s leak detection ability, accuracy and repeatability.

This section of the paper summarises this work.

3.1 Phase 1 - Early research on surface samples (2007)

Initial research work showed that a dog (Blitzen (Figure 2), a Labrador from Dog Detectives Ltd, UK) could be trained to identify traces of jet fuel (obtained from an aviation pipeline), and could distinguish between different types of hydrocarbon (jet fuel and diesel).

The conclusions from this early research were:

- trained dogs with experienced trainers, can detect small amount (droplets, less than 5 ml) of hydrocarbon;
- these levels of detection would allow a dog to be used for pipeline leak detection; and,
- the dogs can identify different hydrocarbons.

3.2 Phase 2 - Field trials on buried samples (2008)

The early research (Section 3.1) used hydrocarbon samples located on the ground surface: the samples were not buried. A real leak in a pipeline will travel from below ground, and travel to the surface; therefore, these early trials were not a true mimic of a pipeline leak.

Figure 2. Blitzen and Wallace.

Phase 2 of the project aimed to investigate if dogs could detect small quantities of buried hydrocarbons, thus aiming to simulate a small leak on an operating buried pipeline.

It was decided to ‘challenge’ the dog by using exceptionally small leak quantities (5 to 20 ml), as dogs can easily detect large quantities. This size of leak would not be detected by any leak detection system, or any mechanical leak detection device.
A simulated leak on a buried pipeline is not easy to design; therefore, the following criteria were set for the simulated leak:

- it must leave no scent at the ground surface as a result of installing the leak;
- it must be easily removed, so that no hydrocarbon (jet fuel) is left behind after the trial;
- it had to be cost-effective to make, and modify where necessary;
- it must allow for different quantities of jet fuel to be placed below the surface; and,
- it must allow the scent, vapour, and/or liquid to rise to ground level from the pipeline level.

These criteria were met by constructing a ‘leak tube’ which contained a sample of jet fuel, Figure 3. When the ‘leak’ tube is installed into the plastic sleeve there should be no chance of contaminating the ground with jet fuel. The only scent that the dog should be able to detect is that which is coming from below the ground, thus simulating an actual pipeline leak.

3.2.1 Field trials

Wallace (Figure 2), a German Longhaired Pointer (also from Dog Detectives Ltd., UK), was used in Phase 2.

![Leak Tubes](image)

**Figure 3. Leak Tubes.**

The trials were conducted on an operational pipeline that provides jet fuel to a UK airport. Figure 4 shows the pipeline’s ‘right of way’. This pipeline is buried to a depth of about 1 metre, and no part of the pipeline was visible in this section of it right of way.

The dog used in this test had been trained to detect jet fuel. Small diameter holes were drilled (Figure 4) along the pipeline’s ‘right of way’: the drill holes were called ‘hides’, and the jet fuel samples in the leak tubes (Figure 3) were buried in these hides. These buried jet fuel samples were then the simulated leaks. It should be noted that there were no actual leaks on the pipeline.
There were various jet fuel samples placed in the hides:

- leak tubes containing samples of jet fuel (5 ml or 20 ml);
- leak tubes containing a ‘decoy’ scent (diesel fuel);
- ‘placebos’ (empty leak tube); and,

There were also hides containing no leak tubes (‘empty’ hides).

The vapours from the ‘leak’ needed to migrate through the soil to the surface, to allow detection. Accordingly, the samples were placed at either 200 mm or 800 mm depth, and were allowed to ‘leak’ (exposed to the surrounding soil) for either four hours, 1 day, or 10 days. This allowed the vapours from the jet fuel to migrate in differing concentrations.

The trial consisted of 28 hides in 14 locations in a 600 m section of the right of way, as illustrated in Figure 5. Each location had at least 1 hide containing jet fuel (i.e., a ‘leak’).

Wallace walked the 600 m trial distance (‘Run 1’), and his results were noted. He identified and located the leak by vigorously scratching of the earth precisely over the location.

He then returned along the trial run (‘Run 2’), and any differing results were noted, Figure 6 and Table 5.

Wallace found most of the samples of jet fuel that were buried along the pipeline right of way. The results (Figure 6[4]) were very encouraging:

- the dog has an 86% chance of detecting a leak at a leak location;
- the dog has a 14% chance of missing a leak at a leak location (‘positive-negative’);

---

[3] A hide constructed in the same way as a ‘leak’ but with no jet fuel added.
[4] √ means the dog indicated a jet fuel leak. X indicates the dog not identifying anything at this location.
there is a chance of falsely identifying a leak in a section of pipeline that contains actual leaks (‘false-positive’); and,

the dog did not indicate a leak in a 165 m length of ROW where there was no leak.

The dog incorrectly indicated jet fuel leaks at:
- 1 of 3 placebo hides;
- 2 out of 2 of the diesel hides; and,
- 1 out of 5 of the empty hides.

Therefore, the dog detected 86% of these simulated leaks, identifying quantities as small as 5 ml, buried at depths of up to 800 mm.

If the trial had been a real leak detection exercise conducted on a real leaking pipeline, an operator would have:
- excavated 13 locations;
- found 12 leaks at 12 excavated locations;
- found no leak at one of the dig location; and,
- not detected two leaks.
<table>
<thead>
<tr>
<th>Location</th>
<th>Hide</th>
<th>Content</th>
<th>Depth (mm)</th>
<th>Vol (ml)</th>
<th>Age (days)</th>
<th>Dog Detect Hide?</th>
<th>Dog Detected Location?</th>
<th>Comments</th>
</tr>
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<tbody>
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<td>1</td>
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<td>No</td>
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<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>19</td>
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<td></td>
<td></td>
<td></td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L10</td>
<td>20</td>
<td>Jet Fuel</td>
<td>800</td>
<td>20</td>
<td>0</td>
<td>No</td>
<td></td>
<td>No</td>
</tr>
<tr>
<td></td>
<td>21</td>
<td>Empty</td>
<td></td>
<td></td>
<td></td>
<td>No</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L11</td>
<td>22</td>
<td>Jet Fuel</td>
<td>200</td>
<td>20</td>
<td>1</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>L12</td>
<td>23</td>
<td>Jet Fuel</td>
<td>800</td>
<td>5</td>
<td>0</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>24</td>
<td>Diesel</td>
<td></td>
<td></td>
<td></td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L13</td>
<td>25</td>
<td>Jet Fuel</td>
<td>200</td>
<td>20</td>
<td>10</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>26</td>
<td>Placebo</td>
<td></td>
<td></td>
<td></td>
<td>No</td>
<td></td>
<td></td>
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<tr>
<td>L14</td>
<td>27</td>
<td>Jet Fuel</td>
<td>200</td>
<td>5</td>
<td>1</td>
<td>Yes</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td></td>
<td>28</td>
<td>Jet Fuel</td>
<td>200</td>
<td>20</td>
<td>0</td>
<td>Yes</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Detailed Results of Field Trial.

The obvious question is... *why was the dog not 100% successful*? There are many reasons; for example:
• experimental complexity – the dog was challenged to find very small quantities of fresh fluid, buried deep underground.
• distractions/curiosity – the dog was distracted by old tin of paint thinner discarded adjacent to the pipeline right of way, and he was excited to find an old golf ball.
• experimental set-up – many of the simulated leaks were close to each other, and vapours may have mingled or settled away from the leaks.
• equipment/researcher – care was taken to ensure no (jet fuel) contamination of the equipment (i.e. empty hides and placebo hides), but all the equipment was installed by the same researcher, and the dog will have picked up the researcher’s scent.
• dogs are not perfect....

3.2.2 Conclusions

Phase 2 simulated pipeline leaks along a real pipeline route. 28 leak tubes were buried to a depth of 800 mm in hides to simulate a leak on a buried pipeline. This allowed the jet fuel scent to migrate to the surface without contaminating the ground. The leak tubes contained jet fuel, diesel (decoy) and ‘placebos’ (empty hides).

The dog successfully identified 86% of the simulated leaks.

3.3 Phase 3 - Field trials on buried samples (2009)

The study in Section 3.2 showed that a trained dog could locate a high percentage of simulated leaks, but did not conduct a detailed investigation into the statistical significance of the results. By carrying out a larger number of tests it is possible to: attribute a greater level of confidence to the results; show that the results from the test are representative of the population; and, that the dog will consistently perform at a given confidence and tolerance.

Phase 3 of the research focussed on the probability of jet fuel detection by a dog, to establish what confidence can be attributed to the dog’s reaction (probability of correct leak location): this will be referred to as the dog’s ‘reliability’. Another aspect of this Phase was to see if, when the dog works for long periods of time, fatigue/boredom will cause it to signal that there is jet fuel present, even if there is none in order to receive a reward. This would allow information to be gathered on the effects of fatigue on a dog’s performance, and recommendations for maximum working time.

The work was carried out on a farm, in Northumberland, UK, owned by Newcastle University, Figure 7, and Blitzen returned to work in this Phase.

![Figure 7. Field used for Trial at Cockle Farm, owned by Newcastle University.](image)
3.3.1 Field trials

Hides were drilled in the field to a depth of 800 mm\textsuperscript{[5]}, within a measured grid, Figure 7. The hides either contained a ‘placebo’ (no jet fuel, but a leak tube filled with soil, Figure 3), or jet fuel in a leak tube, Figure 8.

In total, the dog passed 97 hides in this grid, of which 21 were ‘live’ (contained jet fuel), and hence there were 76 placebo hides.

![Figure 8. Schematic of the Hides.](image)

The results are presented in Table 6 and summarised in Figure 9. The dog’s performance was not as good as in Phase 2, and this raised concerns over the experimental set-up, leak tubes, and working environment (the trials were conducted in high winds and rains (the strong winds had frequent gusts of 31 knots)).

<table>
<thead>
<tr>
<th>Number of hides passed by dog, N</th>
<th>97</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of live hides passed by dog, N\textsubscript{Live}</td>
<td>21</td>
</tr>
<tr>
<td>True Positive – Indicates at live hide</td>
<td>10</td>
</tr>
<tr>
<td>False Negative – Does not indicate at live hide</td>
<td>11</td>
</tr>
<tr>
<td>False Positive – Indicates at placebo hide</td>
<td>12</td>
</tr>
<tr>
<td>True Negative – Does not indicate at placebo hide</td>
<td>61</td>
</tr>
<tr>
<td>Dog indicates at a hide that previously contained jet fuel</td>
<td>3</td>
</tr>
<tr>
<td>Dog Correct? – Indicates live hide or ignores placebo hide</td>
<td>71</td>
</tr>
</tbody>
</table>

**NOTES:**
False Negative: the presence of jet fuel is not indicated when some is present.
True Positive: the presence of jet fuel is indicated when some is present.
False Positive: the presence of jet fuel is indicated when none is present.
True Negative: the presence of jet fuel is not indicated when none is present.

Table 6. Results of Phase 3 ‘Grid’ Tests.

\textsuperscript{[5]} 800 mm was selected as to drill deeper was more expensive. 800 mm is representative of many pipeline depths of cover, and increasing the depth to 1000 mm was not considered significant.
The grid test was extended to include tests on buried and surface samples around the perimeter of the field, Figure 4, and a neighbouring country track. These tests increased the test sample size, and will be reported in a later publication, but the collated results are presented in Figure 10, and Table 7.

**Table 7. Collated Results for Phase 3.**

<table>
<thead>
<tr>
<th>Description</th>
<th>N</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of surface samples and hides passed by dog, N</td>
<td>138</td>
<td>65</td>
</tr>
<tr>
<td>Number of live samples passed by dog, N&lt;sub&gt;Live&lt;/sub&gt;</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>True Positive – Indicates at sample</td>
<td>32</td>
<td>65</td>
</tr>
<tr>
<td>False Negative – Does not indicate at sample</td>
<td>18</td>
<td>35</td>
</tr>
<tr>
<td>False Positive – Indicates at placebo hide</td>
<td>14</td>
<td>10</td>
</tr>
<tr>
<td>True Negative – Does not indicate at placebo hide</td>
<td>79</td>
<td>67</td>
</tr>
<tr>
<td>Dog Correct? – Indicates live sample or ignores placebo hide</td>
<td>103</td>
<td>75</td>
</tr>
</tbody>
</table>

The dog found 48% of the live hides

The dog indicated at 12% of the placebo hides

The dog found 65% of the samples

The dog indicated at 10% of the placebo hides
The dog found 65% of the jet fuel samples; he therefore missed 35%. The results were statistically analysed to find the ranges within which these values (65%/35%) would fall. It showed there is a 95% confidence that the dog would:

- find between 52% and 78% of leaks on a pipeline;
- miss between 22% and 48% of leaks on a pipeline; and,
- incorrectly identify the presence of a leak between 5% and 15% of his indications.

The dog did not give ‘random false positives’ whilst working for long periods of time in order to receive a reward.

3.3.2 Conclusions

This Phase established a confidence value on the capability of a dog correctly locating a leak. It was concluded that there was a 95% chance that the dog would find between 52% and 78% of the simulated leaks.

3.4 Phase 4 - Field trials on dog’s performance (2011)

Phases 1 -3 had revealed the reliability of a leak detection dog. Phase 4 was aimed at evaluations of the dog’s endurance and concentration, performance, and consistency:

- carry out a simulated leak detection inspection to determine if a dog is capable of inspecting up to 10 km per day, as quoted by the dog supplier.
- evaluate the dog’s endurance and ability to maintain a high detection capability over these long distances, and in varied terrain.
- evaluate whether the dog consistently indicates a leak at the point of highest concentration, or at the point of first contact, considering any external influences, i.e., wind direction.

The work was again carried out at Cockle Park Farm, and Blitzen was again used for these trials.

3.4.1 Field trials

Full details of these trials will be presented in a later paper; therefore, only a short summary of the results will be presented here.

![Figure 11. Various Tracks used to Test Dog.](image-url)

The jet fuel samples were not buried using the leak tubes, as these trials were primarily concerned with the dog’s endurance and concentration, performance, and consistency.
Consequently, a large number of surface or shallow-buried samples were used to simulate leaks, but also long routes, with varied terrain, were used, Figure 11.

The dog was required to work for long distances, and his performance and consistency was record during his work periods. He was also distracted, Figure 12, and had to work in differing wind speeds and directions.

The trial results were:

- a dog’s performance will begin to deteriorate when inspecting distances in excess of 2 km.
- a dog will detect 100% of leaks during a 2 km inspection.
- a dog will detect between 88% and 100% of leaks over 2.3 km at the 90% level with 95% confidence.
- a dog can inspect a 2 km section at a speed between 1.4 and 2.2 km per hour.
- a dog will require a substantial rest period every 2 km during an inspection.
- a single dog could inspect a maximum pipeline length of 5 km per day. 2 dogs would be required to inspect 10 km of pipeline per day.
- a dog will indicate at the point of highest concentration if the wind is not blowing in the direction of the inspection (i.e., from behind the dog).
- if no leaks have been found during an inspection, the dog will require continuous rewarding during an inspection to boost confidence and maintain focus.
- a trained dog is not easily distracted during an inspection, even when encountering livestock and other wild animals.

![Figure 12. Dog Faced with Livestock Distractions.](image)

If this trial had been an actual pipeline inspection the dog would have detected 25 out of the 26 leaks. The dog did not once indicate that a location contained jet fuel when there was none, meaning there would be no unnecessary digs by the operator.

3.4.2 Conclusions

This Phase concluded that implementing dogs to detect leaks along pipelines as part of an integrity management plan is a realistic and viable solution. The main advantages of using a dog are the simplicity and sensitivity in detecting exceptionally small quantities of leaking product: leaks which would not be detected by current pipeline leak detection technology.
Dogs would be particularly useful for pipeline leak detection:

- to check for any leaks from deep corrosion identified by in-line inspection, prior to any excavations;
- where coating problems have been identified by above ground surveys;
- ‘un-piggable’ pipelines;
- locations with poor cathodic protection (CP) coverage;
- where there are suspected ‘illegal taps’[^6];
- in areas that are difficult to inspect or excavate; and,
- detecting leaks during a hydrotest (using scented water).

Using ‘sniffer’ dogs, to survey areas like those mentioned above, can greatly increase the probability of finding any leaks. Also, it provides the operator with additional assurance if no leaks are found.

### 4.1 Case study pipeline (2012)^22

A buried pipeline of 8 inch diameter, transporting diesel, had some corrosion problems. It was built circa 1960, and had been internally inspected in 1994. Some deep areas of corrosion were repaired, but some shallower areas remained. Excavations in early 2012 confirmed the nature and location of these remaining corroded areas, Figure 13. The pipeline was to be again internally inspected later in 2012.

![Example of Corrosion on Pipeline](image)

**Figure 13. Example of Corrosion on Pipeline.**

The pipeline was pressure tested (using the product at low pressure) to detect leaks in 2011: no leaks were detected. The operator was concerned that small (e.g., pinhole) leaks from corrosion would not be detected with this pressure test.

Obviously, areas where the corrosion was considered to be deep could be excavated, but these excavations can be costly and disruptive, Figure 14. Hence, an internal inspection using a ‘smart pig’ is the best method to detect and locate corrosion, and this inspection was planned.

Internal inspections of a pipeline will detect most of the corrosion present, but it is well known that smart pigs may not detect very small (pinhole) defects, nor accurately size defects with a depth greater than 80 percent of the pipe’s wall thickness^22.

The facts that neither leak tests nor smart pigs will reliably detect small leaks presented the operator with a problem – how could pinhole leaks be detected and located? The operator decided further leak detection was needed, prior to the 2012 internal inspection, focussed on detecting small leaks which were unlikely to be detected by a leak test or a smart pig.

[^6]: ‘Illegal taps’ are where criminals attach valves to, or drill holes into, a pipeline to steal product.
4.2 Objectives of using a leak detection dog on this pipeline

The operator knew where the deepest corrosion was in the pipeline (as reported by the 1994 inspection), and where a leak would be considered to have significant environmental consequences (e.g., leakage into a stream). Therefore, it was both practical and prudent to check these sites (deep corrosion coinciding with an environmentally-sensitive area) for leaks using a leak detection dog.

4.3 Results of leak detection survey

2.7 km of the 8” oil pipeline was inspected for leaks by a leak detection dog, Figure 15. The dog was experienced and had been extensively calibrated in the trials detailed in this report, Section 3. Blitzen was calibrated using the pipeline’s product (diesel). The dog’s performance, concentration, and consistency, was optimised using the findings of these trials.

The pipeline was inspected in 4 sections totalling 2.7 km: these sections were carefully selected and contained the remaining deepest unrepaired external corrosion anomalies. No leaks were identified along the entire 2.7 km.

The leak detection dog provided the perfect complement to the other leak detection methods being used by this operator, to give maximum confidence on the condition of the pipeline.
5. CONCLUSIONS

The research reported in this paper has clearly shown that dogs can be used to complement existing pipeline patrols and leak detection systems on pipelines.

It is concluded that dogs can detect hydrocarbon leaks as small as 5 ml, at depths up to 800 mm below ground, with an 86% success rate. Larger volume leaks would be easily and consistently detected by dogs.

The research showed there is a 95% confidence that the dog would:

- find between 52% and 78% of extremely small leaks (~5 ml) on a pipeline;
- miss between 22% and 48% of these size leaks on a pipeline; and,
- incorrectly identify the presence of this size of leak between 5% and 15% of his total indications.

The main advantages of using a dog for leak detection are the simplicity and sensitivity in detecting very small quantities of leaking product: quantities which would go undetected by current pipeline leak detection technology.

Finally, the dogs are not only reliable; they are also cost-effective, and environmentally-friendly.
6. ACKNOWLEDGEMENTS

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All this research work was conducted by four MSc students at Newcastle University: Shiplo Zaman, Kelvin Fahey, Antony Bullas, and Brian Kerrigan. Their efforts and analyses are acknowledged.

Finally, all field operations using leak detection dog are managed by Penspen’s Will Sharman (w.sharman@penspen.com), and the Case Study is from one of his projects.

7. REFERENCES