DOG

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TEST

Detecting Corrosion Under Insulation using Trained Dogs: a Novel Approach

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The sense of smell of dogs has been used traditionally by police forces, customs and the military to detect illicit or dangerous substances. During the past few years, it has widened to other applications. In agriculture, for example, specific plant diseases are being detected and truffles are located, and in medical science, dogs are used to detect specific bacteria and cancer (Bomers et al., 2012; Nakash et al., 2000; Pegler, 2003; Williams and Pembroke, 1989). In a two-year project, the use of the dog's acute sense of smell for the detection of corrosion under insulation (CUI) was studied. Corrosion of pipes covered by insulation is a major worry in refineries and processing plants. Removing insulation for a general visual inspection is the technique currently used for corrosion inspection and maintenance schemes. The project group's previous experience in the field of mine detection had shown that dogs readily detect volatile molecules (volatiles) produced by corrosion: as a part of their training dogs sometimes have to be trained to ignore buried rusting scraps of metal and focus on buried landmines instead. This prompted the idea to use dogs to detect hidden corrosion.

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Dogs are used for detection purposes for two main reasons: their sense of smell and their trainability. The sense of smell is difficult to study because there is no scale to measure odor. Odor is best defined as the perception of volatiles. Key factors in odor perception seem to be the number of different kinds of odor receptors an animal species has available, and the proportion of its brain dedicated to the of processing odor information. Dogs and mice both have approximately 1000 different functional odor receptors, while humans have less than 400 (Goldblatt et al., 2009). Dogs also have a much larger proportion of their brain dedicated to odor processing. This means that these animals can perceive and discriminate odors that humans cannot, simply because humans lack the sensors and the processing unit.

Dogs are more versatile than mice in training and are more accepted in the environment. As a result of their long cohabitation with people they are sensitive to human signals, which facilitates training. The flip side of this sensitivity to human cues makes it necessary to be extremely careful in training and testing on odors.

However, dogs cannot access refineries or energy processing plants for direct detection. A technique called remote scent tracing (RST) was therefore used. This technique was originally described for the detection of explosives in mine fields (Fjellanger, 2001). Volatiles in the air (the scent) are collected in the field (the remote location) using a sampling technique. The samples are analyzed by animal detectors, usually dogs, in a laboratory-type setting (the tracing). This technique is now used in screening airfreight (*Commission Regulation [EU] No. 573/2010*) and has shown to be promising in screening for different types of cancer (EU, 2010; Moser and McCulloch, 2010). For the purpose of detecting CUI, samples were taken at the plants and presented to trained dogs in the laboratory.

This paper describes the three main elements involved in using this technique to detect CUI: the remote sampling of the volatiles at the plants, efforts to understand the scent involved (the basis of the detection), and the tracing of this scent by the dogs. It also describes some key results obtained. The study has followed a corporate technology qualification program based on *DNV-RP-A203, Qualification Procedures for New Technology*, and the RST technology using dogs is now accepted as a proven technology (Gassco, 2013).

Remote: the Sampling

The sampling system that was developed in this project was designed to meet the following criteria:

- Rugged system that is safe to use in classified areas;
- Easy to operate and use;
- Provide consistent samples that do not contaminate each other;
- Tuned to the environment and specifications of the volatiles to be sampled.

Field experience had shown large variations of the condition of pipes and insulation: from densely packed insulation covering the process pipe, to significant voids or discontinuities in the insulation due to heating wires or cables, water intrusion and so on. A decision was made to utilize drain plugs that are commonly present in insulated pipes for the sampling. Drain plugs are mounted through the mantel and into the insulation covering the process pipe. The filter cartridge was designed to fit directly into the drain plug, thus limiting usage of materials that could potentially be contaminated.

A severe limitation for providing accurate information of sampling conditions has been the restriction on the use of electronic instruments in the field. The samples were taken by using an ejector vacuum pump connected to the filter cartridge. Since the driving pressure of the ejector pump was constant, the sampling time controlled the amount of air being sampled.

A sketch of the sampling system is given in Figure 1. The field sampling unit consisted of a bayonet closure to access the high pressure supply, a flexible hose between the bayonet and the ejector pump, a valve that controlled the air supply, a manometer that indicated the air supply driving pressure (and thus indirectly the flow rate), an ejector pump, a manometer that controlled the vacuum of the filter cartridge, and a flexible hose to the filter cartridge holder. The ejector pump and manometers were fixed to a belt that the operator wore, allowing freedom of movement between the high pressure point and the sampling locations. For training, samples were prepared in the laboratory. Here a similar system was used, but the sampling was controlled by computer software that monitored the different aspects of the sampling system.

The filter cartridge was designed to meet several criteria: it should ensure the quality of training samples made in laboratory and of those sampled in the field; it should ensure correct storage and ease of transport from the field to the laboratory; and it should allow filter presentation to the dogs without additional handling.

The filter cartridge (patent pending) consisted of an upper and lower part that together formed the training cartridge. By adding an upper and lower

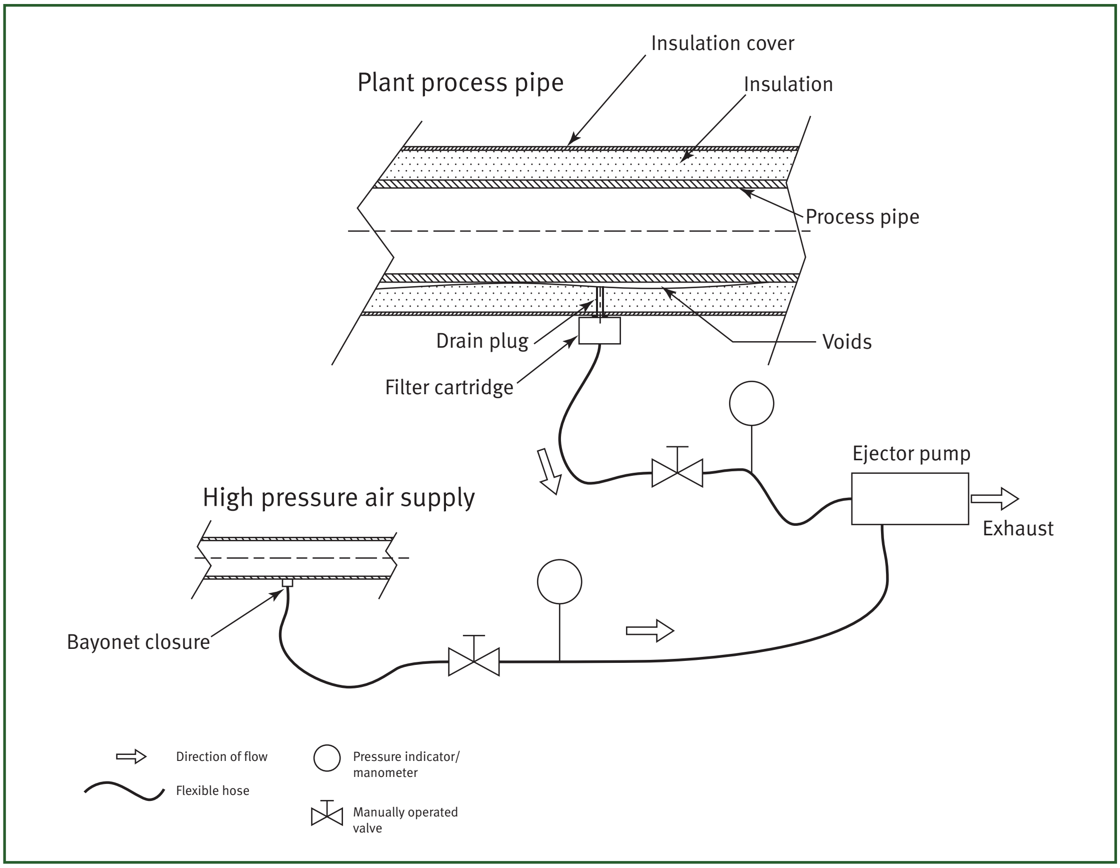

Figure 1. Sketch of sampling system.

housing to this training cartridge, a field cartridge was formed. The filters used in the cartridges had to fit tightly into the filter cartridge, leaving no room for air to pass by the filter. During this study a white polyethylene /polypropylene filter was used. Caps on the inlet and outlet of the filter cartridge were used for storage. All components fit together tightly. The filter cartridge design allowed for easy handling in the field and for secure storage. After removing the outer housing in controlled circumstances, the filters were presented directly to the dogs.

Scent: Volatiles of Corrosion

The volatiles in the headspace of mineral wool insulation material collected from areas with significant corrosion and from areas without corrosion were analyzed. Based on work with odor signatures in the United States by Florida International University, a first choice was made to use solid phase micro extraction (SPME) for sampling the headspace above corroded and un-corroded insulation material, followed by the use of gas chromatography/mass spectrometry (GC/MS) to identify the components (Furton et al., 2000).

Briefly, this technique led to finding many extremely low peaks that could not be identified since they were close to the detection limit. No systematic differences were found between corroded and un-corroded samples. A tentative conclusion was that many of the peaks (hydrocarbons) were in fact collected from the ambient air in the plant.

A second study used a different technology: the mineral wool was flushed with air 5, 50 and 600 L (1.32, 13.21 and 158.5 gal), and the extracted chemicals were trapped on a 2,6-diphenylene-oxide polymer resin sorbent tube. The sorbent was subsequently analyzed with thermodesorption GC/MS. This approach was successful in that it allowed covering a much wider spectrum of chemicals with different volatility as compared to the SPME extraction technique used before. However, the results were not conclusive with respect to significant differences in the chemical pattern of samples from corroded locations and control locations that did not contain corrosion. The overall analysis results were similar for all samples with a large amount of peaks eluting between 8 and 10 min, which is characteristic for rather volatile compounds. A closer look revealed that every sample

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differed somewhat from other samples in terms of the peak-pattern, and one could often find a control sample that looked more similar to a sample from a corroded area than two samples from corroded areas or two control samples from un-corroded areas.

Although the analysis program was adapted, it was not possible to resolve the peaks, or chemicals, in the retention time between 8 and 10 min. It cannot be excluded that within this window a suitable marker substance might be hidden. In addition to searching for single peaks that would occur in the samples from corroded areas but not in the controls or vice versa, the detected peaks were also checked for a significant difference in their elemental composition. No significant difference could be found.

Tracing: the Dogs

To train the dogs, samples were made in a similar manner to field samples by sucking the volatiles coming from insulation material stored in glass jars. Positive samples were taken from jars containing mineral wool insulation material collected at corroded locations, negative samples, or controls, were taken from jars containing material collected from locations without corrosion. These filters were presented to the dogs in a carousel setup, shown in Figure 2. Using shaping and operant conditioning techniques, five dogs were taught to smell each of the 12 arms in the carousel in turn, and responding to positive samples by sitting was reinforced (Fjellanger et al., 2002).

When training dogs in this manner, the utmost care has to be taken so that the only cue available for the dogs to respond to is the positive odor. This means that the handling of all filters has to be exactly the same to prevent other cues that the dogs can learn to respond to. In effect, this implies that all samples have to be prepared in the same manner, in the same location, by the same person and at the same time so there are no sample preparation cues available; the placing of the filters in the carousel has to be randomized to prevent cues; and there must not be a handler in sight during the analysis who can unwittingly provide cues for the dog. Standard operating protocols were developed to prevent this.

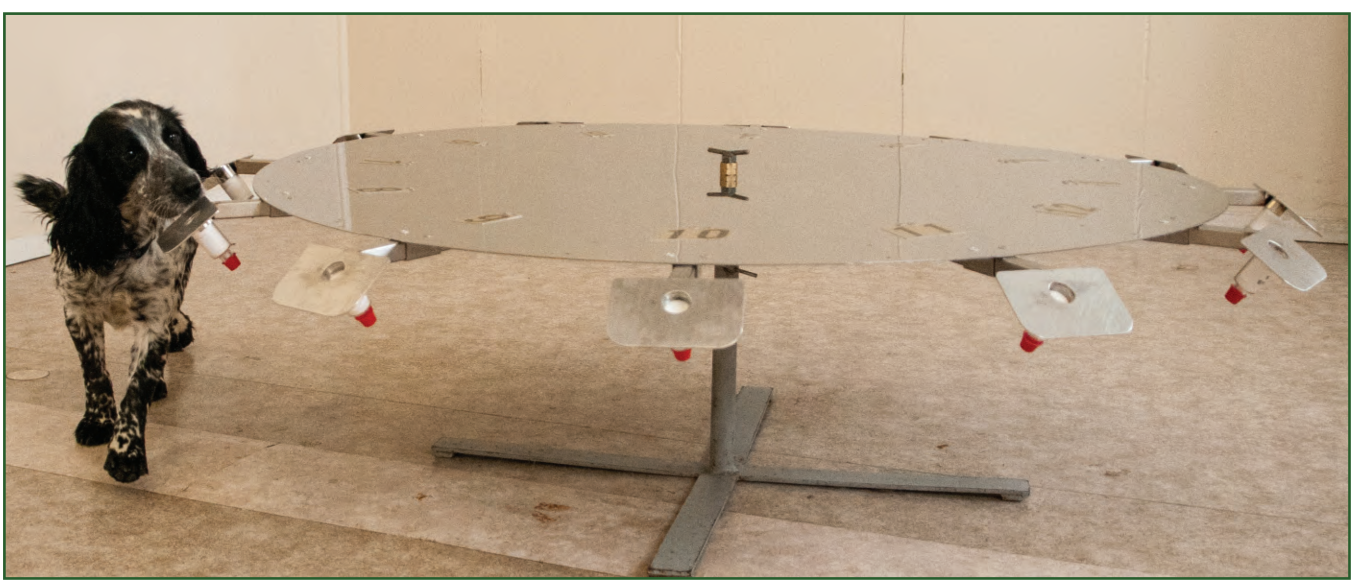

Figure 2. Dog smelling the samples in the carousel.

The results obtained indicated that the five dogs were capable of discriminating between positive and negative filters, with some dogs being slightly more sensitive but also making more mistakes by responding to negatives (hence less specific), and others being less sensitive but with fewer incorrect responses (hence more specific). It was also clear that a higher degree of corrosion led to a higher detection rate. Table 1 shows the average results of the dogs on such laboratory prepared samples from one plant.

The second step was to introduce positive and negative samples from the field. These were collected at a gas processing plant that had also provided material for training. One to five samples had been made per sampling location, identified by a uniquely labeled drain plug. A number of these locations were opened up for visual inspection soon after collecting the samples, and samples taken from these points were used for training since visual inspection had determined their status as being either positive or negative. Table 1 also shows the average results of the dogs on such known field samples from the same plant.

Based on these results, a system approach was developed to categorize the results obtained from field samples. Using this approach, it is possible to tune the detection to be more sensitive, and thus find all corrosion while accepting some false alarms (type I errors). Alternatively, the detection can be tuned to be more specific, that is, missing some corrosion (type II error) but minimizing false alarms. This is summarized in Figure 3. In this case, a highly sensitive system was chosen where detecting all corrosion was considered most important.

A minimum of two samples from a given location were analyzed on separate days by five dogs, meaning a minimum of 10 presentations per location were taken as a basis. Depending on the results of the dogs, the results per location were categorized as suspicious if the dogs responded to more than 10% of the presentations and clean when 10% or less of the presentations led to a response. Table 2 shows the results of the system to the known field samples.

Samples from a number of other locations were analyzed before a visual inspection had taken place. These tests meet the definition of double blind testing, which is the standard for correct testing (SWGDOG, 2009). A number of these locations were later visually inspected. The results of these verified later locations using the system approach are also given in Table 2. The results show a high level of accuracy for detecting samples from corroded /suspicious locations and not responding to samples from non-corroded/clean locations, although the number of locations that were analyzed was limited.

TABLE 1

Average percentage correct responses of five dogs on samples prepared in the laboratory or collected in the field with a known status. Results from analysis conducted between June and December 2012, using mineral wool insulation material from one gas processing plant

Material	Lab prepared samples	Known field samples
Corroded material	58.8% (n = 449)	57.1% (n = 165)
Un-corroded material	97.1% (n = 6654)	97.7% (n = 650)

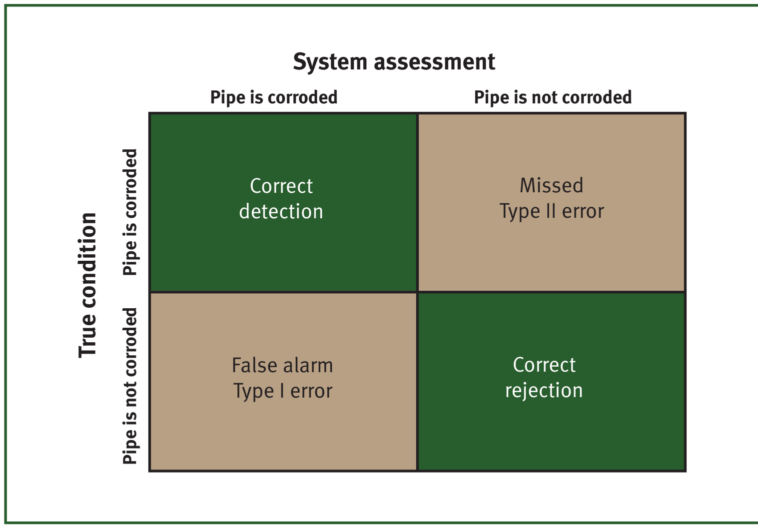

Figure 3. Characterization of possible system results. Sensitivity = % correct detection / *n* corroded areas; specificity = % correct rejection / *n* not corroded areas.

TABLE 2

Correct results of system approach of locations whose status was known before the analysis by the dogs and those where the status was verified later*

Material	Lab prepared samples	Later verified field samples
Corroded material	87.5% (n = 8) suspicious	100.0% (n = 6) suspicious
Un-corroded material	94.6 % (n = 37) clean	90.1% (n = 11) clean

* The results of each location are based on a minimum of 10 presentations.

The limited data collected in the late training and in the double blind testing phase was combined to calculate sensitivity and specificity of the system. The sensitivity of the system approach, which in essence is the chance that corroded locations are labeled “suspicious,” was 92%. The specificity of the system approach, in essence the chance that un-corroded locations are “clean,” was calculated to be 93%. These numbers are satisfactory and met the target of the RST technology development in the project.

Conclusion

Assessing the development of the technology, the following conclusions were reached:

- Dogs were trained to detect CUI with desired reliability (>70% detection of corroded locations, >90% clearing of un-corroded locations);
- A user-friendly sampler was developed for use in gas and oil plants, including classified areas;
- A robust filter cartridge system (patent pending) was developed for sampling in the field and for use in the laboratory;
- A concept system was developed to report evaluations of sampled locations;
- A potential use for the system within an inspection department is described that will benefit all parties involved;
- Chemical identification of volatiles related to corrosion was not viable.

Although the efforts, resources and time required to organize and perform the activities in the field proved to have been underestimated and resulted in a longer duration of the project than initially anticipated, the results were very promising. Using dogs to detect CUI is nondestructive, and the study has provided information on the measurement system used (Robbins, 2012). A follow-up project where CUI dogs are integrated into the activities of the inspection departments is in the process of being set up. This will lead to more data to accurately determine the sensitivity and specificity of the technology and to determine other parameters such as the possibility to assess the degree of corrosion in conjunction with the distance of the corroded area from the sampling location.

Using dogs to detect CUI can be of immense value when integrated into the plant maintenance system. By repetitive sampling of locations over time, areas that develop corrosion can be identified in a timely manner. This information can be used to set priorities and plan maintenance. Costly resources necessary for a general visual inspection can thus be used more efficiently. ◐

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