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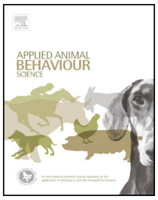

Using dogs to detect hidden corrosion

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ABSTRACT

Dogs used as detectors in remote scent tracing (RST) technology usually detect the presence of explosives or contraband in scent samples collected by sucking air from containers or air freight. In this study, five dogs were trained to detect corrosion under the insulation (CUI) of pipes in scent samples collected at a gas processing plants. CUI is a major problem in oil and gas processing plants, causing safety risks and leading to production loss. Scent samples were made by sucking air through drain plugs in the insulation material surrounding the pipes onto filters. During a two year project, dogs trained to detect corrosion using insulation material collected earlier from other corroded locations at the plant were able to detect corrosion on the filters collected from intact insulated pipes at that plant at the same level of proficiency, detecting corrosion at around 59% while producing on average less than 3% false alarms. The systematic training approach, the integration of field samples into training runs and the use of several dogs to improve the reliability of the system are described. Preliminary results on double blind samples were promising: the sensitivity of the detection of field samples was 92%, and the selectivity 93%. The application of such a system as a tool in a preventive maintenance program at oil and gas processing plants could be useful to determine timing of maintenance, thus allowing a more efficient allocation of costly resources necessary for the customary visual inspection.

1. Introduction

The sense of smell of dogs has been used traditionally by police forces, customs and the military to detect illicit or dangerous substances using “free running” dogs. 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 “odour”. Odour is best defined as the perception of volatile molecules. Key factors in odour perception seem to be the number of different kinds of odour receptors an animal species has available, and the proportion of its brain dedicated to the processing odour information. Dogs and mice both have approximately 1000 different functional odour receptors while humans have less than 400 (Goldblatt et al., 2009). Dogs also have a much larger proportion of their brain dedicated to odour processing. This means that these animals can perceive and discriminate odours that we cannot, simply because we lack the sensors and the processing unit.

Through the years, using dogs for detection purposes has broadened to many other substances, and by many different organisations. Moreover, the traditional “free running” method has been complemented with a “remote scent tracing (RST)” method, as first described for mine detection (Fjellanger, 2001). RST entails collecting scent samples at a location where dogs cannot be deployed efficiently for safety, environmental or logistic reasons. These scent samples are then presented to the dogs in a laboratory-like setting for analysis. For example: heat can

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be a reason dogs cannot be deployed for a long period of time, so at the Palestinian border with Israel scent samples are collected from cars analysed by dogs in a cooler environment (Zoodsma, pers.com.). EU regulations allow air freight to be sampled and analysed by dogs elsewhere for the presence of explosives. In this way, a large amount of freight can be checked in a short period of time (EU regulation 573/2010). Cancer detection dogs essentially work in this manner too: samples are collected from potential patients in hospitals or clinics, and analysed elsewhere by dogs (review Moser and McCulloch, 2010).

In this study, RST was used as a technique to locate potential corrosion of pipes in refineries and processing plants. Such pipes are covered with insulation material and a protective cladding to prevent heat loss. However, this means that the pipes cannot be inspected for corrosion easily. Part of plant maintenance involves taking down the cladding, removing the insulation so a "general visual inspection" (GVI) can take place, and then insulating the pipes again with insulation material and cladding. This is a time and cost consuming but necessary process and time and again serious corrosion is discovered in the nick of time. Collecting scent on filters by sampling the air underneath the insulation without having to remove it, and establishing the odour of corrosion on these filters, could help identify corroded areas and guide plant maintenance planning.

A main challenge in RST systems is to train the dogs in such a manner that they easily transfer from filters made for training purposes to those collected in an operational setting. For example, in training cancer detection dogs, training is done first on diagnosed cancer patients as positive stimuli, and healthy controls as negative stimuli. Collecting scent from cancer patients at a clinic and controls at another location may be logistically efficient, but it provides a systematic cue ("clinic odour") the dogs may learn to respond to. Secondly, diagnosed cancer patients have undergone different medical tests that may make them different in more ways from controls than just the cancer, providing another cue the dogs may learn to respond to. The final testing should be done on samples collected from patients and controls at one location and prior to diagnosis, a level that has not really been achieved yet (Moser and McCulloch, 2010). Training dogs to detect explosives in air freight is even more complicated. It is impossible to mimic operational freight since it would entail placing an explosive in freight when it is being packed at a sender location, transporting it to the airport, and sampling it there. Different solutions are sought for this problem: collecting samples from air freight and adding the odour of explosives to them; or introducing explosives temporarily to air freight, sampling and removing the explosives again. Each of these solutions provides cues the dogs may learn to respond to and controls have to be managed carefully to prevent this – and although the dogs are tested, this is not done in a truly realistic manner (EU regulation 573/2010).

Bearing this in mind, this study focused on creating training samples that were as realistic as possible, on devising a method to introduce operational samples and on establishing transfer of stimulus control. Sampling was standardised by using a sampler specially developed to be used in the field that would ensure a constant and predictable airflow both in the laboratory and in the field. Chemical analysis was sought to elucidate systematic differences between "positive" and "negative" stimuli, which would also allow clarification of systematic false alarms. Finally, the study compared the detection rate of a single dog with that of a group of dogs in an effort to optimize the detection process.

2. Material and methods

2.1. Dogs

Five dogs were used in training: 4 Malinois Shepherds (born in 2008) and 1 Springer Spaniel (born in 2007), all females. The dogs were housed in kennels at Fjellanger Hundeskole in Bergen, Norway. Besides the training for this study, the dogs were trained in a variety of obedience exercises and some agility exercises, and used for teaching pupils basic dog handling skills. They were fed daily and exercised regularly. In general the standard was higher than the prescribed Norwegian animal welfare law. The dogs began the first stages of their training in the fall of 2009 and the final sessions conducted as part of this study were conducted in December 2012. They were trained 2–4 times per week depending on the stage of training and availability of resources. Training sessions varied in length from 10 to 20 min. The progression of the training is described in the results section.

2.2. Training filters

Filters used in training were made using mineral wool insulation material collected from heavily corroded pipes as positive stimuli, and from insulation material collected from pipes that were not corroded as negative stimuli. The difference between the two types was easily seen as the mineral wool collected from heavily corroded pipes was stained with a typical orange–brown colour, and sometimes contained flakes of corroded metal, whereas mineral wool used as controls was not discoloured. Both types of material were collected at two plants in Mongstad and in Kårstø, Norway. Within a training session material from a single plant was used.

The batches of insulation material were coded for the pipe location it came from, and divided into two to six 1 L glass jars depending on the amount available. These jars, nicknamed "mother jars", were used to prepare the training filters. They were closed with a plastic lid that had two needles to allow access for the sampling equipment.

The filters were made from white polyethylene/polypropylene (PP/PE) fibres and cylindrical in shape (25 mm diameter, 40 mm long), purchased from Pentok Ltd., UK. These filters were loaded either by allowing them to "soak" up the volatiles by placing them in a mother jar for a designated period of time and then put into filter cartridges, or used to "sample" the air from the mother jar while already in their cartridge, using specially designed sampling equipment. The cartridges were then sealed until training, usually on the same day.

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The cartridges fit into a carousel for analysis by the dogs. The filters and the cartridges were handled using plastic gloves and tongs to prevent contamination with other odours. They were used for a single training session and then discarded. Approximately 10.000 of such filters have been used during the study period

2.3. Field filters

Field filters were identical to sampled training filters, except that they had an additional outer cartridge for protection against contamination at the plants (Schoon et al., 2014). Sampling was conducted at the plant in Kårstø, Norway. The sampling was done with the same kind of sampling equipment as for the training filters, designed for use in refineries and processing plants (see below). The suction end of the filter cartridge was placed at a drainage hole in the outer mantle covering the insulation material. These drainage holes provide access to (perforated) drainage pipes that cut through the insulation material to the inner pipe, allowing any water inside the insulation to exit. Drainage holes also provide access to air inside the insulation. This air was sampled by sucking air through the filter for 30 s at a speed of 15.5 L/min. After sampling, the cartridges were sealed and stored for use.

Some pipes were inspected within a few days after field filters had been made. In such cases, the status of the field filters became known and was graded in one of six classes ranging from completely clean to heavily corroded (three categories for positive stimuli ranging from “active corrosion with significant material loss of an area >10 cm^2 within 50 cm from the plug” to “rusty pipe without material loss, 50% of the pipe being rusty within 50 cm of the plug”, and three categories for negative stimuli ranging from “not so rusty pipe, between 20% and 50% rusty within 50 cm of the plug” to “clean pipe only within 50 cm of the plug”). These filters were used in final training (field training stage) as known positive or negative stimuli. In other cases, the status of the field filters remained unknown prior to analysis by the dogs. These were used in double blind tests. Approximately 800 field filters were collected during the study period, 421 of these were presented to the dogs.

2.4. Sessions

Training sessions consisted of three to eight runs, where a run consisted of 12 different filters placed on a carousel for analysis by the dogs. A picture of the carousel is given in Fig. 1. The filters were placed on the carousel by a laboratory assistant while the dog and the handler were in a separate waiting room. The assistant would then leave the room and observe through a window, and give a ready signal (a light) to the handler. The handler entered the carousel room alone and would stand behind a screen at the opposite end of the room, the carousel in between the screen and the entrance from the waiting room. The handler released the dog by pulling a rope that operated a hatch next to the waiting room door. The dog would enter the carousel room and begin smelling the filters in the carousel, circling it anti clockwise, smelling each of the samples sequentially. The following 4 situations could then occur:

Fig. 1. Carousel with dog sniffing at the samples.

1. The dog could make a correct hit: sit while focused on a positive sample. A correct sit, or correct positive, was communicated to the handler by the assistant by switching on a green light that lit up behind the screen where the handler was waiting. The handler would then move towards the dog and reward it with a play reward. They would then both leave for the waiting room.
2. The dog could make a false alarm: sit while focused on a negative sample. An incorrect sit, or false positive, would be communicated in a similar manner with a red light. The handler would then move from behind the screen and just lead the dog by the collar to the waiting room without speaking.
3. The dog could indicate on an unknown sample (in the double blind test phase). Since we did not know if such a sample was positive or negative, these situations could not be treated as a correct positive or a false alarm. Here a “praise off” procedure was used (part of training in the later stages). For the praise-off procedure, the handler was given a yellow light, and would call off the dog in a happy voice but not use the play reward, and return to the waiting room.
4. No response: when the dog smelled all the samples without responding to any of them, the handler would move from behind the screen, call the dog in a happy voice and leave for the waiting room with the dog following.

After any hit, the assistant would remove the filter cartridge that the dog had responded to and return to the observation room. The handler would re-enter the carousel room at the signal and repeat the procedure for a second visit of the same run, repeating the procedure until the dog did not respond to any of the filters, rewarding correct positives and leading the dog away at false positives. This concluded a run. All remaining filters would be removed, and a new run would be put prepared by placing the next 12 filter cartridges in the carousel.

The types of filters were selected depending on the stage of the training and the goal of the session. The order of the filters was randomized through a dedicated computer program that also contained information on the mother jars and filter types, and that provided for data entry and

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analysis. A session was used for 2–5 dogs and the order of the dogs was randomized. The progression of this training is described below.

Initially, the sessions only contained training filters. Later, field filters were added: at first only field filters with a known status (either positive or negative stimuli) so a session would consist of a mixture of laboratory prepared training filters and filters collected in the field. Finally, field filters with an unknown status were added to sessions for double blind operational testing. In all, about 245 training sessions were conducted, consisting of about 10,000 training filters and over 400 field filters.

2.5. Training progression

The training progression went through seven steps based on the type of positive stimulus and type of search. Progression from one step to the next was based on observed proficiency during a couple of days for each individual dog.

1. *Pre-training outside the carousel room*, where the dogs were trained to search in different locations and perform a sit indication for progressively smaller pieces of Kong (a rubber dog toy) as a positive stimulus using a successive approximation and positive reinforcement with a whole Kong;
2. *Pre-training inside the carousel room*, where the dogs were trained to systematically search the carousel in an anti-clockwise manner, detect a sliver of Kong placed on top of one of the filters in the carousel upon entering the carousel room, perform a prolonged focused sit as indication, not make false alarms on empty filters, and be able to do a number of zero runs (without a positive stimulus there) within a training session;
3. *Kong discrimination training*, where filters initially were soaked in a glass jar containing a Kong as positive stimuli had to be discriminated from filters soaked in glass jars containing a variety of controls; continuing with progressively shorter soaking times and finally sampling filters by drawing air from these jars as described in the methods section;
4. *Transition training*, where filters were soaked in mother jars containing insulation material, and positive stimulus control was faded from the odour of Kong to the odour of the insulation material from corroded locations; continuing with progressively shorter soaking times and finally sampling filters by drawing air from the mother jars as described in the method section;
5. *Routine training*, where air samples were taken systematically from mother jars containing insulation material from corroded and clean locations in a proportion of 2–4 positive stimuli in on average 4 runs of 12 filters per training session, and dogs were occasionally not rewarded with a toy for correct positives;
6. *Field training*; where filters collected by sampling air in insulation in the field that were known positive or negative stimuli were mixed with training filters prepared from mother jars;
7. *Operational testing*; where filters collected by sampling air in insulation in the field with an unknown status (thus double blind) were mixed with known field samples and training samples.

The basic choice to first train on (the odour of) Kong was based on earlier experience in training mine detection dogs. It allowed a number of technical training aspects such as a systematic search and a prolonged focused indication to be finalized using an unambiguous positive stimulus while preventing possible negative associations as a result of training mistakes with the final positive stimulus odour, in this case the odour of corrosion. The dedicated computer program was used from step 3 onwards to ensure random positioning of all stimuli and to facilitate data collection.

2.6. Sampler

The sampler that was used for making training filters in the laboratory as well as field filters in the plants has been described in some detail elsewhere (Schoon et al., 2014). Briefly, 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. In the laboratory 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 been designed to fit directly into the drain plug, thus limiting usage of materials that could potentially be contaminated. The filter cartridge (patent pending) contained the polyethylene/polypropylene (PP/PE) filter described above that collected volatiles from the air that passed through it.

2.7. Chemical analysis

Several batches of insulation material that had been used in early stages of the training were analysed to characterize the volatiles present in the headspace. This material was partly pooled and consisted of 3 samples of mineral wool taken from non-corroded locations (controls) and 4 samples of mineral wool taken from heavily corroded locations (positives). Mineral wool was filled into a glass tube and was extracted by a humid air stream. The extracted compounds were trapped afterwards on a polymer sorbent. Pressurized air from the lab system was used to create an air stream through the tube. The air humidity in the air stream was increased to reduce the sorption of organic compounds to the mineral surfaces. The relative humidity was controlled by a temperature controlled washing bottle. A picture of the experimental setup is given in Fig. 2.

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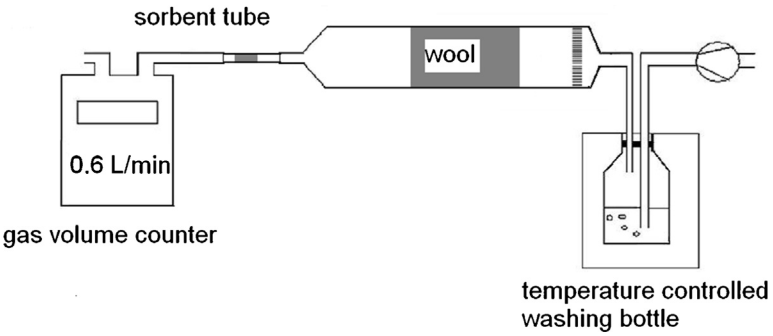

Fig. 2. Experimental setup to extract volatiles from the mineral wool by airstream.

The air flow was up to 0.6 L/min. Every wool sample (1–7) was extracted in three steps:

- Step 1: 60% rh, sample volume 5 L, sorbent Chromosorb
- Step 2: 90% rh, sample volume 50–100 L, sorbent Tenax TA
- Step 3: 90% rh, sample volume 600 or 100 L, sorbent Tenax TA

After the extraction step 2 and 3 the sorbent tubes were dried with a N_2 airstream of ca. 50 mL/min for 4 min before thermodesorption because the humidity from the air flow would cause problems during the analysis.

To analyse and quantify the amount of compounds trapped on the sorbent the thermodesorption unit TDAS 2000 from Chromtech was used in combination with a GC 7890A (column HP-5) and MSD 5975 C system from Agilent Technologies.

The sorbents were desorbed with a Helium flow of 50 mL/min at 150 °C for 10 min. The following conditions were used for analysis: the oven with the column (HP-5) was heated up with a rate of 25 °C/min from 40 to 250 °C (exception sample 5–7, extraction step 3, heating rate 10 °C/min to 20 °C/min). The column flow was 1.5 mL/min. The temperature of the transfer line was 280 °C. The detection by the mass spectrometer was in the SCAN mode.

3. Results

Training sessions were conducted with the dogs from late 2009 to December 2012. Progress was not always smooth, since initially the focus was on samples from one plant and later the focus switched to a second plant, where the bulk of the material presented in this study was collected. Also, initially an earlier version of the sampler was used until increasing false alarms of the dogs led to investigating possible causes, and concluding that cross contamination was the cause. Training was taken back from step 5 to step 4 described below. Once the new sampler was ready, training on sampled filters was resumed, and the results collected during the last 77 sessions are presented here.

3.1. Routine training results

In step 4 in training, filters that had been “soaked” in jars containing different types of insulation material were used in training the dogs. In step 5, the air in these jars was “sampled” over filters. The results of the individual dogs in these two scenarios collected during the last 77 training sessions are given in Figs. 3 and 4. Sessions are grouped together because individual sessions only contain 1 to 4 possible correct positives. Differences between the dogs were tested using Friedman’s test at $\alpha = 0.0125$ using the Bonferroni correction. Dogs do not differ significantly in either FA rate or in the hit rate.

The average level of false alarms and hits in of the dogs in the different conditions is given in Table 1. Differences between the different conditions were tested using Friedman’s test. The level of false alarms is not significantly different in the different conditions, neither is the percentage hits.

The large variability in results can be explained by the way the dogs respond to the different batches of insulation material that was collected. The sampled filters have been made from 12 batches of insulation material taken from corroded areas, and from 58 batches of from uncorroded areas. The dogs do not perform equally well on

Table 1
Overview of average FA and HIT rates for the individual dogs per type of filter used in training. The number of filters each dog has been confronted with is given per filter type (n).

	Un-corroded locations FA rates			Corroded locations HIT rates		
	Soaked ($n = 889$)	Sampled ($n = 1330$) (%)	Field ($n = 368$–370) (%)	Soaked ($n = 67$) (%)	Sampled ($n = 90$) (%)	Field ($n = 50$–51) (%)
Dronning	3.49	3.23	3.25	73.13	60.00	52.94
D-prime	5.46[a]	3.98	8.72	65.31[a]	61.11	78.43
Vinnie	2.81	2.56	1.90	76.12	47.78	60.00
Holly	2.25	2.56	5.68	89.55	67.78	70.00
Fly	2.47	2.48	2.17	50.75	56.67	36.00

[a] D-prime was ill during 4 sessions so this number is based on less presentations than the others ($n = 623$ for the FA, and $n = 49$ for the HITS).

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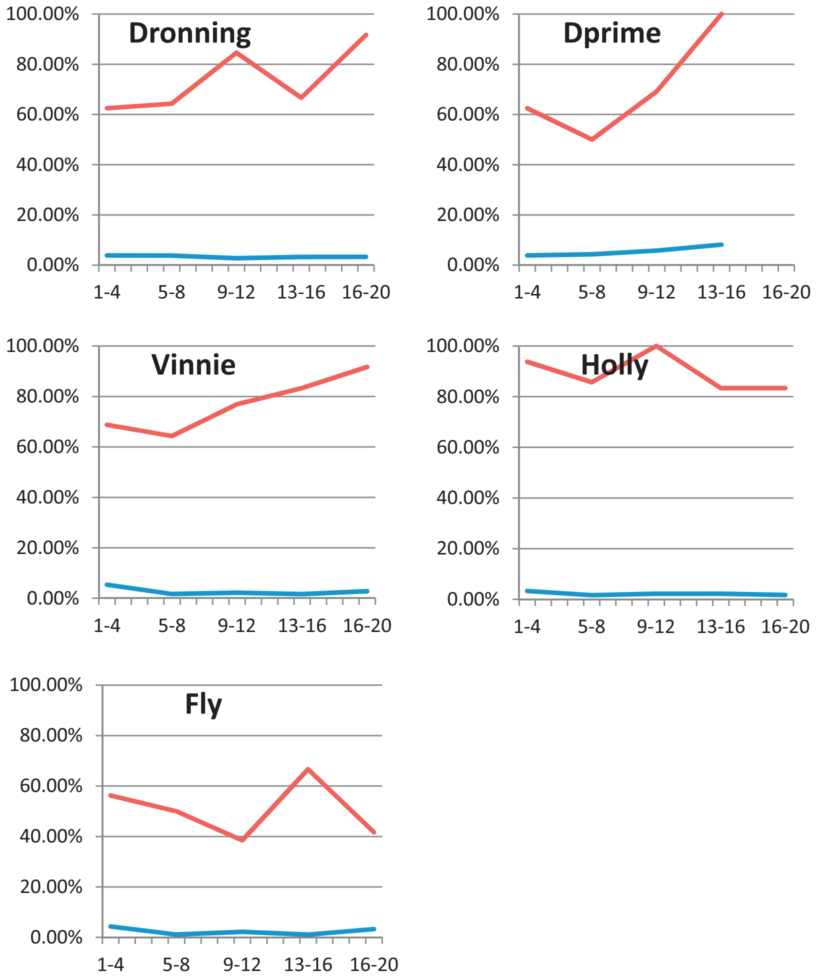

Fig. 3. Correct hits obtained using filters soaked in corroded insulation material (top line) and false alarms on filters soaked in clean insulation material (bottom line), per block of 4 training sessions. D-prime was sick during the last 4 training sessions.

all of these: the differences in hit rate on the corroded material varied from 0 to 100% and the results differ significantly (Chisquare, df = 11, $p < .001$). Also with respect to false alarms, the variability is high, ranging from 0 to 40% and this is also significant (Chisquare, df = 57, $p < .001$).

3.2. Field training results

In step 6 of the training, samples that had been collected in the field were introduced into normal training runs. Since the insulation material had been removed after sampling, these field samples had a “known” status as being either positive or negative stimuli. In Fig. 5, the results of the individual dogs on only these filters are given. The dogs do not differ from each other in either the hit rate, nor in FA rate (Friedman’s test). Table 1 includes the average results obtained on the field samples: these averages do not differ from averages obtained with the soaked or laboratory sampled filters.

When looking at the results of the dogs with respect to the degree of corrosion, it was found that the average hit rate on the highest level of corrosion was 67.7% ($n = 17$ samples) and 51.8% ($n = 13$ samples) on the lowest level. This difference was not significant (Friedmans, df = 1, $p = .18$).

3.3. Operational testing results

In step 7, field samples from locations with an unknown status at the moment of testing were introduced into the sessions. In total, 139 filters collected from 40 different locations were analysed by the dogs. The status of 30 filters from 17 locations was verified by opening up the insulation material after the test: 11 locations were uncorroded, 6 locations were corroded. 12 out of the 15 filters from uncorroded locations were correctly ignored by all dogs, the other 3 filters (from 3 different locations) were incorrectly hit on by one dog each: twice by D-prime and once by Holly.

4 out of the 15 filters collected at corroded locations were incorrectly ignored by all dogs: all of these filters were collected at the same location but a 5th sample from

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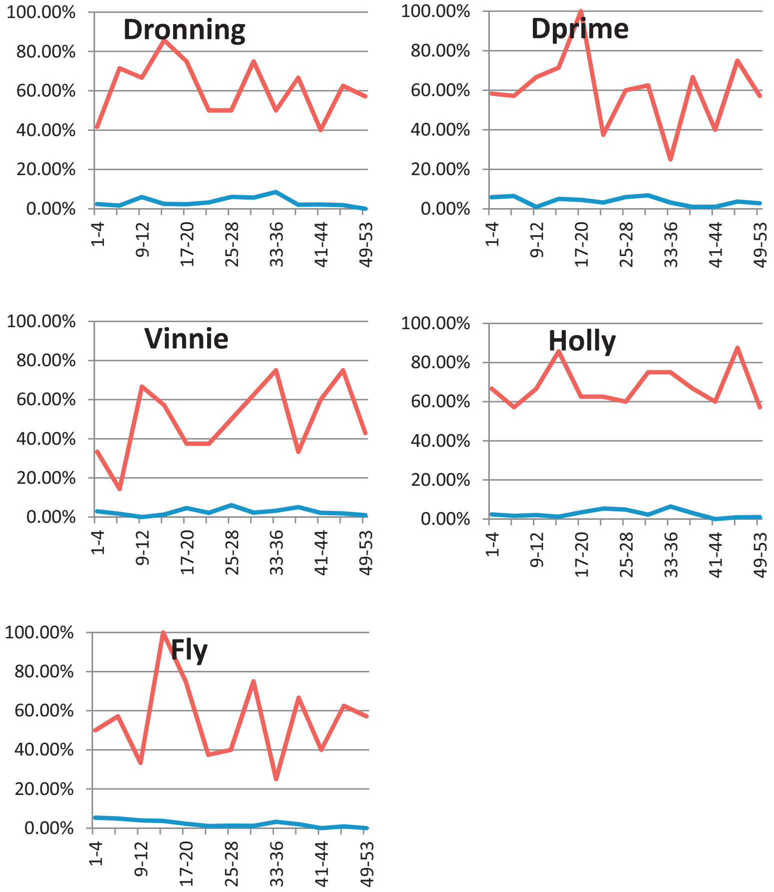

Fig. 4. Correct hits obtained using filters containing sampled air from corroded insulation material (top line) and false alarms on filters containing sampled air from clean insulation material (bottom line), per block of 4 training sessions.

the same location was identified by 3 dogs. By taking the average results of the dogs on all samples collected at a particular location the results become less variable.

The results of 109 other field filters from 23 locations vary in hit rate from 11% to 0% per location, and 3 to 7 filters have been analysed for each of these locations. These locations are not expected to be opened up soon for visual inspection and verification of the dog results.

3.4. Results through a system approach

In a system approach, the results of a number of dogs are combined in a final evaluation. In this study the outcome of a classification of a field sample by a single dog is compared with that of a combined approach, using only those locations that were sampled at least twice, and analysed by all 5 dogs on different days. The result of this comparison for the double blind operational field samples can be seen in Fig. 6. As a system outcome, locations that had 10% or less filters positively indicated were labelled as “clear”. This criterion was chosen based on the observed false alarm rate of less than 10% of individual dogs. A positive system outcome (“high expectation of corrosion”) was attributed to locations that had 40% or more hits, again a criterion chosen on the basis of the observed average hit rates of more than 40% of individual dogs on known samples. An intermediate system outcome “low expectation of corrosion” was given to locations with hit rates between 10 and 40%.

Out of the three verified “clean” locations, one is labelled “low expectation of corrosion” based on this system approach. Five of the six corroded locations are labelled “high expectation of corrosion”, one is given a “low expectation of corrosion”. Reviewing the data on the field training filters with a known status in the same manner, 2 out of the 37 clean locations would have been classified as “low expectation”; the other 35 would have been correctly cleared. Out of 8 corroded locations, 7 would have been correctly classified as high expectation and 1 would have been cleared.

Setting up a system to be very sensitive would lead to considering any location that is not completely cleared as suspicious and to be examined. The sensitivity of such a system approach is 93% (13 out of 14 correct), and the specificity 92% (37 out of 40). On the other hand, the system can also be set up to be very specific. In such a case only those locations that were evaluated as having a “high expectation of corrosion” would be examined. The sensitivity of such a system is less, 86% (12 out of 14) but the specificity higher: 100% (40 out of 40).

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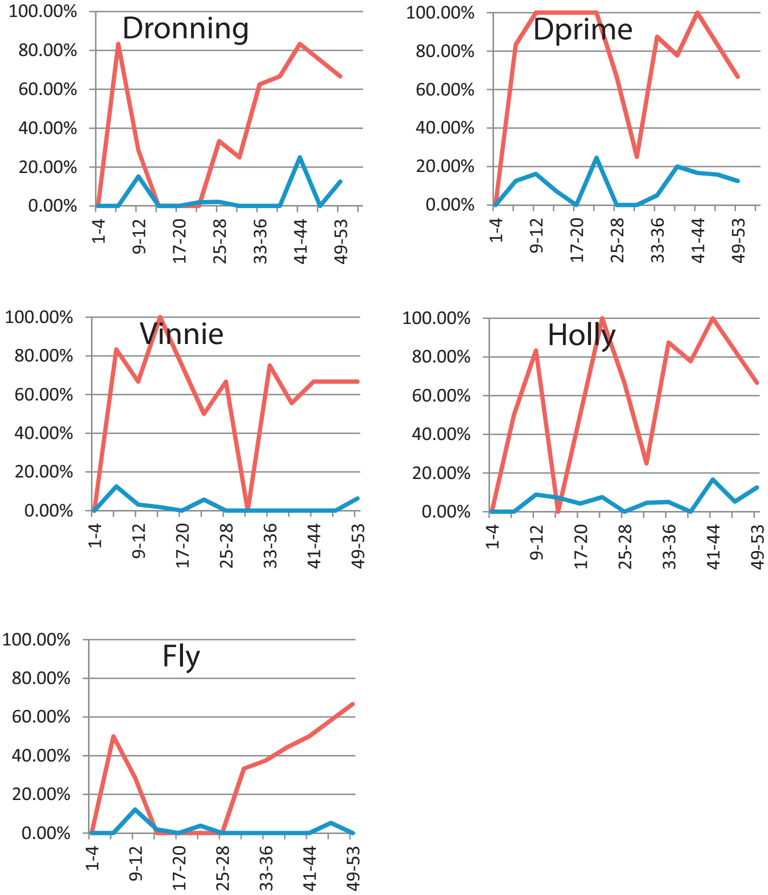

Fig. 5. Correct hits obtained using field filters containing sampled air from corroded locations (top line) and false alarms on field filters containing sampled air from clean locations (bottom line), per block of 4 training sessions.

3.5. *Chemical analysis*

The chosen analytical approach was successful in that it allowed coverage of a wide spectrum of chemicals with different volatility. However the results did not give a conclusive picture with respect to significant differences in the chemical pattern of samples taken from corroded locations and controls. The overall analysis results were similar for all samples with a large amount of peaks in a retention window between 8 and 10 min. A closer look reveals though that every sample differed somewhat from other samples and often one could find a control sample that looked more similar to a positive sample then two positive samples or two control samples. A characteristic example of the results of the analysis is given in Fig. 7.

In addition to searching for single peaks that would occur in the positive samples but not in the controls or “vice versa” the detected peaks were also checked for a significant difference in their elemental composition. The hypothesis was that positive samples might contain chemicals that are more oxidized than in the control samples. To this end 10 peaks with a short retention time (=very volatile chemicals) and ten peaks with a longer retention time (=less volatile chemicals) were selected in both control and positive samples, and the elemental composition of the corresponding molecular formulas suggested by the MS-Library was checked. No significant difference was found, but the whole data interpretation was severely hampered by the insufficient resolution of many peaks.

4. Discussion

We have shown how dogs can be trained to detect corrosion under insulation, using samples prepared under controlled laboratory conditions and later establishing generalization to samples collected in field conditions. The proficiency of the dogs is such that the combined results of several dogs on a number of samples yield sufficient sensitivity and specific for the system to be useful in providing information for plant maintenance.

In usual “real world” detection applications such as narcotics, explosives or fire accelerant detection, a single dog is used based on the expectation that the dog is proficient enough to locate everything and not make mistakes. This expectation is usually not tested as rigorously as in this study. We did not find a single dog proficient enough in the detection of corrosion – the detection level on average is approximately 59%, although the dogs make very few mistakes (on average less than 3%). Combining the results of several dogs, the sensitivity increased without a huge loss

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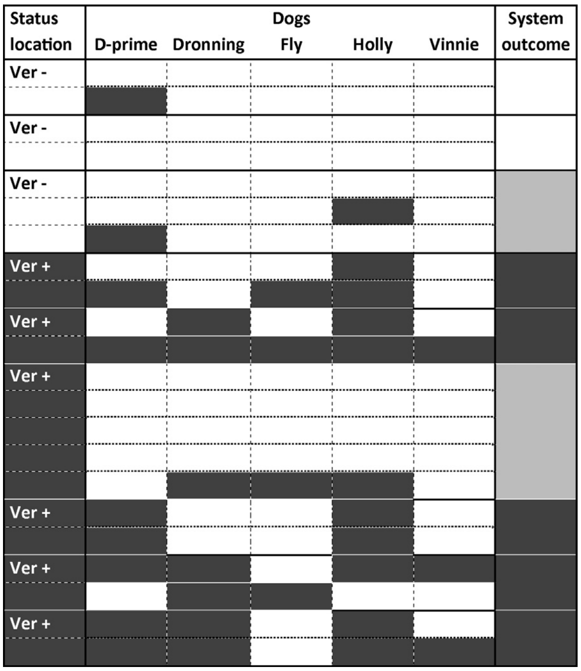

Status location	Dogs					System outcome
	D-prime	Dronning	Fly	Holly	Vinnie	
Ver -	□	□	□	□	□	□
	■	□	□	□	□	
Ver -	□	□	□	□	□	□
	□	□	□	□	□	
Ver -	□	□	□	□	□	▒
	□	□	□	■	□	
	■	□	□	□	□	
Ver +	□	□	□	■	□	■
	■	□	■	■	□	
Ver +	□	■	□	■	□	■
	■	■	■	■	■	
Ver +	□	□	□	□	□	▒
	□	□	□	□	□	
	□	□	□	□	□	
	□	□	□	□	□	
	□	■	■	■	□	
Ver +	■	□	□	■	□	■
	■	□	□	■	□	
Ver +	■	■	□	■	■	■
	□	■	■	□	□	
Ver +	■	■	□	■	□	■
	■	■	□	■	■	

Fig. 6. Comparison of the results of individual dogs and a system approach on samples collected from three verified clean locations (Ver -, white) and six verified corroded locations (Ver+, dark grey). Individual dogs indicated (grey) or not (white) on a sample. In a system approach, the results of 5 dogs on at least two samples per location have been combined: 10% or less hits is white: no expectation of corrosion; between 10 and 40% hits is light grey: low expectation of corrosion, 40% or above is dark grey: high expectation of corrosion.

of specificity. This was the result of variability amongst the dogs – some dogs detected some samples while others did not – and this variability between the dogs merits further attention.

The variability in the results of individual dogs on the same stimuli has been shown to be a result of training on compound stimuli. In experiments where dogs were trained on target odours that were a mixture of different components, individual dogs picked out different components as controlling stimuli. Williams et al. (1998) trained 4 dogs to detect C4, a military explosive consisting of about 90% RDX. RDX has a very low vapour pressure and is usually not found in the vapour phase, which is dominated by cyclohexanone, 2-ethyl-1-hexanol, toluene and cyclopentane. The 4 dogs were trained in the same manner, but each of them responded differently to these individual components. One dog responded to both cyclohexanone and 2-ethyl-1-hexanol in the same way as to C4, one dog only to cyclohexanone, the third only to 2-ethyl-1-hexanol, and the fourth did not respond to any of these separate components as if it were C4. The authors concluded that the dogs had developed individual "odour signatures" of C4 during their training.

In other cases, dogs seem to respond to the same volatile component. This was described by Lorenzo et al. (2003), who found that 5 out of 6 drug detection dogs trained on ecstasy, responded equally well to piporenal, a dominant component in its vapour phase. The variability in results could be reduced if the chemical analysis had identified volatiles characteristic to corrosion as found in mineral wool. Training on these characteristic products first, before introducing the full, rather variable odour picture, could direct the dogs to pay attention to a consistently present signal and reduce variability. Unfortunately, the chemical analysis was not able to identify such characteristic volatiles. Corrosion in itself is a complicated and continuous process that finally results in what we see, which makes identifying such a characteristic volatile component difficult. Although the analysis program was adapted, we were not really able to resolve many of the peaks (=chemicals) especially in the retention window between 8 and 10 min. It can therefore not be exclude that within this window a suitable marker substance might be hidden. For improved resolution of these peaks we suggest two-dimensional gas chromatography, a technique we did not have available.

The variability between the individual dogs can also be seen with respect to their response levels. Vinnie and Fly could be considered conservative in their response: a low hit rate, but also a low FA rate. The other dogs, notably Holly

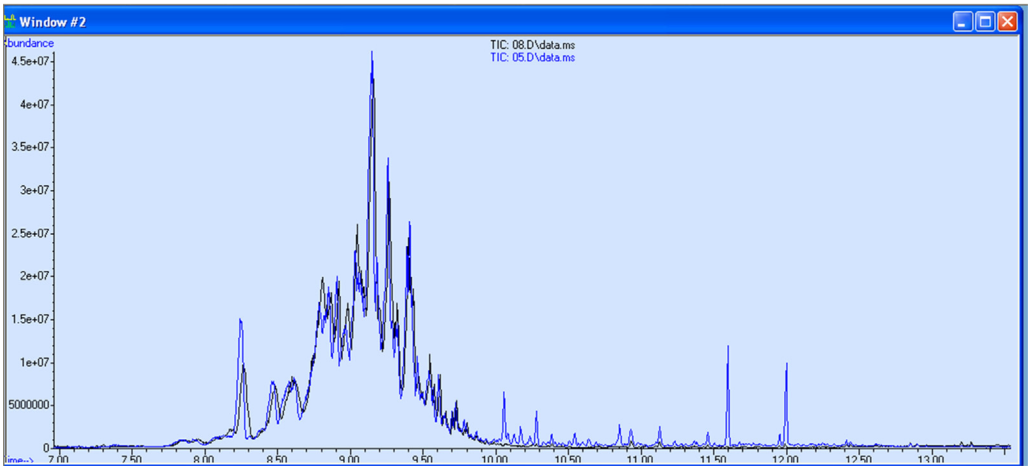

Fig. 7. Example of extraction results of a control and a positive sample.

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and D-prime, were much more liberal in their response as can be seen in a higher hit rate and a higher FA rate. This difference may be the result of different odour signatures that the dogs had developed. The results of Vinnie and Fly can be explained by their responding to a very specific signal, while Holly and D-prime respond to a much wider signal. But this variability can also be the result of personality differences between the dogs that are expressed in how easily they make decisions. Vinnie and Fly can then be seen as dogs that are more cautious, and only indicate when absolutely sure, while Holly and D-prime can be described as more willing to explore, and indicate more quickly to find out if this also leads to a reward. Personality differences between many animals are being investigated, and are of particular interest in working dogs (e.g. Svartberg, 2002).

For further use, a system approach where a number of samples are analysed by a number of dogs seems to offer flexibility of use, allowing a choice between a highly sensitive, or a highly specific system. In a follow-up project this will need to be worked out in more detail. The dogs have been trained to detect corrosion on mineral wool, but other types of insulation are also used. There is no reason to think the system will not work for other types of material, but the dogs will require re-training. Another question that has not been answered yet is how far a sampling point can be from really dangerously active corrosion where the dogs can still detect it. On the sampling side, work is being continued to develop a sampler that can be used in a standalone manner, so without having to use the high pressure supply in the plants. This will increase flexibility of use.

Routine sampling and analysis by dogs will work best if integrated into the plant maintenance system. Using their results to prioritize areas to open up for a general visual inspection can be linked to collecting samples for training, closing the circle from training on lab samples to training on field samples with a known status to field samples from areas under inspection.

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