CATALYTIC COMBUSTION SENSORS FOR LEAK DETECTION

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Introduction

Catalytic combustion sensors are widely used in the Gas Utility Industry, and more generally in industrial safety instruments, to detect and quantify potentially flammable atmospheres. Current instruments use a catalytic bead or “pellistor”, first introduced in the early 1960’s, with a highly dispersed noble metal catalyst on a porous ceramic substrate, usually alumina (1).

Catalytic sensors are generally employed in sensing natural gas and other combustible gases in the range of approximately 100ppm (0.2% LEL in the case of CH_4) to about the lower explosive limit, 5% gas in the case of CH_4. The lower limit is fixed by the discriminating ability of the sensor over various sources of noise and drift. The upper limit is set by ignition of the gas mixture and consequent general heating of the space within a flame arrester enclosure. These limits are, of course, suitable for the purposes of the instruments that employ them, that is, for assessing and monitoring atmospheres for safety. However, there is a need in the Gas Utility industry for extending the lower limit to a few ppm and thereby making possible leak surveys, either by vehicle or on foot, with an intrinsically safe instrument which can also be used for bar holing.

According to Section 192.723 of the Code of Federal Regulations, surface gas detection surveys are to be carried out at ground level over and adjacent to buried gas facilities with a gas detector capable of detecting a concentration of gas in air of 50ppm (2). When the piping is under pavement, surveys at curb lines and at ground openings (manholes, catch basins, and utilities openings) are usually carried out. Instruments used for leak surveys utilize flame ionization, infrared, catalytic combustion, semiconductor, or thermal conductivity sensors (3). This paper describes a leak survey instrument based on specially designed catalytic combustion sensors intended for both outdoor and indoor surveys.

The Gas-Rover™

The lower limit of a catalytic sensor depends on several factors: the ratio of the signal to the power required to maintain a sensor at its operating temperature; the accuracy of the electronics for control and measurement; the noise level, both thermal and electronic; thermal and electronic drift, and the effects of ambient conditions, primarily temperature and humidity. Collectively, these various sources of noise or error are equivalent to the signal generated by about 100ppm of natural gas (methane) and thus define the lower limit for catalytic sensors. A sensitivity of the order of 1ppm methane requires elimination or accurate compensation of these sources of error and noise.

Figure 1. The Gas-Rover™

The effects of ambient conditions (temperature, humidity) are bulk effects in the sense that they affect the medium (air), but not the sensor directly. Since these effects are substantially independent of the surface properties of the sensor, they are subject to compensation by using a pair of pellistor beads (one active, the other inactive) and referring measurements to the inactive pellistor bead. This principle is utilized in most current instruments, though the degree of matching required here is significantly greater than generally employed.

Electronic sources of noise and drift are tractable, even in a hand-held instrument, with modern integrated circuits and other electronic components. We require a precise measurement of 1 μW over a temperature range of about 40°C (5° to 45°C), or, stated differently, a reliable resolution of voltage readings to about 1 part in 100,000. This level of accuracy can be achieved, for example, using XFET (extra implanted function field effect transistors) voltage references which provide low noise, high accuracy, and long-term stability with minimal nonlinearity of the voltage change with temperature, together with low noise, 24-bit analog-to-digital (A/D) counters. Relative values to the required precision are thus attainable.

Thermal drift and natural convection effects are less tractable. Thermal drift arises from a general heating of the sensor cavity when the instrument is in use. A significant part, but not all, of such drift can be compensated by using two pellistors in tandem (see above). The remainder can be minimized by employing pellistors made possible by currently available nanotechniques to maximize response and minimize physical size.

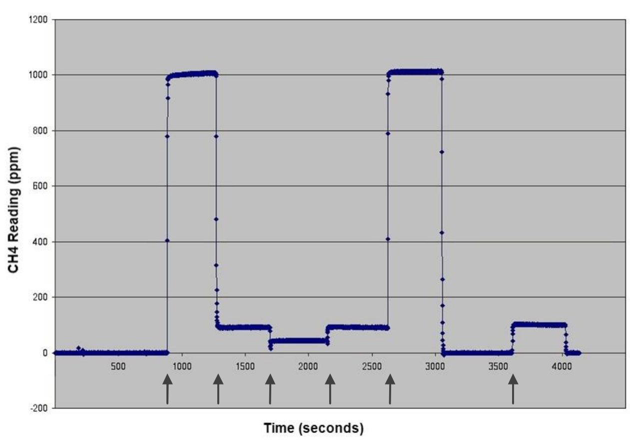

Figure 2. Instrument response to 50ppm, 100ppm and 1000ppm methane, given in random order.

Finally, modern computing based on micro-processors can be used to generate and utilize sophisticated routines for signal processing to screen out effects of thermal noise and drift. Data processing combined with new catalyst structures can yield sensors of the required precision and accuracy.

The performance of sensors constructed in the fashion described above is exemplified in Figs 2 and 3 for methane concentrations up to 1000ppm. Response is linear over this range – in fact, it is linear to at least 25000ppm (50%LEL). The sensor response is reproducible and reversible.

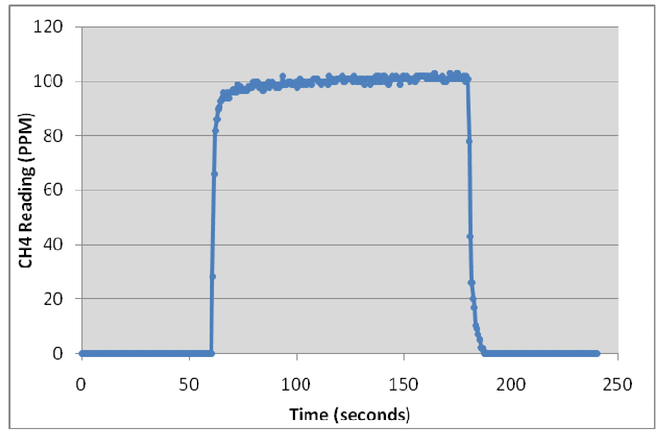

Figure 3. Instrument response to sustained sample of 100ppm methane.

Requirements for Leak Detection

When a catalytic combustion sensor is part of a safe entry detector, the main requirement is an accurate assessment of the safety of the ambient atmosphere over a more or less extended period. Speed of response to ambient transients, if any, is of secondary importance. Typically, a 2 to 5 second response for such instruments is adequate. In leak surveys, on the other hand, all measurements are essentially transient, either because the source (leak) is variable or because the observer is on the move. Accordingly, the ability to respond to brief (0.5 seconds) inputs of natural gas is crucial. It is useful in this connection to make a differentiation between the duration of a pulse of gas and the time that elapses from input to signal. The first is a characteristic of the sensor, the second is determined by the collection system, i.e. the rate of pumping and the "dead" volume that must be swept out before the sample arrives at the sensor. In terms of operating characteristics of the overall instrument, the response to brief pulses of gas is a factor in determining the sensitivity of the instrument, while the elapsed time between input and signal determines the overshoot experienced by the operator, that is, the physical separation in position between source input and first signal.

The actual distance of overshoot is, of course, also dependent on the speed of the operator, for example, whether the operator is on foot or in a vehicle.

Walking Leak Detection

As noted, an operator on foot is expected to test a location for a period of about 0.5s as he moves along a line under test. A well designed catalytic combustion sensor must therefore respond to an input of gas which may last 0.5 seconds.

Fig 4 shows the response to injections of 50ppm gas for 0.5 to 1.5 seconds. There is strong response (>20%) even for a gas sample of only 0.5 seconds. Since the collection system for a walking survey pumps at about 10 cc/s and has a "dead" volume of approximately 7.5 cc, there is an average delay of 0.75s between injection and signal. Although this is a noticeable delay, in actual practice it is without significance in locating a leak whose signal has "just" been picked up.

Leak Survey by Truck

A typical collection system consists of two to four cones pumped at about 35L/min and a collection reservoir having a volume of about 75cc. Typically, the cones are suspended about 2" from the ground and the truck moves at about 10mph. Under these conditions, the sampling flow through the instrument is adjusted to 3 to 5 L/m (85cc/s). With these parameters, timing is approximately the same as for the walking survey – namely, injection times of about 0.5 seconds and detection delays of about 1.0 second. The major difference is dilution of the concentration of the input natural gas which, depending on the actual distribution of the gas emanating from a leak, may range from 2 to 4. However, for any significant leak, the signal is well within the sensitivity of the instrument even after four-fold dilution.

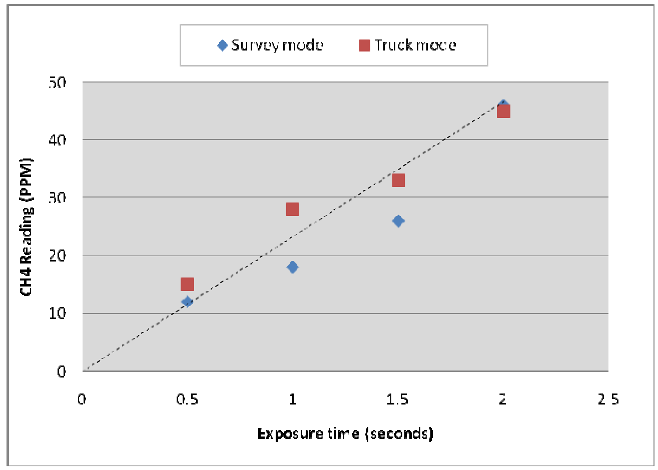

Figure 4. Instrument response to short (0.5 to 2 second) samples of 50ppm methane.

Field Trial

A field trial of the Gas-Rover™ was conducted from February to April 2007 by National Grid (KeySpan Energy). The Gas-Rover™ was compared to a conventional Flame Ionization Detector. As Table 1 shows, the Gas-Rover™ performed as well as an FID.

		Indications: Leaks		Indications: No Leak	
Date	Total Services	FID	Gas-Rover	FID	Gas-Rover
01/30/07	34	0	0	1	0
02/01/07	37	1	1	1	2
02/02/07	33	1	1	1	2
02/07/07	37	0	0	1	2
02/08/07	23	0	0	0	0
02/09/07	37	0	0	2	2
02/13/07	29	0	0	0	0
03/12/07	18	0	0	0	0
03/15/07	15	1	1	0	0
03/21/07	17	1	1	0	0
03/22/07	15	0	1	0	0
04/02/07	55	7	7	1	1
04/03/07	88	1	8	0	0
04/05/07	127	4	3	2	2
04/06/07	144	1	1	3	0
04/09/07	142	4	4	2	2
04/10/07	119	9	9	2	2
04/11/07	61	3	5	0	0
04/18/07	161	2	2	0	0
04/20/07	143	2	2	0	0
04/20/07	175	3	3	1	0
04/23/07	81	4	4	1	0
04/24/07	183	1	1	1	1
04/25/07	141	3	3	1	1
04/26/07	150	2	2	2	2
Total	2065	50	59	22	19

Table 1. Field trial data using an FID and the Gas-Rover™ in parallel in random order. The field trial was conducted by regular utility personnel over three months (February through April 2007).

References

1. A.R. Baker "Combustible Gas Detecting Electrically Heated Element." UK Patent 892530, 1962.
2. CFR Title 99, part 192.
3. ASME Guide for Gas Transmission and Distribution Piping Systems, Appendix G-11, 1986.