Ground Gas Information Sheets

Using purge and recovery tests in ground gas risk assessment
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Using purge and recovery tests in ground gas risk assessment

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Purge and recovery tests involve removing gas from a monitoring well and recording the recovery in gas concentration immediately afterwards. The tests were often used in the early 1990s to assess gas emission rates, but were replaced by direct flow rate measurement from boreholes once accurate flow meters with a low detection limit became available. They are still used by some but BS8576: 2013 recommends that the tests (which it refers to as recharge tests) are not used to replace flow rate measurements. This is because there are concerns over the accuracy of the results, which need careful interpretation and can give misleading indications of gas risk in certain situations. This paper identifies the situations where the results are likely to be reliable or unreliable. It describes how the results in appropriate situations can be used to determine diffusion coefficients for use in detailed gas risk assessment.

Introduction

Purge and recovery tests (PRT) involve removing gas from a monitoring well and recording the rise in gas concentration immediately afterwards (Boult et al, 2011). The tests are referred to as recharge tests in BS8576: 2013 and recirculation tests in CIRIA C665 and earlier CIRIA reports. The tests were often used in the early 1990s to assess gas emissions from the ground (Godson and Witherington, 1996). Once accurate flow meters with low limits of detection became available the tests stopped being used by most companies involved in landfill and ground gas investigations. They started being used again by a few companies when continuous monitoring became more widely available (Boult et al, 2011) mainly because the continuous monitoring equipment at that time could not measure flow rates. However, the completion of purge and recovery tests (which are typically only completed once in a borehole) is not consistent with the ethos of continuous monitoring, whereby the primary purpose of this data collection technique is to obtain a high frequency data set instead of relying on the perceived limitation of spot-monitoring.

Citation: Wilsons S, Card GB and Lavery R (2019). Using purge and recovery tests in ground gas risk assessment. Ground Gas Information Sheet No 6. EPG Limited.

Despite the use of continuous monitoring equipment, the limitations with the tests still remain. This Ground Gas Information Sheet explains the issues that need to be considered when looking at the results from these tests. It outlines when the tests can be useful, how to use the results to determine diffusion coefficients and advises when the results are likely to be unreliable.

PRT and permeability tests

Purge and recovery tests were originally described by Godson and Witherington (1996). Boult et al (2011) and Talbot and Card (2019) suggest that the tests are analogous to rising head permeability tests. However, there are key differences between the tests that means they are not the same at all.

The PRT involves injecting nitrogen gas into the pipe of a monitoring well until the air/gas in the well is displaced (Boult et al suggest a volume of nitrogen that is three times the well volume). However, it does not matter how many volumes of nitrogen are used in this process, it will mainly displace air/gas from the pipe and it cannot be assumed that it has removed any or all gas from the surrounding gravel pack. There is likely to be limited or no removal of gas from the gravel pack and the extent of any removal cannot be confirmed in the field with any level of confidence (Figure 1).

Furthermore, the three volume requirement specified for gas sampling (e.g. Wilson and Haines, 2005) relates to removing three sample volumes by pumping which will draw in gas from the surrounding ground and ensure the gas sample is not stagnant air in the well. Purging with nitrogen is not comparable as it does not draw in gas from the surrounding ground. Therefore, any comparison of the two is invalid.

In a rising head permeability test water in the gravel pack does not make any difference to the test because it will have been removed during drawdown. This is not the case with purge and recovery tests, where gas remaining in the gravel pack can have a significant influence on the results. Another key difference is that in a rising head permeability test there is confidence that water flow from the ground is the only cause of the rising water. In a PRT there could be three sources of gas that cause the recovery of concentrations in the well (Figure 2). The first is the gas remaining in the gravel pack, the second is the gas in the surrounding ground and the third is dissolved gas in groundwater (if groundwater is present).

ACUMEN (2015) suggests that the tests should remove any reservoir of gas in the well. The only way to confirm that this has been achieved in the gravel pack is to repeat the test until the recovery profiles are consistent over three or more tests.

The tests also induce an artificially high concentration gradient over a very short distance which is rarely representative of the gradient to the ground surface. Therefore the tests should not be used to calculate gas flux rates (ie the rate of gas emission) from wells.

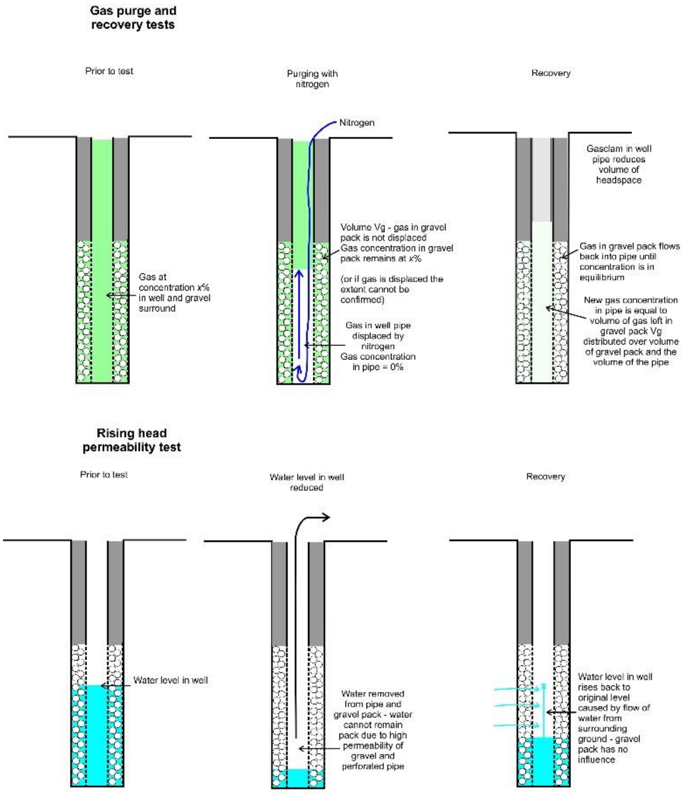

Figure 1 comparison of purge and recover test and rising head permeability test

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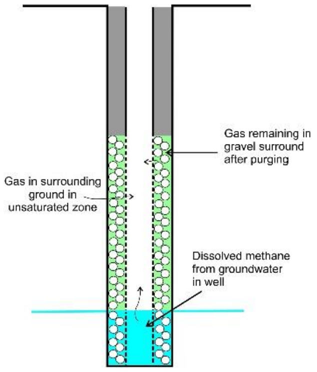

Figure 2 Sources of gas in purge and recovery test

Reliability

CIRIA Report C665 (Wilson et al 2007) suggests that there are concerns about the accuracy of the results of PRT and notes that they were not commonly undertaken at the time that document was prepared (2007). It suggests that the presence of voids in the soil immediately surrounding the well (due to drilling disturbance) cannot be predicted with any confidence and can lead to significant errors in the results (in the same way that gas remaining in the gravel pack does).

A further limitation that was stated in previous guidance (CIIRA 131 – Crowhurst et al) and reinforced in C665 is that the tests should only be used where emission rate is very low or there is no positive flow or pressure in the well.

Nwachukwu (2013) concluded that the reproducibility of purge and recovery tests is questionable with significant variations in test results over three consecutive tests (Figure 3).

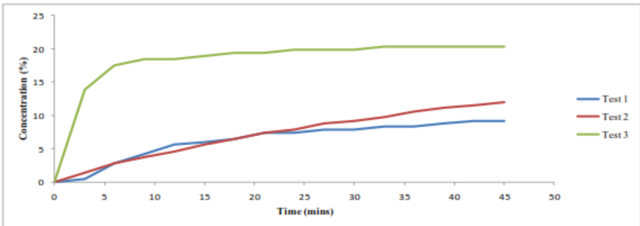

Figure 3 Purge and recovery tests in one borehole – consecutive on same day, Nwachukwu (2013)

CIRIA Report 150 (1995) also states that gross assumptions and sampling error make the results of purge and recovery tests doubtful.

BS8576: 2013 refers to PRT as recharge and recirculation tests. It states that "*There are concerns over the accuracy of this method. In particular, on highly gassing sites, it can underestimate the gas emissions*". It goes on to state "*This method should only be used on sites where there is no flow or positive pressure in the well*. *It should not be used to replace flow rate measurements but may inform a more detailed risk assessment*".

In the right conditions and when carried out in an appropriate manner (see later in this note) the tests may be used to estimate the diffusion coefficient for gas through the ground. The tests should not be used to estimate gas flow out of a well or towards the ground surface.

Influences on test results

There are several factors that can influence the test results.

1. Incomplete purging of the gravel pack;
2. Flooded response zones;
3. Gas concentration prior to test;
4. Minimal gas recovery during the test; and
5. Season.

Each of these has been seen to adversely affect the results of PRTs on numerous sites.

Incomplete purging of gravel pack

Purging using nitrogen will most likely just empty the standpipe of gas and the surrounding gravel pack is not affected (or only minimally). When the gas recovers all that is measured is the concentration in the pipe equalising (through the slots in the pipe) to a concentration that is equal to the gas volume in the gravel pack now occupying the space in the pipe and the gravel pack.

This is demonstrated in the results from consecutive tests by Nwachukwu (2013) that are shown in Figure 4.

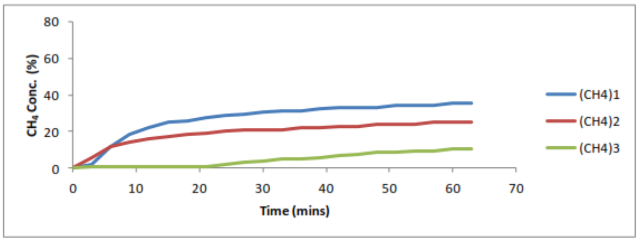

Figure 4 Consecutive purge and recovery tests Nwachukwu (2013)

It was concluded that gas was not being replenished from the source and thus the results cannot be used to calculate flux or diffusion coefficient. This is confirmed by analysis of the results as shown in Table 1. The concentration prior to testing was 40%.

Table 1 Theoretical vs actual recovered gas concentration for results in Figure 4

Test No	Theoretical concentration if gas is equalising from gravel pack (%)	Actual maximum concentration in test (%)
1	29.9	33.3
2	24.9	24.8
3	18.6	10.7

Concentration prior to testing was 40%.

It is impossible to tell whether this effect is influencing the results without repeating each test at least three times consecutively to see whether the recovered concentration is reducing with each test. Single PRTs provide no indication of this at all.

In Figure 5 diffusion has been analysed assuming it occurs from the gravel pack immediately surrounding the well. This is a reasonable fit to the results from the PRT.

The well contained 26% methane prior to the test. The methane recovers to 22% quickly because gas is being driven by diffusion from the surrounding gravel pack. In this case the gas then slowly increased to 26% afterwards.

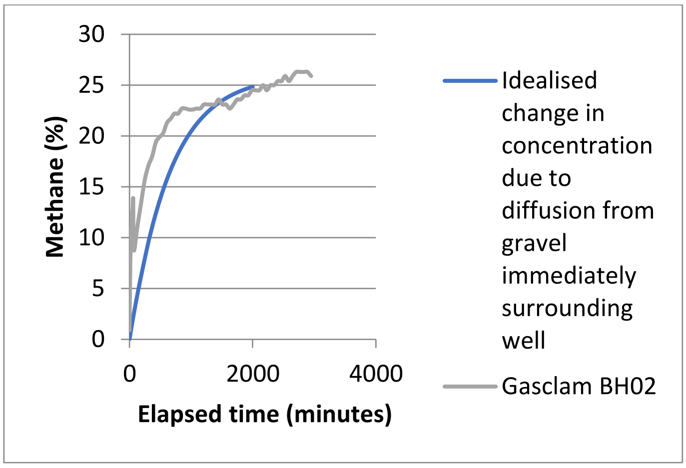

Figure 5 Analysis of gas recovery by diffusion into well from gravel pack

Again, analysis of the concentrations shows a depletion of gas caused by purging the pipe in the first part of the test. The gas concentration then increases rapidly indicating that it has equalised from the gravel surround (theoretical concentration = 20% and actual = 22%). The gas then slowly increases to 26% indicating some contribution from the surrounding ground. However, in this case the test was not repeated three times so the influence of the purging cannot be confirmed and therefore it is not possible to make any inferences about gas flow from the ground around the well.

Flooded response zone

If the well response zone is flooded the result of the PRTs are meaningless as they just measure the recovery of gas from the groundwater into the headspace. This is not normally representative of gas concentrations or flow from the vadose zone of the surrounding ground. Example PRT results from a site where the well response zones were flooded are provided in Table 2. In this situation it is not reasonable to calculate a gas flux based on gas flow from the ground (because it cannot occur). The most likely source of gas is from dissolved methane coming into equilibrium in the headspace.

Table 2 Results from PRT tests in wells with flooded response zones

BH	Test	Calculated methane flux (l/h)	Maximum gas concentration prior to test (%)	Equilibrium CH4 in headpsace from dissolved CH4 in gwater (%)	Max CH4 at end of test (%)
A	1	60.3	93.7	66.3	91.9
	2	58.9			
	3	43.2			
	4	35.4			
B	1	4.9	87.4	92.1	87.7
	2	4.8			
	3	4.6			
	4	4.9			
C	1	15.1	93.6	110.6 (super saturated)	93.6
	2	12			
	3	5.5			
	4	12.1			

It is possible to analyse the PRT plots in a number of ways, all of which are misleading if it is not known that the response zone is flooded. Therefore, it is vital that the results sheets for PRT tests include the response zone depth and the water level at the time of the tests with a warning where the response zone is flooded that the test is invalid (although fundamentally a PRT test should not actually be carried out in these conditions).

The source of the methane for the results in Table 2 is degradation of hydrocarbons present in the groundwater and as expected the water has a high dissolved methane content (as well as other indicators). In this case the tests were repeated three times after the initial test (each test immediately follows the previous). There is clearly a drop in flux with each test in BH A and in BH C, although the latter recovers on the fourth test. This suggests that the reservoir of dissolved gas in the water is limited or that the dissolved gas in the initial tests is from the surface of the water body and with each test the gas is migrating from deeper in the water body so equilibrium takes longer (diffusion through water is much slower than through air).

The tests were in flooded wells and the gas flux and interpretation of the results did not take account of this. The report on the results suggests that:

- The PRT results can be used to calculate a ground gas flux;
- The results can provide information on ground gas behaviour, gas reservoir and gas generation rates; and
- That rapid recovery during the test can indicate either high generation or the presence of a pressurised reservoir of gas is held within the pore space and voids of the vadose zone.

It is difficult to see how any of these points are credible when the response zone is flooded and the headspace is isolated from the vadose zone in the surrounding soil. This demonstrates how important it is to undertake site specific assessment of the results. Without this they can give misleading indicators of gas risk. In particular rapid recovery can occur from dissolved methane in groundwater which is not likely to pose a risk to any overlying development.

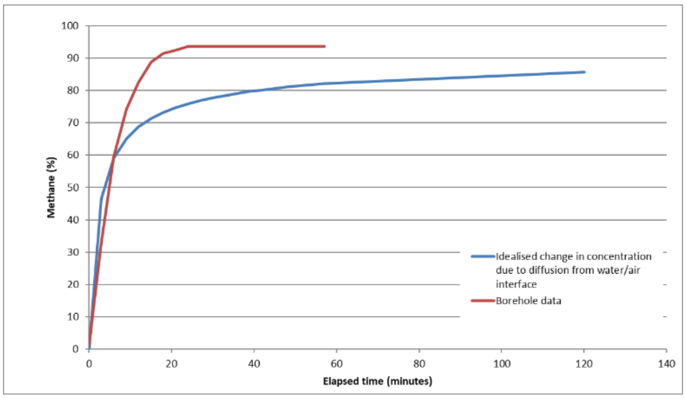

Figure 6 Comparison of test result to predicted recharge from groundwater

Figure 6 compares the results of a PRT with the theoretical diffusion from the groundwater interface into the well headspace. There is close agreement in the early part of the graph. The divergence between the actual and idealised concentration in the later part of the graph is because the analysis for the idealised concentration assumes diffusion occurs to a distant boundary where the gas concentration is zero, whereas in the actual test the headspace is sealed.

Minimal gas recovery during the test

To provide a valid result the gas concentration in the test must rise above the error limits of the instrument. For example for an instrument which has a resolution of 0.5% and an accuracy of +/- 2%, results such as those in Figure 7 (in which there is only a very small increase in concentration) should not be used to calculate a gas flux, especially as it is not clear that an equilibrium has been achieved.

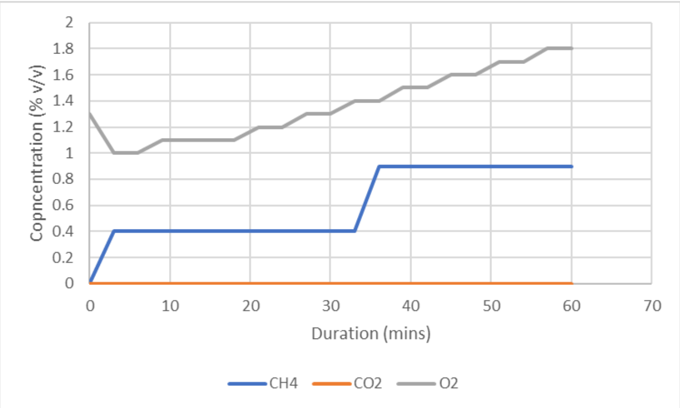

Figure 7 Limited increase in methane concentration during PRT

The data presented in Figure 7 is not a robust indicator of methane flux from the ground, especially as the well is again flooded. It is also interesting to note that there is no increase in carbon dioxide. This suggests that any gas in the well is not from biogenic gas that is migrating into the well via the vadose zone.

A similar concern is present with the results in Figure 8 where a gas flux was calculated for an increase in carbon dioxide of just 0.4% in one step.

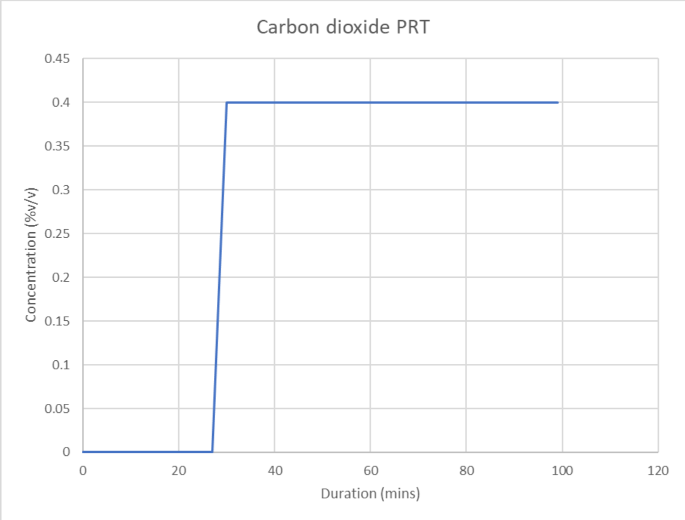

Figure 8 Limited increase in carbon dioxide concentration during PRT

Gas concentration before test

An important requirement in BS8576 is that measurements of gas concentration in the well are made prior to the test. This should be recorded on the results sheet because it is impossible to interpret the tests without it.

Usually gas concentrations measured in a well are variable over time. Using a single PRT test to calculate a gas flux it is the equivalent of taking a single spot flow reading and using this to assess a site, which industry would typically considered to be pretty unacceptable.

If the gas concentration is variable and it is not recorded before the PRT then it is impossible to interpret the test results. Without the preceding gas concentration it is not known whether the slow recovery in concentration during the test is because of a lack of gas or because of low flow. Therefore, PRT test results should include the gas concentration in the well prior to purging and the tests should be carried out at a time when there is elevated gas in the well.

Variable carbon dioxide concentrations are shown in Figure 9. In this monitoring well the PRT tests was completed when the carbon dioxide prior to the test was less than the detection limit (0.3%), so again the tests is meaningless.

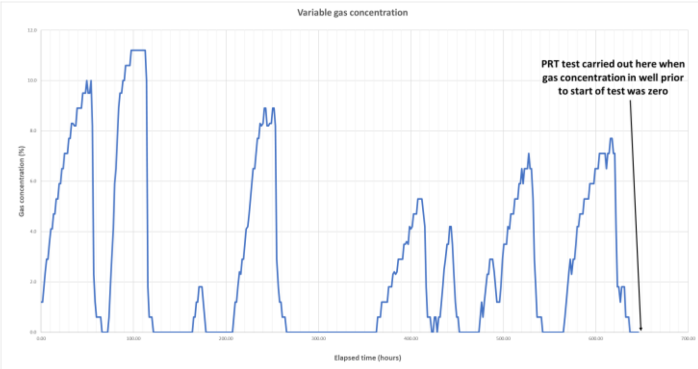

Figure 9 PRT test carried out when there is negligible gas in the well

The flux calculations, not surprisingly, indicated a low flow. The flux calculations would have been completely different when carbon dioxide concentration prior to the test was high. However, analysis of these results and understanding of the site conceptual site model shows that the rise in carbon dioxide is not caused by flow of gas from the ground but because of lack of oxygen ingress from the surface. It is not related to gas generation rates or surface emission rates.

Season

Nwachukwu (2013) reported that the season influences the results from the tests. It was concluded that there is a greater rate of recharge summer>autumn>spring. This may be because of a sealed surface but could equally have been because dissolved methane in shallow groundwater was lower in winter when diluted by rainfall infiltration.

Suggested test method for PRT

Based on the previous discussion if purge and recovery tests are to be used (and the authors very rarely specify them because of the inherent limitations) the following outline method is suggested to help address some of the issues identified.

1. Measure depth to groundwater, depth to base of standpipe and use an interface meter to determine if any free phase product is present (either Light Non Aqueous Phase Liquid or Dense Non Aqueous Phase Liquid);
2. Measure and record gas concentration in well prior to purging (as required in BS8576);
3. Purge well with nitrogen or other inert gas that will not affect the results;
4. Measure recovery of gas in well until it reaches or is close to equilibrium with the prior gas concentration (if equilibrium is not reached it is not a valid test);
5. Repeat the test <u>at least</u> three times <u>and</u> until a consistent recovery is achieved.

Any ingress of gas into the borehole during the test will displace the nitrogen. This initially occurs close to the point of ingress and then the incoming gas will diffuse within the borehole. A further refinement of the test that gives valuable information in this respect is to take measurements within the borehole at three or more different depths. This is achieved by introducing monitoring tubes from the monitor typically at 1m above the base of the borehole (or 1m above the groundwater level where applicable); 1m from the top of the borehole; with the third tube located at the mid-point between the other two tubes. By doing this it is possible to identify areas where the nitrogen is being displaced i.e. where another gas concentration is found to be greater than the nitrogen. This is the point at which ingress can be assumed to be taking place.

Gas concentrations are again logged continuously and the data presented as a simple time series plot showing landfill gas recharge at each of the three horizons over time.

A continuous gas monitor set up to do this is shown in Figure 10 or it can be done with hand held instruments set to data log.

Figure 10 Continuous monitor with manifold to take readings at different depths within a single well

The nitrogen purge of boreholes with this method would require gas readings to be taken from all three levels. Nitrogen is introduced via the lower tube at a steady rate with the borehole cap removed, allowing the borehole to fill with nitrogen and purging all the in-situ gas from the pipe.

Once all three gas readings show 100% nitrogen it can then be assumed that all in-situ gas has been removed from the pipe (but not necessarily the gravel pack), the cap is replaced (or the borehole sealed at the top) and data logging started at all three levels with a reading taken at all three levels every three minutes. This will continue until it is considered that conclusive results are obtained. The test is repeated a minimum of three times and until a consistent recovery is achieved.

When analysing the results of these tests it is important that the volume of any instruments inserted into the well is known. This must be taken account of when calculating the volume of gas accumulating in the headspace.

Determination of diffusion coefficient from PRT results

If none of the interferences described above have been identified and the tests have been repeated at last three times then the results of a PRT can be used to estimate the diffusion coefficient of gas in the ground surrounding the well (Timmen, 2013). Before undertaking such an analysis the following should be confirmed:

- Is the well flooded or nearly flooded;
- Is gas just equalising from the gravel surround to the pipe (need to repeat the test at least three times consecutively);
- Is dissolved methane in groundwater present which could be contributing to the gas concentrations recorded (need to measure dissolved methane);
- Is the gas inflow just at a discrete location at depth that will take time to diffuse up the borehole to the sensor;
- Is there a concentration gradient over the length of the response zone that will affect data interpretation.

Providing that none of the above are applicable the analysis of the results can be completed using Fick's second law of diffusion. The solution for radial flow into a cylinder is:

$$C_t = C_0 e^{\frac{-a^2}{4Dt}}$$

C_t = gas concentration at time t

C_0 = source concentration (i.e. gas concentration in well prior to test)

A = radius to the source of the gas.

D= diffusion coefficient of soil around the well.

t = time.

Even with this method there is some uncertainty as the fit of the curve is dependent on the assumed radius to the gas source.

In the example below (Figure 11) curve fitting has been carried out for a PRT that was completed in a 50mm diameter pipe installed in a 150mm diameter borehole. This gives a diffusion coefficient for carbon dioxide of 3.7 x 10^{-7}m^2/s. This result is in agreement with a diffusion coefficient of 1.8 x 10^{-7}m^2/s obtained by analysis of flux chamber data and the carbon dioxide concentration gradient in the ground at this site (note the concentration gradient is not considered sufficient to have significantly affected the interpretation of the PRT in this particular well).

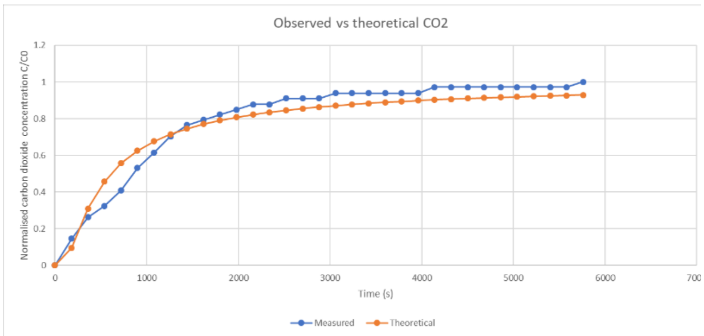

Figure 11 Curve fit for carbon dioxide in a PRT test

Conclusions

There are concerns over the accuracy of purge and recovery tests. They are not appropriate in flooded monitoring wells and there are other factors that can affect the results.

For this reason BS8576: 2013 recommends that the tests (which it refers to as recharge tests) are not used to replace flow rate measurements. PRT tests can give misleading indications of gas risk.

If the conditions in a well are suitable the tests should be repeated at least three times to ensure that the test is not just measuring the recharge of residual gas from the gravel pack around the monitoring standpipe.

Where DQRA is required and modelling of diffusive gas flow from the ground will be completed, the results can be used to estimate diffusion coefficients for the surrounding ground. This is not a typical requirement for most gas risk assessments.

Gas flux rates from the tests are an unreliable indicator of the risk of gas emissions from the ground. Flux rates into the wells should not be used an indicator of gas flow out of the well. The results from PRTs should not be used under any circumstances to calculate Hazardous Gas Flow Rates for use in determining GSVs.

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