Hydraulic Fracture, Gas Seepage and Other Environmental Issues Concerning Shale Gas

E.H. Rutter and S. Boult, School of Earth, Atmospheric and Environmental Sciences, University of Manchester,
Manchester M13 9PL.
Email: e.rutter@manchester.ac.uk; s.boult@manchester.ac.uk

E.H.Rutter

S.Boult

The production of unconventional gas trapped in shales (thermogenic gas, generated from the breakdown of organic matter trapped in the shale when it formed, as a result of heating during progressive burial of the formation) has proved very successful in the United States, leading to substantial reductions in prices to consumers, reduced reliance on imports, and providing essential baseload electricity generation capacity to support renewable but discontinuous energy sources. But this has not been without controversy and environmental problems. The potential development of such resources in other parts of the world must learn from the American experience.

Shale Gas: Occurrence and Exploitation

Unconventional gas has been for millennia trapped in the very small and poorly connected pores spaces and dissolved in organic compounds in shales (mudstones) because such rocks are very impermeable. Unlike conventional gas that is produced from high permeability rocks, tightly held gas will not generally flow to a production well. Gas must be tapped throughout the volume of the reservoir formation. Enhancement of the permeability is generally required by means of extensive hydraulic fracturing (fracking) and gas is extracted through a large number of horizontal boreholes that drain the gas-bearing formation. Fig.1 illustrates the process. Production boreholes are deviated horizontally in several directions (10 or more), radiating outward from a vertical hole, and tapping an area of perhaps 12 km^2 of the shale formation if the horizontal deviation extends for 2 km. By injecting water into a packed-off section of the borehole under a pressure slightly greater than the natural downhole pressure, hydraulic fractures form that propagate away from the hole in a plane normal to the least value of in-situ stress (Figs. 2 and 3). Fractures usually form vertically, because the smallest in situ-stress direction is commonly horizontal. To prevent the crack from closing when the excess water is allowed to flow back, the fluid usually carries a small percentage of sand to act as a prop to keep the crack open and therefore conductive to the gas that flows into it. Other additives to the water (<0.5%) may be a scale inhibitor, biocides (such as are used in swimming pools), pH adjustors, and gelling agents to control viscosity. The mix has been compared to commercial shampoo.

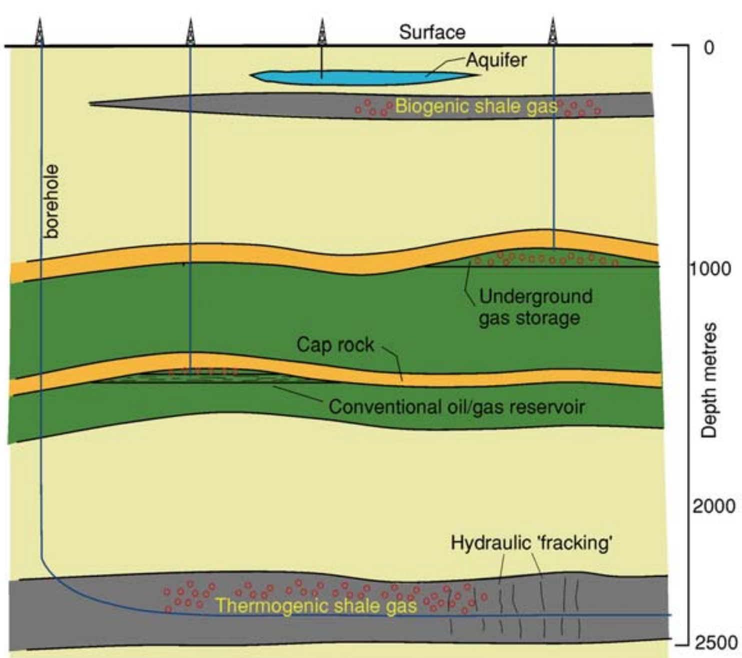

Figure 1: Schematic illustration of spatial relationships in the occurrence and storage of gas underground (vertical cross-section). Differently shaded approximately horizontal bands represent different rock formations. Conventional gas is trapped in porous and permeable layers beneath suitably-shaped impermeable rock bands (cap rock). Thermogenic shale gas is produced from the impermeable formation where it is generated and stored, stimulated by hydraulic fracturing about 2.5 km underground. Conventional gas is usually produced at shallower depths, and imported gas can also be stored at such depths in porous rock formations for later use.

In the early days of the industry, horizontal deviations were shorter; a few hundred metres, therefore the vertical access holes were quite close together, making an enormous environmental impact on the surface. The scale of the activity is illustrated by the fact that Devon Energy has drilled about 5000 producing wells in the Barnett Shale field of northern Texas USA. Such a density (Fig. 3) of surface operations would probably be quite unacceptable in many countries, such as the UK. Drill pad spacing by 4km or more may be essential to acceptance in such countries.

The operation of drilling each site (over about 2 months) may require the availability of 4000 m^3 (a municipal swimming pool) of water for the fracturing process, with satisfactory procedures for handling flowback water. About 100 trucking operations at each site may be required to move water and equipment. Whilst environmental protestors are concerning themselves with the hydrofracking process, a small fraction of the whole industrial activity, the main environmental impact is likely to lie in the scale of surface operations.

Gas seepage

It is essential to minimise leakage into the atmosphere of gas released by hydraulic fracturing, either by upward percolation along pre-existing connected fracture networks or via imperfect casing of the production boreholes. There is an enormous amount of industrial experience of hydraulic fracturing operations (many tens of thousands) acquired over the past half-century,

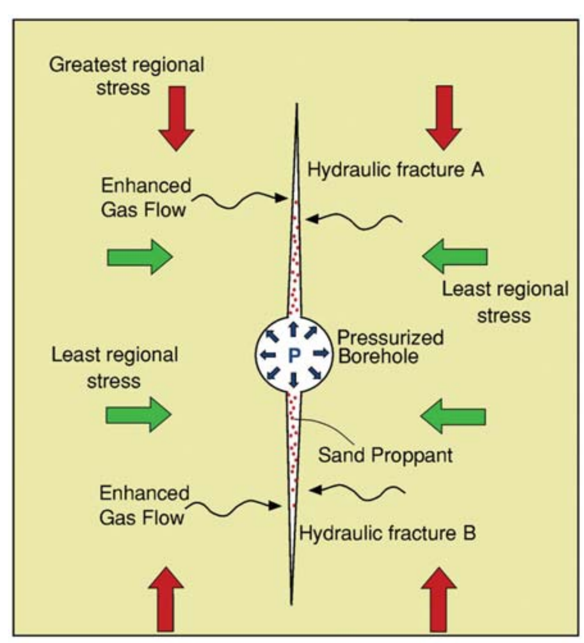

Figure 2: Schematic illustration of hydraulic fracture produced by pressurizing a borehole with water. When fluid pressure P is made to exceed the least regional stress, a pair of hydraulic fractures propagate some metres away from the borehole wall, parallel to the greatest regional stress, increasing the effective cross-sectional area over which gas can flow into the hole from the low permeability shale. A sandy proppant is carried by the fracturing fluid to prevent the crack from closing when the water pressure is reduced to allow the gas to flow out of the pores of the rock.

Figure 3: Hydraulic fractures produced in a laboratory specimen of slate. Fractures parallel to the length of the cylindrical sample (25 mm diameter) are oozing oil. The fractures were produced by injecting pressurised hydraulic oil into the specimen until it split apart on several fracture planes.

therefore with good practice these issues can be managed. A great deal of worry has been voiced that escaping gas or drilling fluid will contaminate aquifers, but it is important to remember that the source regions for shale gas are likely to be 2 km or more below the surface, ten times deeper than typical aquifers. Hydraulic fractures typically do not extend more than tens of metres away from their boreholes, staying within the confines of the gas-producing horizon, therefore upward leakage through the rock formation is very unlikely. Nevertheless, the effective and long term monitoring of gas fluxes will be an essential part of shale gas exploitation.

There is always some natural seepage of hydrocarbon gases out of the ground, and it is essential to establish the natural background gas flux, against which to assess any potential additional flux as a result of hydraulic fracturing or long-term during production operations. This is of particular importance given the potency of methane as an atmospheric greenhouse-gas. Preliminary monitoring was not done prior to the development of US resources, but it can be done before future developments elsewhere.

Until now most commercial monitoring of methane emissions from the ground has been related to predicting risk from fluxes of "ground-gas" produced from buried anthropogenic waste material. A typical example is ground-gas monitoring around active or closed landfill sites, where putrescible material is maintained in an anaerobic environment and therefore ferments to produce methane. Methods and best practice for this type of monitoring are relatively mature, having been established in the UK subsequent to the Loscoe and Abbeystead incidents in the 1980s. These were methane explosions that resulted in loss of life and prompted production of advisory protocols concerning monitoring to assess risk by BRE (Building Research Establishment), CIRIA (Construction Industries Research and Information Association) and the Department of Environment.

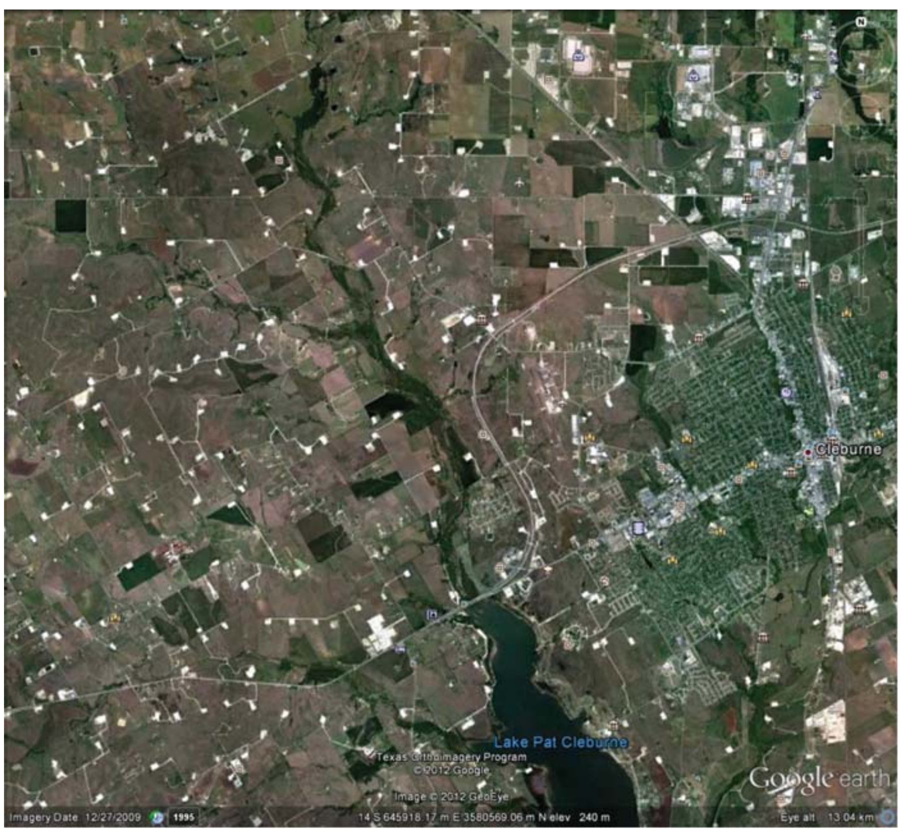

Figure 4: High density of vacated drill pads (light-coloured spots, about 40 m across) near Cleburne, Texas, USA, in the Barnett Shale gas play. Field of view is approximately 5 km across. Google Earth image, reproduced in accordance with Google Fair Use policy.

These guidance protocols called for regular monitoring of gas concentrations on site, generally in boreholes, and resulted in the expansion of the market for portable ground-gas analysers. However, although this guidance on monitoring has been established and the requisite instrumentation is available to fulfil it, wholesale transfer of current technology and methods to monitoring around hydrofracturing sites may not be the optimal solution. This is because progress in understanding the process of ground-gas production and migration means the guidance protocols are subject to continual evolution. Additionally, the guidance has been primarily concerned with quantifying risk of explosion rather than evaluating emissions of greenhouse gas.

The results of ground-gas monitoring as required by the above guidance scheme over the last 30 years has shown that gas concentrations are subject to strong temporal variability. They also demonstrated that the variability is primarily controlled by the fluid movements of the atmosphere and groundwater. These movements are mediated through the subsurface, the permeability of which may itself change spatially and temporally. It is the consequent complicated and time dependent relationship between gas concentration and its controlling factors that makes the determination of worst case concentration difficult and the continual evolution of guidance necessary. Similarly, developing procedures for the determination of worst case concentration and representative average concentrations pre- and post-hydrofracturing must be done with care.

Given the variability of ground-gas concentration, risk assessment has progressed by reliance on the development of specific conceptual site models (CSM). These are a summation of expert judgement integrating all available information, including site-specific history, geology and generic physics of gas migration, in order to predict worst case gas concentration. Gas concentration monitoring programmes have largely been used, therefore, to validate the CSM rather than to define the gas risk directly. However, in managing many large distributed assets, technological advance has improved the quality of monitoring so far as to reduce the requirement for modelling, hence improving ability to predict behaviour. This shift is now also occurring in managing the environment as it is recognised to also be both a large complex system and an asset.

Sensor	Method/type	Range	Resolution
CH_4	Infrared	0-100 % 0-5%	1% of measuring range above 50%, 0.5% below 50%.
CO_2	Infrared	0-100 % 0-5%	1% of measuring range above 50%, 0.5% below 50%.
O_2	Galvanic	0-25 %	0.1 %
CO	Electrochemical	0-1000 PPM	1 PPM
H_2S	Electrochemical	0 – 100 PPM	1 PPM
VOC	PID	0-4,000 PPM	1 PPM
Atm/BH Pressure	Piezoelectric	800 – 1200 mBar	1 mBar
Water depth	Piezoelectric	0 – 25m	0.01 m

Table 1: Gasclam sensor types and specification.

Monitoring Instrumentation

The limitations on the utility of gas concentration survey data have tended to arise from low temporal resolution – typically measurements every fortnight. Increased temporal resolution in monitoring of ground-gas concentration can reduce the error associated with both quantification of worst case and representative average concentration. If sampling frequency is high enough to match the rate of change of the main controlling variable – atmospheric pressure – then the origins of time-dependence can be quantified and prediction of worst case and average concentration can also be improved. Recent developments in availability of instrumentation have made the collection of high temporal resolution ground-gas concentration data possible at much reduced cost, and this approach has begun to be adopted in ground-gas risk assessment. The expansion in the gas monitoring instrumentation market with requirements for GHG greenhouse gas emission auditing, whether for monitoring around fracturing operations or the corollary of carbon sequestration and storage, is likely to be filled by equipment capable of high temporal resolution monitoring.

Figure 5: Cutaway diagram showing major components of Gasclam and method of installation.

Unmanned operation is necessary for high temporal resolution data collection and the device must be protected from theft or interference and water ingress. The Gasclam (Figs. 5 and 6), is currently the only device with these capabilities. It fits within the secure environment of a

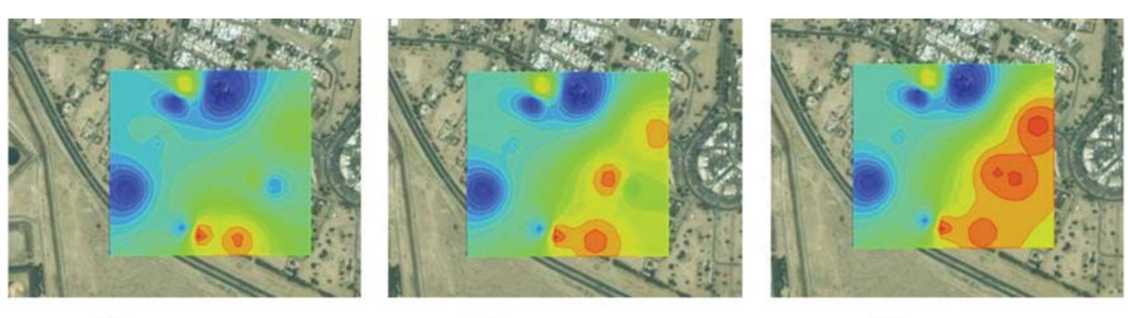

Figure 6: Examples of high temporal and spatial resolution gas concentration data collected by gasclam..

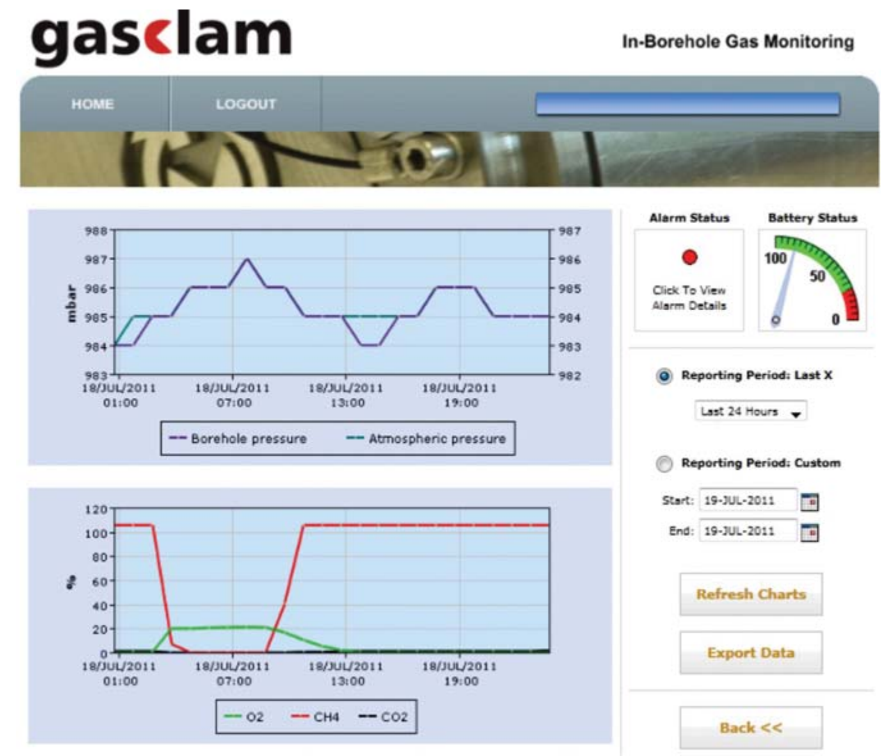

Figure 7: Website interface to Gasclam M2M telemetry showing test data from prior 24 hours and indicating whether an alarm condition has been breached (http://www.salamander-group.co.uk/).

standard 50mm borehole; only possible since miniature infra-red (IR) sensors became widely available 8 years ago. The drawn-in gas must be dry for the IR sensors to work correctly. The separation of water from the gas sample and protection of the instrument from water ingress during the sampling sequence is achieved via the software and valve control system. A critical design constraint met in Gasclam is that of ATEX (Explosive Atmosphere Testing) and IECex (Equipment for use in Explosive Atmospheres) certification as the device may be installed in a hazardous area.

In addition to measuring the bulk components of ground-gas, Gasclam also contains a standard VOC sorbent tube and photoionisation detector (PID) that provides a measurement of aggregate volatile organic carbon (VOC) concentration (Table 1). This capability is useful in many contaminated land investigations and may also be relevant to monitoring around fracturing if the fluids used contain any VOC's. Given the capability automatically to collect high temporal resolution gas concentration data, telemetry (Fig. 7) is necessary because operational benefits can accrue from frequent status updates from multiple monitoring points, as there may be around fracturing operations in large gas fields.

Application in the UK – and earth tremors

The collection of high resolution gas concentration data has over the last 3 years started to become recognised as best practice for certain sites requiring ground-gas risk assessment. Whilst Gasclams have been sold worldwide for this purpose, they are also presently being used by the company currently undertaking the only shale gas exploration in the UK, to monitor their own operations. These same operations near Blackpool, England, at a depth of 2000 m during year 2010 triggered some small earth tremors that were felt (about magnitude 2.5). These cause a great deal of alarm to local people and led to temporary suspension of drilling and hydraulic fracture operations whilst investigations were carried out. Induced earth tremors are not caused by drilling and are very rarely caused by hydraulic fracturing operations. Induced seismicity requires unusual local circumstances such that pressurized fluid can be injected along accessible, favourably-oriented conductive cracks or faults so that they slip in response to the local stress field. Fluid cannot penetrate more than a few tens of metres along such faults, and this limits the size of induced tremors to a level unlikely to cause surface damage. The hydraulic conductivity of shear-oriented cracks also is much less than the opening-mode (hydraulically-induced) tensile cracks that form preferentially, because the resolved normal stress across a shear-oriented crack (tending to close the crack) is larger than across a tensile crack. However, the experience of these hydraulically-induced small tremors is likely to lead to the adoption of measures to minimise the risk of inducing them in future.

Conclusion

Exploitation of shale gas must be seen as a highly intensive industrial process involving advanced technologies that is always likely to impact significantly upon the local environment and communities, sometimes adversely but also through positive effects on local economies. Effective engagement, regulation and application of best practice to all stages of the process are essential to earn and maintain the confidence of the affected populace.