Continuous monitoring system for soil gas migration in leaking Oil and Gas wells

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Abstract. The cost of repairing leaking Oil and Gas wells is of major concern for operators and regulatory authorities. After each intervention is completed, the success of repair attempt is measured at surface by various devices. The current monitoring procedure is recognized as labour intensive, requiring field personnel to physically travel to wellsite and manually measure gas concentration levels with expensive hand-held instrumentation. Due to complex nature of surface casing vent flow and gas migration mechanisms, continuous monitoring with a real-time data access is a new paradigm for analyzing the repair success. This article presents a cost-effective and efficient system prototype for continuously monitoring surface casing vent flow and gas migration of methane concentration levels.

1. Introduction

Current trend in the upstream Oil and Gas is aging and deterioration of infrastructure created by industry during more than 100 years. Unwanted gas and/or liquid flows to surface either between the surface/production casing annulus or outside the surface casing are a serious liability in the development and production of oil and gas [1]. Based on the mechanism of migration, there are three types of leaks – internal, surface casing vent flow (SCVF) and soil gas migration (GM, see figure1 and figure 2).

Internal leaking often occurs due to failed casing, well completions or cement plugs. It typically creates a pressure inside the production casing. SCVF is commonly encountered in the oil and gas industry and is variously referred to as sustained annular pressure, sustained casing pressure, annular gas pressure, casing vent flow or annular gas flow. This condition exists when gas enters the exterior production casing annulus from a source formation below the surface casing shoe and flows to surface or builds gas pressure at surface. Soil gas migration (GM) occurs when gas migrates outside of the cemented surface casing. Soil gas migration can be caused by deep gas from formations below the surface casing shoe migrating upwards past the surface casing shoe. This leakage may be caused by poor surface casing cement, or fracturing of cement or rock at the surface casing shoe due to overpressuring. Gas migration may also occur from shallow gas accumulations located above the surface casing shoe leaking through poorly cemented surface casing [2].

A good understanding of the geology penetrated by the wellbore is essential in order to assess all potential gas bearing reservoirs that may be contributing to the problem. In complex scenarios, there could be gas movement between adjacent wells due to primary cementing issues that permit uphole horizons to be invaded. Natural gas and liquids negotiate their journey to surface due to the lack of
integrity of the cement between the production casing and the openhole/surface casing. It is a complex combination of inadequate bond of cement to casing, lack of bond of cement to the openhole interface plus discontinuities within the cement. Also, for wells in which cement returns to surface have not been achieved during the primary cementing operations of the casing string an obvious ability for this problem to precipitate exists. Mature fields are especially vulnerable as the cementing practices during their development were inadequate [1]. However, even the most sophisticated drilling and primary cementing technologies and practices still leave a significant chance for wellbore integrity issues at any given time of the well existence. The industry is confronted with a significant challenge to understand and remediate these scenarios.

In order to understand the magnitude of the problem it would be necessary to look at the total number of wells drilled by industry. Access to this data is often difficult or completely unavailable for some countries. However, there are countries where data transparency is a crucial component of public trust and such data is publicly available as a collaboration between industry and regulatory authorities. For example, in 2017, Western Canada had over 600,000 wells that were owned by more than 600 Oil and Gas operators. According to the study conducted by the Alberta Energy Regulator in 2011 – 2013, on average 10% of abandoned wells are leaking. In addition, approximately 6% of active and inactive wells have reported SCVF or GM issues [4].

The repair and monitoring of these situations is a non-revenue generating exercise with the potential to reach significant expenditures. As result, there is an emerging need for cost-effective technologies in relation to decommissioning and repair of Oil and Gas wells around the globe.

2. Environmental impact

There were many technological developments and enhancements in the Oil and Gas industry since the first well was drilled in 1859. With a constant goal of making hydrocarbon recovery more cost-effective, industry developed many great tools and technologies to help improving exploration, drilling and production operations. However, plug and abandonment (P&A) techniques, remediating well integrity issues, fundamentally did not change for decades. In majority of P&A operations today cement is still considered to be a primary barrier. The hypothesis that industry operates under is once cement plugs were properly placed, it will maintain its integrity indefinitely. However, number of consistent operational incidents of leaking Oil and Gas wells every year, studies conducted by the Alberta Energy Regulator, as well as learnings about the longevity of infrastructure in civil engineering really question the validity of this hypothesis. As the infrastructure ages, its elements and materials deteriorate, new effective and reliable technological solutions are required to mitigate the potential for future catastrophic environmental impact from Oil and Gas industry.
2.1. Greenhouse emissions
Methane gas is an air pollutant and a global warming contributor. Global warming is recognized as a serious worldwide challenge. According to one recent study, there are an estimated 3 million abandoned oil and gas wells throughout the United States alone. Methane emissions from these wells are assumed to be the second largest potential contribution to total US methane emissions above US Environmental Protection Agency estimates and are not included in any emissions inventory. There is a lack of empirical studies that can be used to estimate the methane emission potential of these wells [5].

2.2. Contamination of fresh water aquifers
Fresh drinking water aquifers penetrated by Oil and Gas wells are exposed to a risk of being contaminated by various contaminants (natural gas from formations, oil, drilling fluids, disposal and storage well chemicals, etc.). All wells, including fully abandoned, can provide pathways for contaminating groundwater supplies or to travel up to the surface. If the useable water aquifers are present and gas migration has been confirmed at surface coming from the source below the depth of the aquifer, it is safe to conclude that this aquifer is contaminated (see figure 2). As result, fresh water wells drilled into the same aquifer and located in a short proximity from the leaking Oil and Gas wells must be tested for contamination, and potentially completely decommissioned.

2.3. People safety
Methane is non-toxic and creates no hazard when inhaled in limited quantities; however, if large quantities of natural gas or methane is allowed to displace air, lack of oxygen may result in suffocation. Methane also can be flammable when mixed with air in certain concentrations (4.5 percent to 15 percent) and considered to be a major fire hazard. If introduced into confined spaces or household water systems, presence of methane could force evacuation of homes. These risks create certain limitations on land development and construction work in a proximity to any existing Oil and Gas well.

Figure 2. SCVF and GM in operating and abandoned wells (A – operating well, B – abandoned well).
3. Methodology of detecting gas migration issues

In simple terms, gas migration is a flow of gas that is detectable at surface outside of the outermost casing string. To test a well for gas migration, a series of boreholes no larger than 64 mm in diameter are strategically drilled around the outermost casing string and a “Lower Explosives Level” meter is utilized to recognize the presence of natural gas. Testing can only be conducted during frost free conditions and avoiding periods immediately after a rainfall. Most gas migration scenarios can be addressed at the time of well abandonment unless there is a fire, public safety or environment concern associated with the gas migration situation.

There are two ways to measure gas migration - single point or short time measurement (completed in one day), and continuous or prolonged measurement (over few weeks or months).

Single point measurement is represented by a number of instruments. Large size operators often complete such testing by using an in-house professionally trained personnel.

According to Provincial regulations in Western Canada there is a minimum number of sample testing points [6, 7]:

- Two within 30 cm of wellbore on opposite sides
- At two-meter intervals outward from the wellbore every 90° (a cross with the wellbore at center) to a distance of six meters and
- At any points within 75 meters of the wellbore where there is apparent vegetation stress

Regulations also describe a minimum required equipment for successful gas migration testing:

- Bar or auger (64 mm or less in diameter) capable of penetrating a minimum of 50 cm
- Calibrated monitor or other instrument capable of detecting hydrocarbon at one percent lower explosive limit (LEL)
- Equipment or material to seal the hole at surface while soil gases are being evacuated from the soil through the instrument

Once all the preparations completed, the following testing procedure is prescribed:

1) Perform instrument check (for example, calibration, voltage, zero)
2) Insert auger or make a bar hole a minimum of 50 cm deep
3) Isolate the hole from atmospheric contaminations
4) Insert hose, wand, or other equipment a minimum of 30 cm into hole, maintaining a seal at surface to prevent atmospheric gas and soil gas mixing
5) Withdraw soil gas sample. The volume, rate, etc., will depend on the instrumentation being used.

Ensure that a sufficient sample is removed to purge lines and instrumentation
6) Record observations
7) Purge instrument and lines

If less than full scale readings are obtained, the soil horizon must be examined to ensure that readings are not the result of contaminated solids due to spills of diesel fuel, solvents, oil, etc. If contaminated soils are suspected, the soil must be excavated and removed. Retesting is then required. Instrumentation must be calibrated regularly and checked daily when in use.

Conventionally, gas migration testing was performed using a combustible gas indicator (CGI) or explosion meter, or in some cases using a flame ionization detector (FID). With a significant improvement in infrared technology, gas migration is mostly measured with Portable Methane Detectors (PMD) equipped with pump and suction cap. There are examples of autonomous greenhouse gas measurement systems for analysis of gas migration on landfill sites [8, 9]. However, no continuous measurement solution is currently available for leaking Oil and Gas wells, the proposed in this article system is designed to address this technological gap.

4. Continuous monitoring system for gas migration

Designed continuous monitoring system is engineered to deliver three key pieces of information about the leaking well in a real-time mode:
Surface casing vent flow measurements (Pressure, Temperature, Gas flow rate, Gas concentration (ppm for CH₄, CO, CO₂, H₂S), Fluid volume per day) with gas and fluid sampling lines for chemical and isotope laboratory analysis;

Gas migration measurements (CH₄ concentration in ppm and % LEL with a gas sampling line for chemical and isotope laboratory analysis);

Wellsite image (live HD camera feed, picture per day archived) to monitor vegetation distress at location.

System has a data protection from internet connectivity issues and records both offline and online, and with unit power (combination of solar power panel and accumulator battery) sustaining autonomous operating time without maintenance for 6 months, it allows utilizing it in very remote locations.

Field testing of a gas migration continuous monitoring system prototype (gas migration meter) is described below.

4.1. System Configuration

System configuration is presented on figure 3. Gas migration meter consists of 49 samplers (or ground probes) connected to concentration measurement system. Sampler is a mechanical element that consists of perforated stainless steel tube and handheld valve for gas sampling outlet.
Each testing point where ground probe is installed provides a continuous measurement of CH₄ concentration (ppm, and %LEL). Measurement range for CH₄ is:

- 0 - 100% LEL ± 5% of reading or ± 2% LEL
- 0 - 50,000 ppm ± 50 ppm or ± 5% of reading

Each ground probe is equipped with a gas sampling line (and has the ability to bypass it) for plastic/metal containers for chemical and isotope laboratory analysis of evacuated gases.

Concentration measurement system is equipped with filtered infrared spectroscopy technology sensors for measuring gas concentration. This laser technology is widely used for methane leak detection, and provides high effectiveness, short response time, high accuracy in a range of 1 ppm to 100 % vol. gas, and high selectivity with respect to the target gas.

Gas migration meter shares power supply and electronics with surface casing vent flow positive displacement meter and video surveillance units constructed in the same housing.

System is connected to online cloud based central data hub and also has an offline wellsite data storage. Field internet access is obtained via regular wireless cellular 3G/4G networks.

Proprietary software was developed to collect, process and present the data from all 49 testing points (see figure 4). Software also allows to record GIS visualization results in motion format for more efficient visual analysis of remediation success.

![Figure 4. Gas migration continuous monitoring dashboard.](image)

4.2. Field Testing

Testing of the gas migration meter was conducted in a period from late spring to mid fall of 2018. As a test object a leaking gas well was chosen located in Kazakhstan.

Before a deployment of the system all sensors were tested and calibrated in laboratory conditions. All 49 probes were installed as it shown on figure 3. Sampling frequency was set to one measurement (all 49 testing points) every 30 minutes. Gas sampling was also conducted in a rain-free days for chemical composition and isotope analysis.

When physically present at the wellsite for gas sampling, all 49 testing point readings were verified with a hand-held portable methane detector calibrated each time before the test.

Collected gas samples were processed in laboratory conditions within 24 hours from the sampling time with gas chromatography and carbon isotope analysis [10]. Elevated levels of methane measured by gas migration meter were confirmed to be of thermogenic nature (see figure 5) originating from a deep formation source downhole.
5. Conclusions
Gas migration meter prototype was successfully realized and validated as platform for real time monitoring of leaking Oil and Gas wells. Gas migration meter measures in-soil methane concentrations in 48 points strategically located within 6 meter radius around the wellhead, and background in-soil methane concentration measured 25 meters away from the wellhead.

Key advantages of the designed continuous monitoring system is data consistency, GIS visualization in motion for the entire monitoring period, and higher quality information in comparison to manual sampling process. Thus, utilizing gas migration meter reduces the risk of missing events and possibilities for human operator error. Also, higher sampling frequency, provides a source of new environmental information about the dynamics of leaking well gas migration mechanisms, and ultimately leads to a better, more effective remediation work.

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Figure 5. C$_2$+ and methane concentration in gas samples.
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