Evaluation of the Potential for Gas and CO_2 Leakage Along Wellbores

Implementation of carbon dioxide (CO_2) storage in geological media requires proper assessment of the risk of CO_2 leakage from storage sites. Leakage pathways may exist through and along wellbores that penetrate or are near the storage site. One method of assessing the potential for CO_2 leakage is by mining databases that usually reside with regulatory agencies.

Introduction

CO_2-injection schemes have been in operation since as early as the 1970s for tertiary oil recovery as miscible floods, with the indirect benefit of CO_2 removal from the atmosphere. Other gas-injection schemes also are used in the oil and gas industry, such as natural-gas storage and acid-gas disposal. In the case of CO_2 sequestration, the storage unit must be almost leak free to the atmosphere or other geological formations to meet safety requirements and greenhouse-gas-reduction objectives. The full-length paper focuses on human-created leakage paths—in particular, abandoned wellbores that were drilled for oil and gas exploration and production. The analysis is based on data collected by the Alberta Energy and Utilities Board (EUB) for more than 315,000 wells drilled until the end of 2004 in the province of Alberta, Canada. EUB also records well leakage at the surface as surface-casing vent flow (SCVF) through wellbore annuli and gas migration (GM) outside casing.

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Background

Abandonment Methods. ***Wells Drilled and Abandoned.*** For a typical openhole abandoment scenario in Alberta, regulations require that any porous zone be isolated or covered to prevent crossflow between geological formations. In addition, useable groundwater must be covered with cement and isolated from potential hydrocarbon-bearing zones. After the downhole cement plugs have been set, the well must remain open for inspection for a minimum of 5 days. After this time, the well is checked for static fluid level or other indications of plug leakage before the casing can be cut and capped below grade level.

Wells Drilled, Cased, Completed, and Abandoned. There are three main types of zonal isolation and abandonment for a typical cased-hole well after reservoir depletion.

1. Bridge plug capped with cement above perforations.
2. Retainer and cement squeezed into perforations.
3. Cement plug set across perforations.

Regulations since 2003 require zonal isolation behind casing and that useable groundwater be protected. In many cases, older wells were constructed with low annular cement tops, allowing many zones to be in communication behind casing. Under the current regulations, a cement squeeze would be required to achieve isolation before final abandonment.

Wellbores must be abandoned with inhibited fluid inside the casing and be pressure tested to a minimum of 7000 kPa. Before cutting and capping the production and surface casing, the well must be checked for SCVF and GM. If flow is detected, then repair operations to stop the flow must be undertaken before abandonment.

Wells Drilled, Cased, and Abandoned. Wells drilled, cased, and abandoned have requirements similar to wells drilled, cased, completed, and abandoned. SCVF occurs 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. EUB requires that all wells drilled and cased be tested for SCVF within 60 days of drilling-rig release and before final abandonment. Wells that have positive SCVF and exhibit gas-flow rates greater than 300 m^3/d, have liquid-hydrocarbon or saline-water flow, or have stabilized buildup pressures greater than 9.8 kPa/m to the depth of the surface-casing shoe must be repaired immediately. Wells with positive SCVF that fall below these criteria must be checked regularly and reported to EUB, with repair required at the time of abandoment. Regulations require that suface-casing vents remain open to ensure that pressure does not build up against the surface-casing shoe and to allow SCVF monitoring.

Soil GM occurs when gas migrates outside of the cemented surface casing. Soil GM can be caused by deep gas from formations below the surface-casing shoe migrating upward 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 because of overpressuring. GM also can occur from shallow gas accumulations located above the surface-casing shoe leaking through poorly cemented surface casing.

GM testing is required in Alberta in a special test area. EUB designated this

*For a limited time, the full-length paper is available free to SPE members at **www.spe.org/jpt**. The paper has not been peer reviewed.*

area for testing because of field observations of high GM occurrence compared with other areas of the province. In this area, GM testing is required within 60 days of drilling-rig release and also before final abandonment. Many operators conduct this test as part of their due diligence when abandoning a well anywhere in the province.

Data Mining

EUB collects well and production data from industry on a routine basis, and this information is readily available to the public. It includes data on wellbore construction and production such as casing size and weight, borehole depth, completion intervals, production and abandonment method, stimulation, gas composition, and geological formations. This information is available in electronic format and was the database used to evaluate wellbore-leakage potential. In addition, EUB maintains information about SCVF, soil GM, casing failures, and nonroutine abandonment. Details within this data set, which is not publicly available, include SCVF/GM source depth, pressure, fluid type, detection date, and repair information. Casing-failure information includes failure depth and mechanism, along with detection method and date. Nonroutine-abandonment information includes reported openhole plug failures, re-entry information, and other special abandonment requests and approvals. This information was used to provide a baseline of known wellbore leakage against which to evaluate potential indicators.

Historical documents within the archives of EUB were reviewed to determine regulatory changes that may have affected the potential for wellbore leakage. The archives also were used to develop an electronic data table of historical primary-cementing requirements. Actual annular-cement-top information was not available in the existing electronic information, and the historical regulated requirement was used as a default for the cement top in the wellbore. The historical oil price, obtained from public sources and expressed in constant USD, was used as an indicator of the level of economic activity that could have affected drilling, well-completion, and abandonment practices.

Casing-inspection logs that indicated both internal and external corrosion were evaluated against cement-bond logs (or equivalent). Data were collected for approximately 500 wells. These wells were selected for analysis on the basis of the existence of both SCVF/GM and casing failure in the same well or of geographic location in fields known to have a high incidence of SCVF/GM or casing failure. Information on casing and cement condition was recorded against a depth register to determine the effects of cementing on casing corrosion. A subset of these wells (142) had adequate data to conduct full evaluations.

Results

Factors showing no apparent effect included well age, well operational mode, completion interval, and H_2S or CO_2 presence in the produced hydrocarbons. Factors showing minor effects were licensee, surface-casing depth, total depth, well density, and topography. Factors showing major effect were geographic area, wellbore deviation, well type, abandonment method, uncemented casing/hole annulus, oil price, regulatory changes, and SCVF/GM testing.

Prediction of Wellbore Leakage

The following factors or well attributes can be used to evaluate the probability of well leakage qualitatively.

1. Is the well cased, or drilled and abandoned? From the information presented, drilled and abandoned wells have a very low occurrence of leakage as documented in the EUB data. Only 0.5% of all drilled and abandoned wells have reported SCVF/GM. Cased wells account for 98% of the SCVF/GM incidence in the EUB data.
2. In Alberta, important regulatory changes went into effect in 1995 requiring testing for SCVF/GM. Was the well abandoned before or after 1995? Wells abandoned after 1995 should exhibit lower probability of leakage because any detected leakage would have been repaired before surface abandonment.
3. Was the well drilled before the introduction of regulatory changes in 1995 in a period of time with high relative oil prices? The information shows a strong correlation between the percentage of wells with leakage and oil price. It is hypothesized that higher oil price led to greater activity with limited equipment and manpower. The only way to increase the number of wells drilled was to drill them faster, potentially leading to substandard cementing practices.
4. Is there a high incidence of SCVF/GM in a particular area? The information presented shows that in a certain area, the wells are more prone to leakage. This may be because of specific conditions relating to geology and shallow gas accumulations in the area, but this requires further investigation.
5. What is the historical cement-top requirement? The information shows that cement absence is possibly the highest predictor of SCVF/GM and casing failure.

Conclusions

1. The majority of leakage occurrence is the result of time-independent mechanical factors controlled during wellbore drilling, construction, or abandonment, mainly cementing. Several of these factors may be inferred from readily available information such as spud date relating to regulation, oil price, and technology.
2. Exposed (uncemented) casing is the main factor in the occurrence of SCVF/GM and casing failure.
3. Good-quality cementing likely will protect wellbores against cement degradation and casing corrosion by reducing contact with formation or injected fluids.
4. Enforced regulations are key in controlling and detecting wellbore leakage from annular flow (SCVF/GM), casing failure, or zonal abandonment failure.
5. Cement-log evaluations indicate that the majority of wellbores are well cemented and zonally isolated in the deeper sections (across economically productive formations) of the wellbore, thus reducing the probability of leakage through casing/openhole annuli from deep uncompleted reservoirs.
6. Deep hydrocarbon reservoirs or saline aquifers that are penetrated by fewer wells should be considered for CO_2 storage to minimize the potential for well-to-well crossflow or vertical wellbore leakage to overlying strata, shallow groundwater aquifers, and possibly to the atmosphere.
7. Abandonment methods should incorporate adequate methods to withstand CO_2 attack, especially where elastomers and steel are the main plugging materials. **JPT**