PRESSURE FALLOFF TESTING GUIDELINE: CLASS-I INDUSTRIAL WASTE INJECTION WELLS[1]

Louisiana Office of Conservation
Injection & Mining Division

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BACKGROUND

On November 20, 1989, the Injection & Mining Division of the Louisiana Office of Conservation promulgated Statewide Order No. 29-N-2 (LAC 43:XVII, Subpart 2). While this set of regulations focuses primarily with establishing new guidelines by which Class-I hazardous waste injection wells are to be administered, it also containes a provision applicable to all Class-I wells; both hazardous and non-hazardous injection wells.

The provision relevant to all Class-I wells is codified as Statewide Order No. 29-N-2, § 209.I.7 (LAC 43:XVII.209.I.7) entitled *Ambient Monitoring*. The specific paragraph of interest being § 209.I.7.a (LAC 43:XVII.209.I.7.a) which requires operators to annually monitor the pressure buildup in the injection interval, including at a minimum, a shut down of the well for a time sufficient to conduct a valid observation of the pressure falloff curve.

Hazardous waste injection well operators which have previously received a "no migration" petition exemption approval to the land disposal restrictions of the Hazardous and Solid Waste Amendments of 1984 from the Environmental Protection Agency Region 6 under 40 CFR Part 148 have already begun meeting this annual monitoring requirement for both the State and Region 6. As part of this petition approval, hazardous waste facilities are required by Region 6 to meet certain conditions including annual monitoring in accordance to 40 CFR 148.20(d)(2). Region 6 has adopted the 40 CFR 146.68(e)(1) requirement for monitoring Class-I hazardous waste disposal wells which is identical to Statewide Order No. 29-N-2 § 209.I.7.a (LAC 43:XVII.209.I.7.a).

PURPOSE OF GUIDELINE

This document is provided for use as a reference for all Class-I operators so as to offer guidance and consistency in the preparation and submission of the annual reservoir monitoring report. The submitted report will consists primarily of a discussion of the falloff test procedure, test data and interpretive results. Finally, the test results and reservoir parameters obtained will be compared with previous tests or conceptually modeled data and results. For hazardous waste well operators having received a federal "no migration" petition exemption, a comparison of reservoir parameters derived from each successive falloff tests will be made with the reservoir parameters of the petition demonstration. This document is intended to provide suggestions and standardization as to the correct performance of injection well falloff testing. In turn, the test results will be used as a means of validating past reservoir modeling and/or petition demonstrations. This guideline may be subject to periodic updates.

FALLOFF TESTING REQUIREMENTS

A falloff test consists of injecting at a constant rate, shutting-in the well, and measuring the pressure falloff. The falloff test should be properly designed so that valid results are obtained. The following thoughts should be carefully considered when planning and/or conducting a falloff test:

1. The injection rate should be held constant throughout the injection (buildup) portion of the test. Small fluctuations due to the design of the injection pump are acceptable provided this can be substantiated. The injection rate should be high enough and for a time period sufficient to produce a pressure buildup which will result in a valid test. *Caution: As with all well work, proper safety precautions should be exerised.* The amount of pressure buildup required will depend largely on the sensitivity of the pressure gauge used and the specific properties of the formation. The injection rate must result in a pressure buildup such that a semilog straight line can be determined from the Horner plot.

2. Bottom hole pressure measurements are more desirable and considered superior to surface pressure measurements. However, surface pressure measurements may be used if it can be shown that a positive pressure was maintained at the surface throughout the falloff portion of the test.

3. If surface pressure measurements are to be used and it is predicted that the injection well will go on vacuum during the test, then a two-rate test should be used in order to maintain a positive pressure. Failure to maintain a positive pressure will result in changing wellbore storage

[1] Adapted from "Pressure Falloff Testing Guideline", US-EPA Region 6, May 22, 1992.

effects making analysis of the test difficult. A relatively high initial rate should be followed by a decreased rate. The pressure decrease resulting from the rate decrease is thus analyzed. Choosing the two rates correctly should result in a positive surface pressure during the falloff portion of the test; thus, interpretation problems resulting from changing wellbore storage effects is eliminated.

4. Properties of the injection fluid as viscosity and density should be held as uniform as possible throughout the test. Use of the facility's normal waste stream as the test fluid is highly desirable provided sufficient fluid volume is available which will sustain a consistent injection rate. The viscosity value applied in evaluating the test should be that of the fluid through which the pressure transients disperse. This is covered in greater length under the heading Treatment of Significant Mobility Ratio Changes. *Caution: The value of fluid viscosity may or may not be that of the injected fluid. Based on the size of the historically injected waste plume (through calculation or other identifiable means), it could be either the viscosity of the historical waste plume or the formation fluid.*

5. No injection into nearby facility wells should occur in the injection interval being tested. Any buildup of pressure in the injection interval being tested due to offset injection well operations should be stabilized prior to testing. Should operational problems prohibit the shutting-in of offset injection wells, the establishment of an injection rate in the offset injection wells which is nearer the planned test rate should be maintained prior to and throughout the test. The injection rates and surface pressures of the offset well(s) should be recorded before and during the test period. This procedure does not guarantee good results. The suggested method is to shut-in all injection communicable zones, although it is realized that this may not be possible in situations where facilities are located close together and utilize the same injection interval.

6. The depth to any fill in the well being tested should be located and recorded with the test data to assist in the determination of the thickness of the injection interval available to flow.

7. The falloff portion of the well test should be run such that ample data points lie well within the infinite acting period and the semilog straight line is well developed.

8. A Horner plot of the data should be submitted; a Miller-Dynes-Hutchinson (MDH) type plot is optional. The straight line segment of the Horner plot should also be reproduced on an enlarged scale so that a closer examination of any data fluctuations can be accomplished. The semilog straight line should be physically drawn on the Horner plots.

9. A log-log plot with a semilog derivative should be furnished to aid in the identification of the end of the wellbore storage period. The end of wellbore storage effects should be identified on both plots.

10. All data including the viscosity determination should be submitted. All equations used in the analysis should be provided with the appropriate parameters substituted into the equations. Any abnormal data fluctuations should be explained. If the falloff test data is determined to be unanalyzable, a new test should be carefully planned and completed to obtain meaningful results.

TREATMENT OF SIGNIFICANT MOBILITY RATIO CHANGES

In those situations in which the viscosity of the historically injected fluids varies significantly from that of the formation fluid, it is not unusual for the resulting mobility ratio $(k/\mu)_w/(k/\mu)_f$ change to be reflected in the falloff plot (the subscripts *'w'* and *'f'* refer to the waste and formation fluid). This may be revealed by a change of slope. The radial flow portion of the derivative curve should also change and level to another value. Negating geologic causes, such as a sealing fault, leads to the interpretation of this change in slope as representing the boundary of multiple fluid banks.

The correct interpretation of this type of Horner plot begins by volumetrically calculating the *radius (r)* of the historical waste plume using Equation 1:

$$r=\sqrt{\frac{0.13368q}{\pi h\Phi}} \qquad (1)$$

where: r = estimated waste front radius, FEET
q = cumulative injection into completed interval only, GALLONS
h = injection interval thickness, FEET
ϕ = porosity, FRACTION
π = pi, ≈ 3.1416

The calculated radius should be used in evaluating the Horner plot to determine whether the viscosity of the waste or formation fluid is appropriate for use in the continuing analysis.

The injection interval thickness value used in the analysis should be justified. Include the value of the depth to the top of any wellbore fill and whether or not the injection interval is composed of hydraulically isolated units (membered sand) or a single massive unit. It may be necessary to define the amount of flow entering the fill or sand(s) in situations where hydraulically isolated injection sands are present. Operators are urged to regularly clean out any wellbore fill in an effort to avoid interpretation problems.

The *radius of investigation* *(r_i)* should be calculated (Equation 2) and compared to the radius of the waste front (Equation 1) so as to determine the predominate fluid through which the pressure transients disperse. *(Lee, J.: Well Testing, Society of Petroleum Engineers of AIME, Dallas (1982), p. 15, Equation 1.47):*

$$r_i = \sqrt{\frac{kt}{948\phi\mu c_t}} \qquad (2)$$

where: r_i = radius of investigation, FEET
k = reservoir permeability, MD
t = time injected, HOURS
ϕ = porosity, FRACTION
c_t = total compressibility, PSI^{-1}
μ = viscosity of fluid, CP

Based on the preceeding calculations, if the pressure transients primarily disperse through the waste plume, the appropriate viscosity to use in the continuing analysis is the viscosity of the historically injected waste. This could be the case for older wells having a long injection history with a large historical waste plume. Conversely, a relatively new well with little or no historical plume development would use the viscosity of the formation fluid. In either case, adequate data and justification must be presented in order that the viscosity of the appropriate fluid at reservoir conditions can be verified.

If sufficient semilog straight line data exists on both sides of the slope change, then the use of the appropriate viscosities should produce approximately the same kh product for both sides of the slope change. If both slopes are analyzable, the kh product should be calculated and compared for both slopes.

APPROPRIATE FLOW RATE

Theoretically, the time required to achieve a particular radius of investigation is independent of flow rate. However, in practice, the flow rate must be large enough such that pressure changes with time can be recorded with sufficient precision to be useful for analysis.

HORNER PLOT ANALYSIS

The time at which the end of wellbore storage occurs should be converted to Horner time. This time approximates the point where the pressure transient has moved beyond the influence of the altered zone near the well and wellbore storage has ceased distorting the pressure falloff test data. At this time the semilog straight line whose slope is related to formation permeability can be observed on the Horner plot. This straight line ordinarily will continue until the radius of investigation reaches a fluid/fluid contact, one or more reservoir boundaries, massive heterogeneities, or runs out of measurable pressure transients.

The *slope of the Horner plot (m)* is used to determine the injection reservoir transmissivity (kh/μ) from the equation:

$$\frac{kh}{\mu} = \frac{162.6qB}{m} \qquad (3)$$

where: k = reservoir permeability, MD
h = interval thickness. FEET
μ = viscosity of fluid, CP
q = injection rate BARRELS/DAY
B = formation volume factor, RVB/STB
m = slope of the Horner plot, dP/CYCLE

The *interval thickness (h)* used in the equation should represent only the formation interval influenced by injection. This value may periodically change. This thickness value may be greater than or less than the actual completed interval or the value used in previous demonstrations or test analysis due to factors as wellbore fill, wellbore damage, or completions that do not correspond to the full thickness of the injection unit interval.

PRESSURE DERIVATIVE ANALYSIS

The pressure derivative curve is a log-log plot of the change in slope of the semilog plot of pressure with respect to time. Although it may be employed for several reasons, such as the detection of the end of the wellbore storage period and the detection of restrictive boundaries, the former case is the only purpose for which this tool will be utilized in the analysis of the annual reports. Either the natural logarithm of time or Horner time may be used. The derivative curve should be presented on a log-log scale with the pressure versus time plot superimposed. The derivative plot accentuates the infinite acting radial flow portion of the test. This allows the start of this period to be readily identified.

Characteristically, the end of the wellbore storage period (and consequently the beginning of the infinite acting radial flow period) can be identified by a flattening out of the derivative curve. The derivative plot allows for a more accurate determination of this time period, as opposed to the customary method of moving one and one-half log cycles past the end of the unit slope line on the log-log plot of the pressure versus time data. The end of wellbore storage effects should be identified on the log-log and derivative plots.

HAZARDOUS WASTE INJECTION WELLS: COMPARISON TO PETITION DATA

This section is pertinent only to operators of Class-I hazardous waste injection wells who have received a Federal "no migration" petition exemption approval to the land disposal restrictions of the Hazardous and Solid Waste Amendments of 1984 to the Resource Conservation and Recovery Act.

A comparison must be made between the results of the current falloff test and the parameters used in the demonstration for the "no migration" petition. In particular, the following must be demonstrated:

1. The bottom hole pressure as determined from the current falloff test should be equal to or less than that predicted by the pressure buildup model of the petition demonstration.

2. The reservoir transmissivity (kh/μ) calculated from the current falloff data is equal to or greater than that employed in the pressure buildup model of the petition demonstration.

3. If in the original petition demonstration, the permeability calculated from falloff testing was used in determining a background reservoir velocity, that petitioned permeability should be compared to the permeability derived from the current falloff test.

NON-HAZARDOUS WASTE INJECTION WELLS: COMPARISON TO PERMIT DATA

This section is applicable only to operators of Class-I non-hazardous waste injection wells who received the Compliance Notice dated January 29, 1992, from the Louisiana Office of Conservation concerning adherence to the ambient monitoring requirements of Statewide Order No. 29-N-2 § 209.I.7 (LAC 43:XVII.209.I.7) as well as those parties becoming owners/operators of Class-I non-hazardous waste injection wells subsequent to that date.

A comparison should be made between the results of the current falloff test, past testing and the injection reservoir parameters used in the disposal well's permit application. At a minimum, the following should be demonstrated:

1. The bottom hole pressure as determined from the current falloff test should be equal to or less than that predicted by the pressure buildup model in the permit application.

2. The reservoir transmissivity (kh/μ) calculated from the current falloff test data is equal to or greater than that employed in the pressure buildup calculation of the permit application.

SUBMISSION OF REPORT TO EPA AND/OR LOUISIANA OFFICE OF CONSERVATION

A detailed report should be submitted to the Louisiana Office of Conservation, Injection & Mining Division and the U.S. Environmental Protection Agency Region 6, which summarizes and compares the results of the falloff test with the parameters used in the "no migration" demonstration (hazardous waste wells) or the permit application (nonhazardous waste wells). The static bottom hole pressure should be below that predicted by the pressure buildup model. The reservoir transmissivity (kh/μ) and permeability values calculated from the falloff test should lie within the range used in the petition and/or permit application. The report should include all raw data, a discussion of the testing procedure, all graphs and calculations, interpretations and conclusions from the test, as well as a comparison of all parameters with those used in the petition demonstration and/or permit application including references where the parameters can be found in the appropriate petition or permit document. For hazardous waste wells, the comparison of parameters should include an evaluation of the impact of parameter changes on the "no migration" demonstration.

For all wells, the report summary should include the following data:

A. FALLOFF TEST DATA

1) PRE-TEST PERIOD
   Date of test (beginning and ending dates),
   Shut-in time prior to test (hours),
   Stabilized pressure and temperature prior to test (psia and °F)
   Cumulative injection into completed interval,
   Wellbore radius,
   Completed interval depth(s),
   Type of completion,
   Depth to fill if any,
   Justified interval thickness,

Average historical waste fluid viscosity,
Formation fluid viscosity,
Porosity,
Total compressibility,
Formation volume factor,
Initial formation bottom hole pressure and temperature.

2) INJECTION PERIOD
Time of injection period (hours),
Type of test fluid,
Injection rate,
Pumps used for test (plant, halliburton, etc.)
Injection fluid viscosity,
Method and time viscosity tested,
Final injection pressure and temperature,
Gauge type (Panex, Amerada, etc),
Gauge sensitivity,
Gauge depth.

3) FALLOFF PERIOD
Total shut-in time (hours),
Final shut-in pressure and temperature.

B. CALCULATED TEST DATA
Distance to waste front,
Radius of investigation,
Time to end of wellbore storage (derivative plot),
Horner time at end of wellbore storage,
Slope or slopes from Horner plot,
Injection reservoir transmissivity (kh/μ),
Permeability (range based on values of h),
Skin.

TIMING OF REPORT SUBMISSION: EPA AND LOUISIANA OFFICE OF CONSERVATION

A. HAZARDOUS WASTE WELLS

The report is due at EPA Region 6 within one year from the date of "no migration" petition approval. It will not be acceptable to have simply completed the testing by the deadline without submission of a complete report. This does not mean that all correspondence or discusions between EPA and the disposal well facility concerning the test must be settled by the deadline; however, a complete report must have been received by EPA. Additionally, the report should be submitted no later than 45 days following the performance of the test.

The deadline for successive reports will be in yearly intervals from the date of the original petition approval and not from the date of the last test. In no case should the time interval between successive tests be less than nine months. This will ensure that the tests be performed at relatively even intervals throughout the duration of the petition approval period. Disposal well operators can, at their discretion, plan these tests to coincide with the performance of their annual State mechanical integrity testing requirements as long as the aforementioned requirements are met.

Failure to submit a complete report by the appropriate date will be considered a violation of one of the conditions of the petition approval and may result in the revocation of the petition approval.

B. NON-HAZARDOUS WASTE WELLS

For Class-I non-hazardous waste disposal wells permitted before November 20, 1989, the initial falloff test should be performed no later than December 31, 1992. If the effective date of the disposal well's permit (Order) is after November 20, 1989, then the requirements of that permit (Order) must be adhered to as it applies to the performance of the falloff test. Each subsequent test should then be performed within one year of the most recent test performance date. However, in no case should the time interval between the performance of successive tests be less than nine months. Tests results should be submitted to the Louisiana Office of Conservation, Injection & Mining Division no later than 60 days from the performance of the test.

REFERENCES

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