MECHANICAL INTEGRITY TESTING (MIT)

EPA Region 6
Brian Graves
(214) 665-7193
graves.brian@epa.gov
(Credits to George Robin, Steve Platt & Chuck Tinsley)
What we protect:

USDWs
(Underground Sources of Drinking Water)

Pronounced:

you wess dee duhyas
Mechanical Integrity (MI)

Part 1
Internal Mechanical Integrity
40 CFR §146.8(a)(1)

Part 2
External Mechanical Integrity
40 CFR §146.8(a)(2)
(a) An injection well has mechanical integrity if:

(Internal)

(1) There is no significant leak in the casing, tubing or packer;

(b) One of the following methods must be used to evaluate the absence of significant leaks under paragraph (a)(1) of this section:

(1) Following an initial pressure test, monitoring of the tubing-casing annulus pressure with sufficient frequency to be representative, as determined by the Director, while maintaining an annulus pressure different from atmospheric pressure measured at the surface;

(2) Pressure test with liquid or gas; or
(3) Records of monitoring showing the absence of significant changes in the relationship between injection pressure and injection flow rate for the following Class II enhanced recovery wells:

(i) Existing wells completed without a packer provided that a pressure test has been performed and the data is available and provided further that one pressure test shall be performed at a time when the well is shut down and if the running of such a test will not cause further loss of significant amounts of oil or gas; or

(ii) Existing wells constructed without a long string casing, but with surface casing which terminates at the base of fresh water provided that local geological and hydrological features allow such construction and provided further that the annular space shall be visually inspected. For these wells, the Director shall prescribe a monitoring program which will verify the absence of significant fluid movement from the injection zone into an USDW.
(a)(2) There is no significant fluid movement into an underground source of drinking water through vertical channels adjacent to the injection well bore.

c) One of the following methods must be used to determine the absence of significant fluid movement under paragraph (a)(2) of this section:

(1) The results of a temperature or noise log; or

(2) For Class II only, cementing records demonstrating the presence of adequate cement to prevent such migration; or

(3) For Class III wells where the nature of the casing precludes the use of the logging techniques prescribed at paragraph (c)(1) of this section, cementing records demonstrating the presence of adequate cement to prevent such migration;
4) For Class III wells where the Director elects to rely on cementing records to demonstrate the absence of significant fluid movement, the monitoring program prescribed by §146.33(b) shall be designed to verify the absence of significant fluid movement.

(Alternative tests)

(d) The Director may allow the use of a test to demonstrate mechanical integrity other than those listed in paragraphs (b) and (c)(2) of this section with the written approval of the Administrator. To obtain approval, the Director shall submit a written request to the Administrator, which shall set forth the proposed test and all technical data supporting its use. The Administrator shall approve the request if it will reliably demonstrate the mechanical integrity of wells for which its use is proposed. Any alternate method approved by the Administrator shall be published in the FEDERAL REGISTER and may be used in all States unless its use is restricted at the time of approval by the Administrator.
(e) In conducting and evaluating the tests enumerated in this section or others to be allowed by the Director, the owner or operator and the Director shall apply methods and standards generally accepted in the industry. When the owner or operator reports the results of mechanical integrity tests to the Director, he shall include a description of the test(s) and the method(s) used. In making his/her evaluation, the Director shall review monitoring and other test data submitted since the previous evaluation.

(f) The Director may require additional or alternative tests if the results presented by the owner or operator under §146.8(e) are not satisfactory to the Director to demonstrate that there is no movement of fluid into or between USDWs resulting from the injection activity.
INTERNAL & EXTERNAL INTEGRITY FAILURE

Casing

Cement

Formation

Leak Hole in Casing

Fluid Movement

Channel in Annulus

Well Bore

Injection Zone

Confining Bed

Injection Fluid
What are our main MI concerns?

1. Any leaks in the system?
What are our main MI concerns?

1. Any leaks in the system?

2. Is injected fluid entering and remaining in the approved interval?
What are our main MI concerns?

1 Any *leaks* in the system?

2 Is injected fluid *entering and remaining* in the approved interval?

3 Is there *crossflow* of fluid into USDWs?
What are our main MI goals?

1. Any leaks in the system?
   
   (Internal MI)

   Goal:
   Prevention of leakage through the “walls” of the well (casing, tubing, etc.)
Prevention of Leakage through the “walls” of the well (casing, tubing, etc.).

How leakage can be discovered:

- pressure tests
INTERNAL MI ANNULUS PRESSURE TEST

- Tests the tubing, casing and packer for leaks.

- Testing requirements vary by well Class and UIC program requirements. These vary by State or Tribe.

- Typically the casing/tubing annulus is pressured to the maximum allowable injection pressure to ensure the casing can withstand this pressure should the tubing or packer fail. Director variances can also be allowed.

- The test length is typically 30 minutes to 1 hour.

- Test failure is typically a pressure loss of > 5 – 10%
January 23, 2018
(Beginning Pressure = 653.20 psi & Ending Pressure = 653.03 psi;
Beginning Temperature = 44.85°F & Ending Temperature = 44.30°F)
Prevention of Leakage through the “walls” of the well (casing, tubing, etc.).

How leakage can be discovered:

• pressure tests

• downhole logging (discussed later)
Prevention of Leakage through the “walls” of the well (casing, tubing, etc.).

How leakage can be discovered:

- pressure tests
- downhole logging
- monitoring of injection activities.
  - Annulus pressure
  - Injection pressure/rate relationship
What are our main MI Goals?

Prevention of Fluid Movement through Casing/Wellbore Annular Space

2 Is injected fluid entering and remaining in the approved interval? (External MI)
What are our main MI Goals?

Prevention of Fluid Movement through Casing/Wellbore Annular Space

2 Is injected fluid **entering and remaining** in the approved interval?
   
   *(External MI)*

3 Is there **crossflow** of fluid into USDWs?
   
   *(External MI)*
What are our main MI Goals?

Prevention of Fluid Movement through Casing/Wellbore Annular Space

Proper cementing and construction
Casing Cementing Operations

- Top plug
- Centralizer
- Bottom plug
- Float collar or landing collar
- Shoe track
- Guide shoe or float shoe

Top plug: Solid core
Bottom plug: Rupture disk, Hollow core
Two-stage Cementing Tools:
(Float Collar, DV tool, and Plugs)
1st - Shut-off Plug (Ends first stage)

2nd - Opening Plug (Opens DV tool)

3rd - Closing Plug (Closes DV tool)

Float Collar near TD

DV tool @ 4000 ft
Centralizers
Cement Bond Log (CBL)
• Cement needs to set properly before a cement integrity log is run. This can take from 10 to 50 hours for typical cement jobs.

• Full compressive strength is reached in 7 to 10 days. The setting time depends on the type of cement, temperature, pressure, and the use of setting accelerants.

• Excess pressure on the casing should be avoided during the curing period so that the cement bond to the pipe is not disturbed.
• Cement bond logs were run as early as 1958 with early sonic logs and the temperature log was used to find the cement top beginning in 1933.

• Cement integrity logs are run to determine the quality of the cement bond to the casing, to evaluate cement fill-up between the casing and the wellbore rock and to evaluate the cement bond to the wellbore rock.

• A poor cement bond may allow unwanted fluids to enter the wellbore or injected fluid to leave the injection interval.
Figure 78. Typical transit times for various media inspection by the cement bond tool (Schlumberger, no date).
Figure 80. Principle of operation of the variable density log (Schlumberger, 1976).
Identification of important features on a variable-density log (VDL) (courtesy of Baker Atlas).
Typical cement-bond log presentation (courtesy of Baker Atlas).
In cases of poor bonding, casing-collar signals may also be identified as "w" patterns (anomalies)
Pressuring the casing improves the acoustic coupling to the formation and the casing signal will decrease and the formation signal will become more obvious.

Field example showing microannulus effect on amplitude and VDL log displays (courtesy of Baker Atlas).
Figure 90. Elimination of a channel by cement squeezing (Walker, 1968).
CEMENT EVALUATION TOOL (CET)
Cement Evaluation Tool
(Courtesy of Schlumberger)
CET
PURPOSE

• SAME AS CEMENT BOND LOG (CBL) ONLY MORE ADVANCED PRINCIPLE

• INVESTIGATES CEMENT RADially

• MEASURES CASING DIAMETER, CASING ROUNDNESS, AND TOOL ECCENTERING
CET
PRINCIPLE OF OPERATION

• ULTRA SONIC ENERGY MAKES CASING RESONATE

• RATE OF DAMPENING IS MEASURED

• RADIAL INVESTIGATION IS ACHIEVED WITH 9 TRANSDUCERS
FACTORS AFFECTING MEASUREMENT

- TYPE OF FLUID IN WELL
- THICKNESS OF CASING WALL
- AMOUNT OF CEMENT BONDED TO CASING
- COMPRESSIVE STRENGTH OF CEMENT
CET EQUIPMENT

• 8 TRANSDUCERS IN HELICAL PATTERN

• 1 TRANSDUCER (MEASURES FLUID SOUND VELOCITY)

• TOOL SIZE = 3-3/8 inches to 4 inches
CET PROCEDURE

• REMOVE TUBING

• ENSURE TOOL IS CENTRALIZED

• LOG ONLY IN LIQUID FILLED CASING

• RUN WITH CASING COLLAR LOCATOR AND GAMMA RAY
CET ADVANTAGES

• RADIAL CEMENT EVALUATION

• CEMENT CHANNEL IDENTIFICATION

• IMMUNE TO MICROANNULUS

• NOT AFFECTED BY “FAST FORMATIONS”

• “EASIER” TO INTERPRET
Temperature, Radioactive Tracer, and Noise Logging for Injection Well Integrity

by

R. M. McKinley
Exxon Production Research

Cooperative Agreement No. CR-818926

Project Officer

Jerry T. Thornhill
Extramural Activities and Assistance Division
Robert S. Kerr Environmental Research Laboratory
Ada, Oklahoma 74820
RADIOACTIVE TRACER SURVEYS (RATS)
RADIOACTIVE TRACER SURVEY PURPOSE

• FLOW PROFILING (volumetric)

• DETERMINE FLUID MIGRATION

  ➢ BOTTOMHOLE CEMENT CHANNELS (Time Drive)

  ➢ CASING, TUBING, PACKER LEAKS (Internal MI)(Slug Chase)
RATS OPERATION PRINCIPLES

- USE RADIOACTIVE IODINE (1/2 life = 8 days)
- EJECT TRACER @ surface or downhole
- FOLLOW TRACER as it travels
- USE GAMMA RAY TOOL as detector
- DETECT MIGRATION OF TRACER through tubing and/or casing
RATS EQUIPMENT

- Radioactive material **EJECTOR**
  Surface or downhole

- 2 or more Gamma Ray **DETECTORS**

- Ejector/Detector **CONFIGURATION** varies depending on objective

- Tool **DIAMETER** as small as 1-1/2 inches
RATS PROCEDURE

- **LOAD TRACER** at surface
- **RUN** tool in tubing or casing
- **RUN BASE LOG** with well on injection
- **EJECT** tracer at or near surface if running in casing
- **EJECT** tracer above the packer if in tubing
- **FOLLOW** tracer to injection zone, while checking for leaks
- **LOG ABOVE PERFORATIONS/SCREEN** for channels outside casing
- Can check **FLOW PROFILE** with Spinner
- Run with **CASING COLLAR LOCATOR**
FACTORS AFFECTING GAMMA-RAY MEASUREMENT

• RADIOACTIVE (HOT) formations
• INJECTION RATE
• Ejector/Detector CONFIGURATION
• PIPE SCALE
SCHEMATIC OF RADIOACTIVE TRACER FOR INJECTION LOGGING
Figure 73. Radioactive tracer tool (Ford, 1962).
Figure 74. Three possible configurations of a radioactive tracer tool (courtesy Schlumberger) (Dewan, 1982).
Slug

Chase
RAT tool typically starts here
Figure 41. Slug-tracking survey from well on injection at 950 BPD
TIME

DRIVES
Leak detected by lower detector

Leak detected by upper detector
Flow Profiles
TEMPERATURE SURVEYS (External MI)
TEMPERATURE SURVEYS

• Oldest of the Production Surveying Instruments (mid 1930s)
  • Mercury/piston
  • Vapor pressure/bourdon type element (Bottomhole temperature measurements)
  • Thermistor – platinum element – resolves temperature changes of 0.05 deg F
    » Analog Logging Units
    » Digital Logging Units
A surface recording, continuous thermometer
Figure 16. Schematic of RDT logging tool (Cooke, 1978).
TEMPERATURE SURVEY
PURPOSE

• LOCATE CEMENT TOPS AFTER PRIMARY CEMENTING (HEAT FROM EXOTHERMIC REACTION)

• FLUID MIGRATION DETERMINATION
  ➢ CASING SHOE BEHIND PIPE
  ➢ TUBING, CASING, PACKER LEAKS
  ➢ INTERFORMATIONAL FLUID FLOW

• FLOW (VOLUMETRIC) PROFILING (RARE)

• IDENTIFICATION OF INTERVALS PRODUCING GAS (COOLING EFFECT FROM EXPANSION)
TEMPERATURE SURVEY
OPERATION PRINCIPLE

• DOWNHOLE TEMPERATURE GOVERNED BY GEOTHERMAL GRADIENT

• INJECTION OF FLUID WITH LARGE TEMPERATURE DIFFERENCE (FROM GRADIENT)

• ZONES (OR LEAKS) TAKING INJECTED FLUIDS WILL RETURN TO GEOTHERMAL GRADIENT AT A SLOWER RATE
• Since cement gives off heat as it cures, the temperature log was used to provide evidence that the well was actually cemented to a level that met expectations. An example is shown at right.

• The top of cement is located where the temperature returns to geothermal gradient.

• The log must be run during the cement curing period as the temperature anomaly will fade with time.
TEMP SURVEY – A BASIC PROCEDURE

• LET WELL **STAND IDLE** AT LEAST 24 HOURS
• RUN “**BASE LOG**” – GEOTHERMAL GRADIENT
• ENSURE INJECTION FLUID **TEMPERATURE IS SIGNIFICANTLY DIFFERENT** FROM BOTTOM-HOLE TEMPERATURE
• START **INJECTION WHILE LOGGING** HOLE (OPTIONAL)
• **SHUT-IN** AFTER PREDETERMINED VOLUME IS INJECTED
• LOG HOLE **AFTER 0, 12, AND 24 HOURS** SHUT-IN
Figure 20. Injecting and shut-in temperature surveys from well on continuous injection at about 500 BPD for almost one year.
Figure 22. Temperature surveys from a well on injection at 960 BPD with flow behind pipe even on shut-in status.
Figure 22. Temperature logs used in locating a casing leak (Peacock, 1965).
NOISE LOG
(External MI)
NOISE LOG PURPOSE

• TO “HEAR” FLUID FLOW OCCURRING INSIDE OR OUTSIDE WELL TUBULARS

✓ BEHIND CASING CHANNELS (water flow pressure drop OR gas thru liquid)

✓ TUBING AND/OR CASING LEAKS
• FLUID TURBULENCE (FLOW) - - - NOISE

• NOISE OCCURS OVER A RANGE OF FREQUENCIES - - TYPICAL TO THE KIND OF FLOW CREATED

– GAS flow upward thru liquid

» Flows in “bubbles” which “ring”
• FLUID TURBULENCE (FLOW) - - - NOISE

• NOISE OCCURS OVER A RANGE OF FREQUENCIES - - TYPICAL TO THE KIND OF FLOW CREATED
  – FLUID turbulence when forced across constriction – pressure drop
NOISE LOG
OPERATION PRINCIPLES

• FLUID TURBULENCE (FLOW) - - - NOISE

• NOISE OCCURS OVER A RANGE OF FREQUENCIES - - TYPICAL TO THE KIND OF FLOW CREATED
  - 200 Hz (cycles per second)
  - 600 Hz
  - 1000 Hz
  - 2000 Hz
NOISE LOG
EQUIPMENT

- TRANSDUCER (converts sound to electrical signal - to be amplified)

- FREQUENCY SEPARATING FILTERS

- SPEAKER (esp. headphones for operator)

- TYPICAL SIZE = 1\(\frac{3}{4}\) inch X 3\(\frac{1}{2}\) feet (as small as 1 inch O.D.)
NOISE  LOG
CHARACTERISTICS
ESSENTIAL TO INTERPRETATION

• **LOUDNESS** - measured levels above ambient... amplitude... on all 4 frequencies
  - severity of the problem

• **CHARACTER** – variation in level on a particular cut from station to station is related to the path of flow
  - how flow is taking place

• **PITCH** – frequency content of sound at a peak in noise level
  - type of flow (single phase or gas thru liquid)
NOISE LOG
OPERATION GUIDELINES

- Logging Sonde takes readings at different depths while STATIONARY.

- Log can be utilized in virtually any DOWNHOLE CONDITION (liquid or gas filled).

- APPLY CRITERIA
NOISE LOG
OPERATION CRITERIA

• Operator consults CONSTRUCTION DETAILS

• WELL SHUT-IN (for behind-pipe flow)

• Record Noise Levels at the 4 FREQUENCIES (200Hz, 600Hz, 1000Hz, 2000Hz)

• MINIMUM READINGS taken opposite the Confining Layer, Base of USDWs and Well Construction changes

• SPACING: readings every 50 to 200 feet (low noise areas); 10 feet or less (zones of interest)

• READING TIMES of 3 or more minutes each
EXAMPLE NOISE LOG PROCEDURE

• PULL TUBING ONLY if necessary

• RUN BASE LOG – well shut-in

• START INJECTION (if necessary to initiate flow)

• RUN NOISE LOG – at same base log stops

• ENSURE TOOL IS STATIONARY at stops

• At ZONES OF INTEREST, perform readings at 10 ft. intervals plus/minus for locating source
Noise (sound) logging sonde with piezoelectric detection elements shown separately.
Figure 24. Typical noise logging tool (Robinson, 1976b).
Noise log from shut-in well with water flow behind pipe @ 5,000 BPD estimated rate
Figure 79. Noise log format with a 20-BPD water flow behind pipe into a gas zone depleted by 250 PSI.
OXYGEN ACTIVATION

TRACER SURVEYS

(OA Logs)

(External MI)
OA LOG
PURPOSE

• Determine presence of
FLUID FLOW BEHIND CASING

• Measure
  ➢ Flow DIRECTION
  ➢ Linear Flow VELOCITY
  ➢ Volume Flow RATE ESTIMATE
  ➢ RADIAL DISTANCE From Tool
OA LOG
PRINCIPLE OF OPERATION

• Similar to **Radioactive Tracer Survey (RATS)**

• **Tracer is CREATED** within the flowing water behind the casing
  - Water behind pipe is bombarded with **ENERGETIC NEUTRONS**
  - **Radioactive Nitrogen Isotope** with half-life of 7 seconds formed when neutrons react with oxygen in water

• **EMMITED GAMMA RAYS** detected by two detectors at different distances
OA LOG

LIMITATIONS

• DEPTH OF INVESTIGATION
  (approximately 12 inches)

• FLUID COMPOSITION
  (must contain Oxygen)

• FLUID VELOCITY
OA LOG EQUIPMENT

- NEUTRON SOURCE
- NEUTRON SHIELD
- 2 GAMMA RAY DETECTORS above source to detect upward flow
- TOOL SIZES
  1-3/4 to 3-5/8 inches X 34 to 26 feet
- COMPUTER ANALYSIS @ surface
OA LOG PROCEDURE

• RUN LOG @ NORMAL INJECTION RATE
• CALIBRATE INSTRUMENT
• RUN BASE GAMMA-RAY LOG
• LOG @ 10 FT. STOPS (5 MIN. EA.)
  START BELOW PERFS (NO FLOW)
  ➢ RELEASE SOURCE
  ➢ READINGS FOR 5 MINUTES
  ➢ REPEAT 10 FEET UP HOLE
OXYGEN ACTIVATION TOOL SCHEMATIC
Figure 31A. Mechanical integrity (near counter) at 2493.6 ft
SAMPLE AVERAGE SPECTRUM FAR COUNTER