

**STANDARD OPERATING PROCEDURES
FOR
BOREHOLE PACKER TESTING**

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STANDARD OPERATING PROCEDURE FOR BOREHOLE PACKER TESTING

1.0 INTRODUCTION

1.1 Scope of Document

This document is to outline various common procedures for operating a wireline packer testing assembly. The document covers the general operating procedures, testing methods, and basic troubleshooting. It is imperative, however, that the tester has sufficient experience working with wireline drilling equipment in order to be able to visualize what is happening during tests and, especially, if problems arise. Numerous difficulties can arise during the drilling and testing process, and so the user is cautioned to make sure they are aware of both the complexity and the potential risks (safety and cost) that can be incurred carrying out these tests.

Furthermore, it is stressed that the operation of the packer system can be hazardous if carried out by inexperienced staff, and therefore proper training and supervision must be carried out for all personnel involved. This is especially true for staff without previous drilling experience.

The final section of the document has a brief discussion of data analysis. However, as this is a very involved topic, we have not included anything more than what is needed to make an appropriate and meaningful interpretation of the data collected.

1.2 Reasons for Packer Testing

Packer tests are carried out to assess the variability of a borehole as it intersects various hydrogeological units. Open hole water levels and pumping tests can give misleading results in such environments. Therefore, packer testing is often utilized to help understand the detailed hydrogeological properties of the various horizons. This knowledge can often be essential to the proper design of the hydrogeological program.

1.3 Types of Test Apparatus

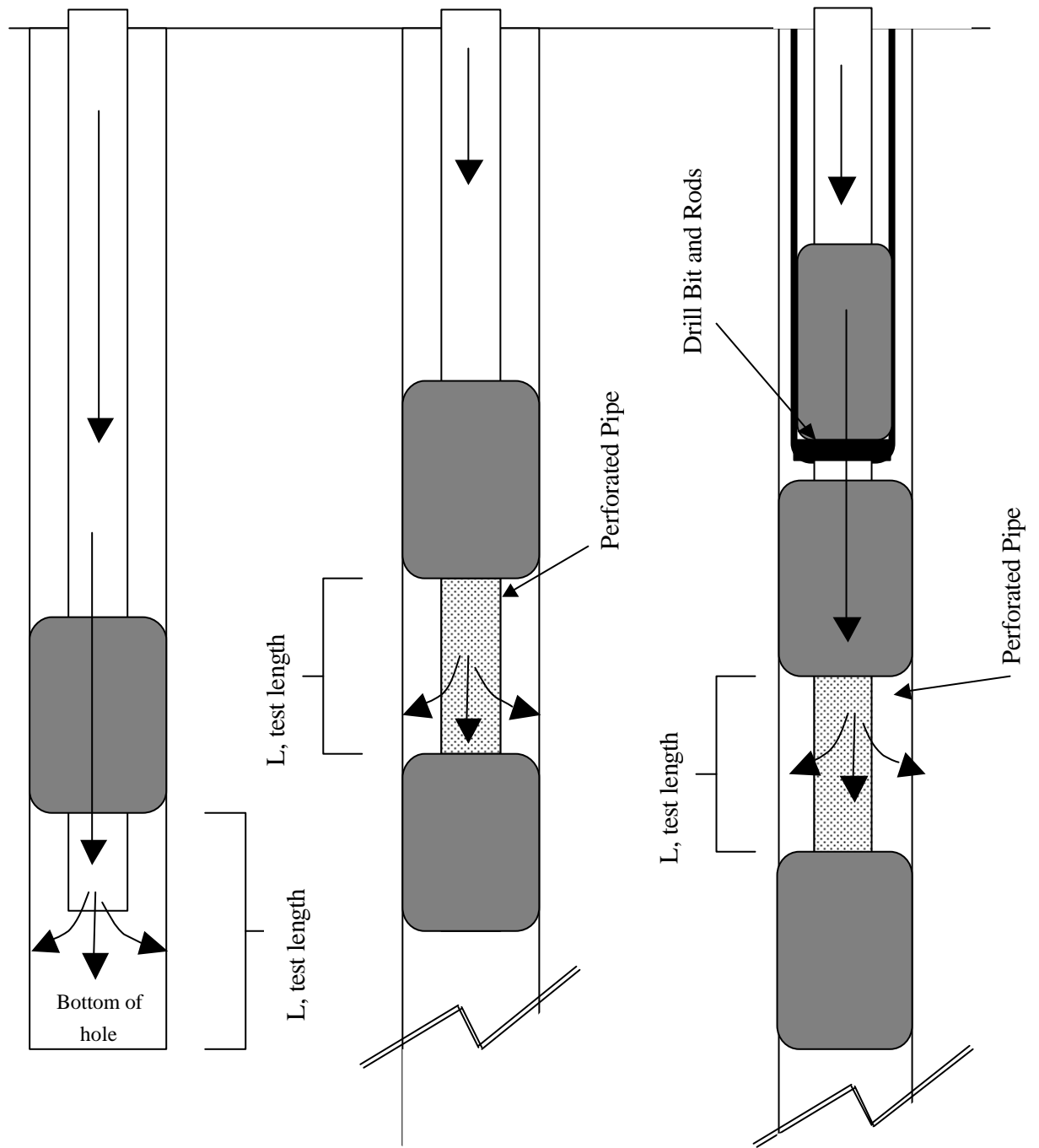
Packer testing is carried out in either open boreholes or through the wireline drilling rods. The latter situation allows for the packer equipment to be used in unstable boreholes where unstable wall rock conditions would likely cause the tool to become jammed by falling rock or sand. It also allows for the drill rods to be used as the test water supply line, thus making it far easier to deal with the equipment involved in deep testing scenarios.

The packer assemblies used in open boreholes and through wireline rods have different configurations. The two types of test apparatus (see Figure 1) are referred to as:

- a) Single Packer tests (Figure 1A); and
- b) Double or straddle packer tests (Figures 1B and 1C).

Both types of tests are carried out in open boreholes and through the wireline drill rods as illustrated.

FIGURE 1: Packer Test Assemblies



1A: Single Packer Test,
Open Borehole

1B: Double Packer Test
Open Borehole

1C: Double Packer Test,
Wireline Assembly

1.4 Types of Tests

Packer tests consist of measuring the rate of flow and/or pressure build-up/decay in the test interval over a period of time. The upper range of hydraulic conductivity that can be measured using packer systems will be limited by the hydraulics of the injection system (rate and pressure output limit of pump, supply line (friction losses), water availability, etc.). Therefore, it is important to determine before finalising equipment what the expected testing range of the zones of interest will be, before starting the testing program.

1.4.1 Injection (Lujeon) Tests

Injection testing methods, otherwise known as Lujeon tests, are carried out in drillholes with static water levels below ground surface. Water is injected at specific pressure “steps” and the resulting pressure is recorded when the flow has reached a quasi-steady state condition.

The steps are used to “ramp” up and down through the expected pressure range. The behaviour of the system to the increasing and recovery injection can render useful information on the rock and fracture behaviour, as well as packer and injection performance. This is discussed further below in Section 5.

1.4.2 Discharge Tests

Discharge tests are carried out in drillholes with flowing artesian conditions. In these drillholes, the natural formation pressure response is monitored after the equilibrated shut-in is allowed to decay with respect to time. The data are plotted logarithmically and analysed using standard Jacob straight line techniques. This will be discussed further below in Section 5.

1.4.3 Shut-In Recovery Tests

Shut-In recovery tests are usually run immediately following a Discharge Test. The shut-in pressure build-up over time is monitored and plotted against $\log_{10}(t/t')$, where t is the time elapsed since the start of the discharge test, and t' is the time since the recovery test was started. This is explained in more detail in Section 5 below.

2.0 EQUIPMENT REQUIRED

The general list of equipment required for carrying out wireline packer testing is given below for an HQ sized wireline system. Any equipment listed as HQ will need to be duplicated as PQ or NQ if using different sized systems. Note that most of the actual packer assembly components are usually made of stainless steel.

Recommended list

(Note: this list may not be fully inclusive and should only be used as a guide)

- 1) HQ size wireline straddle packer unit (2 complete units);
- 2) Spare HQ sized glands (2);
- 3) Spare o-rings for unit;
- 4) HQ sized stuffing box;
- 5) Spare o-rings for stuffing box
- 6) HQ sized seating cone;
- 7) Lifting bail and top supply tube for packer assembly;
- 8) Pipe couplings for connecting packer assembly (with spares);
- 9) Packer End cap (for blocking flow through bottom of straddle packers)
- 10) Double packer set-up will require 1.5m, perforated spacers (5) and 3.0m, perforated spacers (2) in order to test variable length intervals;
- 11) Dampened gauges able to measure L/s or m³ to within 5% accuracy;
- 12) Pump capable of up to 3.75 L/s (50 Igpm) at 120 psi (flow rate and pressure specified may be greater if testing in high permeability environments);
- 13) Require minimum of 2 spares for all glands, gauges, regulators, and meters;
- 14) Regulator (if using gas) or hydraulic packer inflation pump (if using water) and all lines and fittings, capable of maintaining 2000 psi or 500psi pressure respectively;
- 15) Composite inflation line and support cable;
- 16) Reel (motorized if tests planned for greater than 200 m in depth);
- 17) Lifting Sheave or Pulley block for running composite cable through (to be equipped with cable counter if possible).

In addition, equipment must be tested prior to starting program. The following testing criteria are recommended

- 1) All inflation equipment must be pressure tested to 2000 psi (for pneumatic systems) or 500psi pressure (for hydraulic systems);
- 2) All packers must be tested to maximum design pressure;
- 3) Require ability to calibrate friction losses in pumping system and packer system prior to testing;
- 4) Will need to have bypass valves installed before and after the pressure gauge/flow meter assembly in order to control pressure/flow and to protect flow meter from back-pressure;
- 5) Pressure gauges should be calibrated if possible (plumbing in spare gauges and comparing measurements may be only means available on site); and
- 6) Flow gauges should be calibrated using a container of known volume (should exceed 100 L)

3.0 PACKER INFLATION

When packers are inflated downhole, the inflation line pressure is a combination of the pressure required to:

- stretch the packer gland to where it will contact the drillhole wall;
- overcome the hydrostatic pressure (ie: pressure exerted by the overlying water column), and
- inflate it to the working pressure (dependent on the gland).

The inflation pressure will therefore change based on the equipment used and the height of the overlying column of water above the packer. The various aspects of the inflation pressure determination are discussed below.

3.1 Hydraulic vs. Pneumatic - overcoming hydrostatic head

Packers are commonly inflated with compressed gas. Generally, an inert gas such as nitrogen is used for safety reasons (ie: risk of ignition). A disadvantage of compressed gas in deep testing applications is the inherent safety concern of bursting inflation lines or fittings at surface (ie: in close proximity to testing crew) due to the high working pressures required.

Alternatively, for deeper applications, water or hydraulic fluid/antifreeze can be used to inflate the packers. The advantage is that water is essentially inelastic, and so burst lines do not have the same degree of stored potential energy that an elastic gas filled line does. Therefore, burst hydraulic lines pose a lower risk than pneumatic lines. A further advantage to a hydraulic (water) system in deep test situations is that the natural hydrostatic pressure of the water in the inflation line will equal, or exceed (if static water level is below ground surface), that of the adjacent water in the formation, and therefore, the only pressure required is to inflate the packer itself.

It should be noted that both pneumatic and water inflated systems are prone to freezing in cold conditions. Antifreeze or hydraulic fluid can be used to overcome this problem, but may pose an unacceptable environmental risk. Brine solutions can also be used to reduce freezing susceptibility, but this can cause corrosion issues that are just as problematic. Inflation fluids must be assessed for compatibility with the packer gland material as well.

Use of antifreeze or brine solutions could also affect permeability results if interactions with clay gouge in open fractures causes these materials to swell, thus reducing the

apparent permeability of the rock being tested. This can be assessed by inspecting gouge material in the rock core and carrying out surface tests with the expected test fluid.

3.2 Packer Inflation Pressure

The testing unit packers must be inflated to the working pressure to ensure a proper seal. This pressure is normally in the range of 250 psi. As mentioned above, when the packers are inflated downhole, allowances for the hydrostatic pressure (pressure from overlying water column) must also be accounted for.

If the water column is assumed to be approximately 1.4 psi/m of water (based on density of fresh water), then the inflation pressure (gauge pressure at surface) required will be:

$$P_i = P_w + H_{wc} \times 1.4 \text{ psi/m}$$

Where:

P_i = packer inflation pressure

P_w = packer working pressure

H_{wc} = Height (vertical) of water column above packer (adjust for angled holes)

It is important to note that in a drillhole with water levels close to, or at surface, such as in a flowing artesian hole, the water column in the inflation line and in the drillhole will be essentially equal; therefore H_{wc} will be approximately equal to 0 m. This is not the case for pneumatically inflated packers, which require extremely high inflation line pressures, presenting a significant safety and gas usage problem. (Note: in a flowing artesian hole and a 750 m deep test zone, the hydrostatic pressure would be approximately 1050 psi. This inflation line pressure would then need to be increased to approximately 1250 psi to inflate the packers to the required working pressure.).

3.3 Hydraulic vs. Compressed Gas Inflation in Deep Drillholes

3.3.1 Hydraulic Packers - Single vs. Dual Inflate/Deflate Line

In a packer system equipped with hydraulically inflated packers, it is common to have a dual inflate/deflate line. This apparatus allow for water to be pumped down one line when inflating the packer, and allows water to be returned up the second line when deflating the packers. The packer gland, and both the inflate and the deflate line, can also be evacuated using compressed gas to push the water out.

However, for very deep testing systems, the dual inflate/deflate line is prohibitively expensive and bulky. Therefore, a single line cable system is used. This then requires that the single line acts as both the inflation line and the deflation line. For a compressed gas system this does not pose a problem. However, for a hydraulic system, the water in the line can cause unwanted packer inflation as the equipment is lowered and raised in the un-submerged portion of the drillhole if the water level is significantly below ground surface (i.e.: causes enough hydrostatic head in the inflation line to cause flow into the packer gland.)

The water capacity of the inflation line will be of limited capacity, and therefore, will not supply significant inflation fluid. However, it can be enough to distort the packer gland if the depth to water is significant. If water levels are more than 25m below ground surface, the hydraulic packer system should be equipped with an inflation activation valve as part of the inflation line that prevents inflation when lowering the tool into a drillhole where the water level is below ground surface (otherwise hydrostatic level in inflation line would begin to inflate the packers). To prevent this, the pressure valve is set to a predetermined opening pressure (i.e.: 100 psi; equal to ~70m of hydrostatic head) to compensate.

Alternately, it is possible to use compressed gas. However, "pressure compensation" will likely be required in deep tests as the gas filled gland can distort due to the hydrostatic pressure during tripping in and out of the drillhole. This procedure will require that the packer glands to be pressurized during lowering, and depressurized during raising, to compensate for the applied hydrostatic pressure. The line pressure used will be dependent on the hydrostatic pressure (overlying water column height) and will, therefore, need to be calculated based on drillhole conditions, and depth of test, and tested by trial and error. Great care must be taken in the initial tripping in and out as incorrect pressures could cause the tool to jam. This could damage the gland and/or the cable and reel system.

4.0 PACKER TEST – PREPARATION

This section has been written for wireline, hydraulically inflated packer systems, but is similar to pneumatic system operation. Greater care must be taken with pneumatically inflated packers systems; however, due to the elastic energy in the compressed gas and the potential for explosive release if airlines, etc. burst, especially when working in deep drillholes where high operating pressures are required.

The basic steps for preparing for a packer test are outlined below. It is important to make a systematic

- 1) Prepare packer assembly: two packers with open bottom for single test or three packers with perforated middle pipe section and closed cap on the bottom for straddle packer test (see figure 1);
- 2) Check inflation line connecting the packers and fittings – do not over tighten as you might strip the threads;
- 3) Check packer assembly for any leakage. Inflate to maximum gland working pressure in appropriate length and diameter of drill casing or drilling rods;
- 4) Check wire line connectors on packer assembly and stuffing box components (especially seals);
- 5) Prepare and check water feeding system: tank, supply, pump, connection hoses, pressure gauges, valves and flow-meter;
- 6) Design test parameters: depth and length of tested zone, drilling bit depth (double check drillers count of rods in drillhole), position of packers, inflation pressure and water pressure for three stages
- 7) Drill hole preparation: removal of drilling mud and cuttings (flush with clear water);
- 8) Pull rods up to locate drill bit at selected depth;
- 9) Prepare wire line winch;
- 10) Install stuffing box on drill rods;
- 11) Measure groundwater level prior to installing packer system several times to assess static groundwater level (or measure pressure, if flowing artesian, once packer assembly and stuffing box are installed);
- 12) Lift the packer assembly using the wireline and lower to landing ring at drill bit– check if seats on landing ring by "listening" to rods using wrench, etc. If possible, check depth marking on wire line if this has been marked for the expected depth;
- 13) If hole is flowing artesian, install stuffing box seals around wireline and inflation lines – if not, go to step 15;
- 14) Measure shut-in pressure if hole is flowing artesian;

- 15) Inflate packer slowly (by 50 psi steps) until working pressure has been reached. This will require filling to working pressure plus calculated hydrostatic pressure (see below for calculation);
- 16) After inflation is complete, monitor packer inflation line pressure for 2 minutes minimum to see if system is leaking. If no leaks apparent, then;
- 17) Seal stuffing box cap and attach water feed system;
- 18) If flowing artesian conditions exist, wait for pressure to stabilize and record pressure.
- 19) Note: a shut-in test can be carried out during the pressure stabilization (this will be described below);
- 20) Check inflation lines and inflation pressure to ensure no leaks occur, check water feeding system, prepare stop-watch and field test form
- 21) Packer system is now ready for testing.

5.0 PACKER TEST PROCEDURES

Procedures for various packer testing methods are described below. The procedures also include basic analytical procedures that can be applied (supporting equations are referenced in section 7 below).

5.1 Injection (Lugeon) Tests

Injection (Lugeon) tests consist of isolating a section of borehole and injecting water under pressure in to the rock to determine the effective transmissivity (T) of the zone. The transmissivity can be related to the hydraulic conductivity (K) of the rock or hydrogeological features (fractures, etc.) by means of $K = T/L$, where L = length of test zone).

The data recorded during the test simply consists of the flow rate and the corresponding pressure when "steady-state" conditions have been achieved. These data are recorded over a number of increasing and decreasing steps, as explained below.

5.1.1 Test Description

Based on the drill core, an assessment of the expected injection rates and pressure can be made. This will become easier as the testing program proceeds and the tester becomes familiar with the hydrogeological setting.

Observations of flow are made every minute until three consecutive, consistent readings are taken. This should represent steady-state flow. The pressure is then increased, usually for 5 equal increments, followed by 3 decreasing pressures. The steady-state flow at each pressure is recorded.

To begin the test, the tester will need to have an idea of the pressures to be tested (these are referred to as pressure steps A, B, and C below). The expected pressure range will be based on the estimated permeability of the rock and the expected intake of injected water. These will have to be assessed based on previous experience in the drillhole(s), and correlated to the pumping equipment available. If insufficient, or excessive, pressures are used for Pressure A, the test can be extended (more pressure steps for the former) or stopped and restarted for the latter at a lower initial pressure.

It is common practice to "ramp up" over at least three (3) "increasing" steps in the test, and to "ramp back down" two or three decreasing steps (at pressures that match the ramping up pressures). This is done to test for hysteresis in the plotted data. Deviation

from a straight-line match can indicate hydrofracturing (if decreasing data is above the line) or non-Darcian flow (if decreasing data is below the line).

Note that it is assumed that injection losses due to friction losses in the drill rods will not be significant because of the large diameter. Friction losses through the packer assembly flow pipe would be significant, but the short length involved reduces this impact and so it will be ignored in subsequent calculations.

5.1.2 Basic Testing Procedures

Data should be plotted on a flow rate vs. pressure graph, for each pressure step. The shape of the plot, especially with regard to the decreasing pressure curve match, is used to assess the test results. This is described below in the Data Interpretation section (5.1.3).

The test usually consists of 3 to 5 ascending pressure steps, and 2 to 4 recovery pressure steps, as illustrated in the example below.

Pressure Step	Pressure (psi)
A	20
B	40
C	60
D	80
E	100
D _r	80
C _r	60
B _r	40
A _r	20

Note that step “B_r” refers to recovery pressure B, which should equal, or be similar, to ascending pressure step B

Using the expected initial pressure and estimated range of steps as a starting point, the following procedures are followed. If pressures and/or required pumping rates are not as expected, the tester will have to adjust the pressure steps as required.

The basic test procedures are as listed below:

- 1) Open water feeding system valve and maintain constant initial pressure A until it appears to have stabilized (often about 10-15 minutes);
- 2) During this time, record the elapsed time and total volume of consumed water every 0.5 min or so, for the first 2-3 min of the test stage, then every minute;
- 3) After pressure A has stabilized for approximately 3 minutes, increase the pressure to pressure B;
- 4) Record time vs. flow rate as for A
- 5) Increase the pressure, after pressure B has stabilized for approximately 3 minutes, to pressure C;
- 6) Test can be carried out for pressures D and E if the pump system has sufficient range left. The final pump rate should not be more than 80% of the maximum rate if possible;
- 7) Repeat pressure stage B (or last ascending pressure, D or C, if more than 3 steps used in test) – if formation is tight, release pressure by bypass valve on water feeding system to decrease pressure from C to B quickly;
- 8) Repeat pressure stage A – if formation is tight, release pressure by bypass valve on water feeding system to decrease pressure from B to A quickly;
- 9) After repeating stage A, perform recovery test: shut the feed valve and record pressure decrease vs. time for about 10-15 min, or until 90% recovery has occurred;
- 10) Deflate packer assembly and remove stuffing box cap and seal;
- 11) Wait until all nitrogen escapes from the packer cells, wait an additional 5 minutes and then pull the assembly carefully to top of drill rods, watching for the marker flag to prevent pulling assembly into overhead sheave; and
- 12) Measure groundwater level after the test several time to assess level recovery and static level.

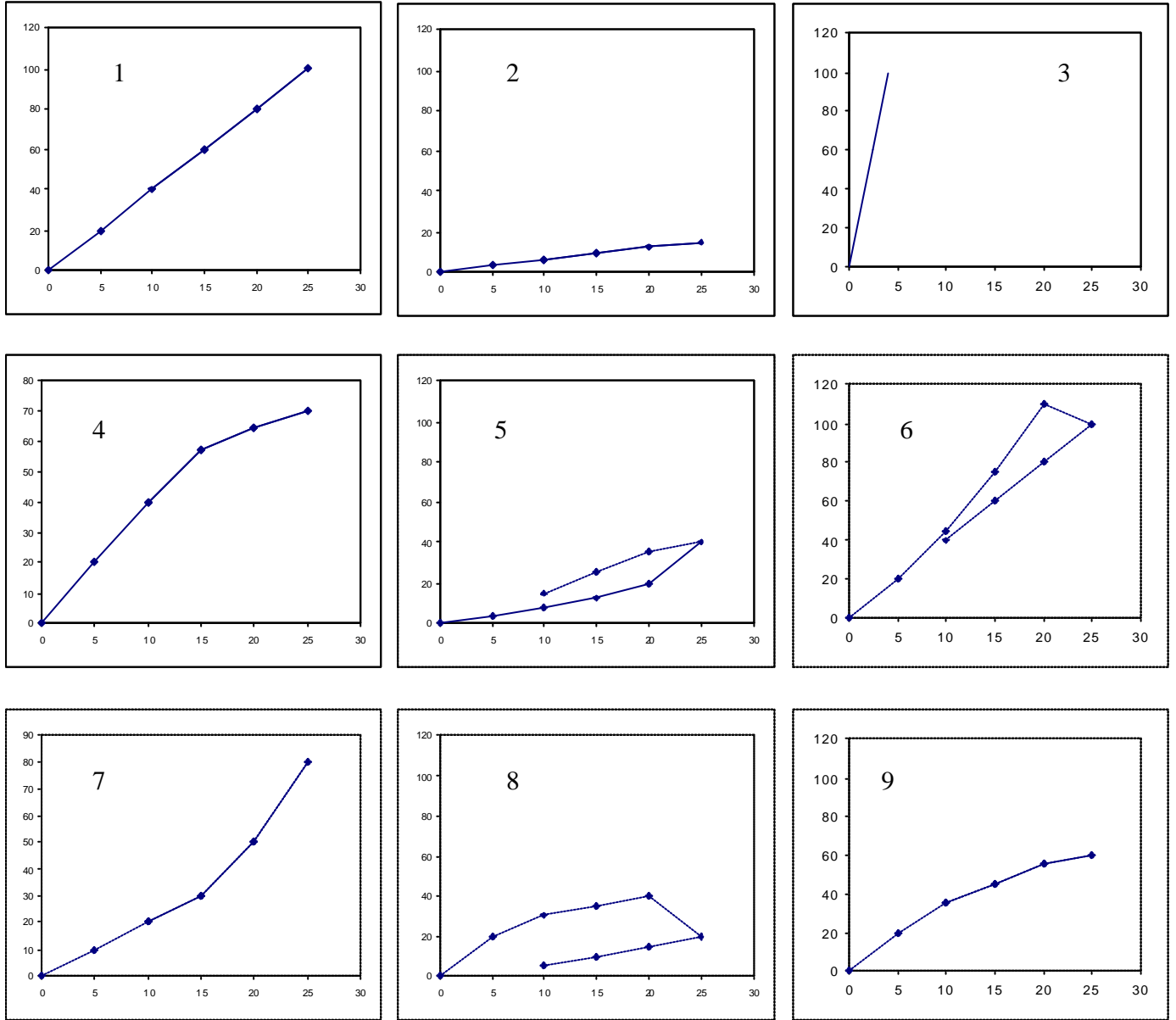
Test can be modified and made shorter or longer. One option is to perform only a constant head test with water level maintained near the head of drilling rods. When steady state occurs, measure flow-rate using calibrated bucket. Constant head test can be followed by simple falling head test with duration about 10-15 min.

5.1.3 Data Interpretation

The graphs in Figure 2 illustrate a selection of type curves, which are commonly observed. The following describes each curve. (Note that the recovery curve -reducing pressure curve- is indicated by a dashed line in the plots, otherwise the recovery curve is seen to mimic the ascending pressure curve).

1. Ideal result where flow is laminar, probably on clean fractures, discharge proportional to pressure head.
2. Tight fractures, impermeable material
3. Highly permeable, large open fractures. Water acceptance exceeds capacity of the test system and pressure recorded is due to friction in supply system.
4. Fairly high permeability with a decrease in flow with time due partially to a change from laminar to turbulent flow, as well as partial clogging of fractures with time.
5. Low permeability, but washing out of gouge material from the fractures, increasing the permeability.
6. Laminar flow, moderate permeability but with an increase in flow with pressure. Increasing packer pressure brings the flow back to a linear relationship with pressure, indicating increased flow was previous leakage past the packer.
7. Increase in permeability with increased pressure and the recovery curve follows the same path. This indicates that fractures have been opened up due to excess pressure (hydrofracking).
8. Progressive decrease in permeability with pressure (and time) indicating incomplete blocking of the fractures by transported material.
9. Moderate permeability and flow rate is not linear. The down turned curve and similar recovery curve indicate that turbulent flow conditions exist beyond 15 bars.

FIGURE 2: Typical Flow vs. Pressure Curves



The data from the injection test can be used to determine the effective transmissivity (T) by means of the Thiem equation:

$$T = \frac{Q \ln \left(\frac{R}{r_b} \right)}{2 p P_i}$$

where:

T	= transmissivity (m ² /day);
Q	= injection rate (m ³ /day);
R	= radius of influence (m);
r_b	= radius of borehole (m); and
P_i	= net injection pressure (m).

5.1.4 Effective radius or radius of influence; R

Determining a reasonable value for R , the effective radius or radius of influence, is not a simple matter. This is because the parameter is a function of the hydraulic conductivity of the test zone, heavily influenced on variations in primary and secondary (fractures, etc.) permeability within the zone, specific storage of the rock mass and fractures, etc, test interval length, pump pressure, and time of test period.

However, as the parameter occurs within a natural logarithmic function, we can substitute a reasonable value. For example, if the drillhole radius is assumed to be approximately 0.04 m (1.5"), or approximately HQ wireline size, then values of R equal to 1, 5, 10, and 100 m would result in values of " $\ln (R/r_b)$ " equal to 3.3, 4.9, 5.6, and 7.9, respectively. Consequently, it can be seen that the R value used in the equation above will have a fairly insignificant effect on the value of T calculated using the equations for analysing the packer data. This is especially true when all the possible variables and potential cumulative errors in the testing process are taken into account. Therefore, it is considered that an R value of between 5 and 10 is reasonable and yields a reasonable value for K .

5.1.5 Net Injection Pressure; P_i

The net injection pressure is calculated as the combined pressure head (m) that is exerted on the test zone. It is calculated as follows:

$$P_i = P_g + h_g + h_s - h_f$$

where:

P_i	= net injection pressure (m);
P_g	= gauge pressure (m);
h_g	= height of gauge above ground level (m);
h_s	= depth to pre-test water level (m); and
h_f	= friction losses (m).

The sum of h_g and h_s is usually referred to as the column height. Both components of the column height should be measured before the test is carried out. The value for h_g should be the same for each test if the testing apparatus is not changed, but h_s will vary depending on the hydrogeologic zone penetrated by the drillhole.

5.2 Discharge Tests

5.2.1 Test Description and Basic Procedures

To carry out a discharge test, the packer is located at the drill bit in the same manner as for the injection test. The procedures for testing is fairly simple, but care must be taken to ensure a good packer seal as pressure response curves will not indicate leaking seals as in an injection test.

The following procedures outline the basic test set-up:

1. Locate drillbit and packer assembly as in an injection test;
2. Close flow valve at top of drill rods and monitor pressure;
3. After pressure has equilibrated (steady reading for at least 3 minutes), record shut-in pressure;
4. Start timer and record pressure vs. time logarithmically (i.e.: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 80, 100, 120, 150, 200, etc. minutes);
5. Plot data as Psi/Q vs. log₁₀t (see below for parameter list).

5.2.2 Data Analysis

The apparent transmissivity of the packer isolated interval can be estimated from the time and discharge data using a modified Jacob-Lohman (straight line) equation:

$$T = \frac{2.30}{4p [\Delta(P_{si}/Q)/\log_{10} t]}$$

where:

T	= transmissivity (m ² /day);
P_{si}	= shut-in pressure (m).
Q	= discharge rate (m ³ /day);
R	= radius of influence (m); and
t	= elapsed time since valve opened (min).

The simplest method of analysis involves plotting P_{si}/Q vs. $\log_{10} t$ and, with a best-fit straight line, estimating the change in P_{si}/Q over one cycle of t . Selection of the change in P_{si}/Q over one log cycle is not necessary, but simplifies the calculation since; in that case, the value of the term $\log_{10} t$ equals one. Therefore, the equation simply becomes:

$$T = \frac{0.183}{\Delta_1(P_{si}/Q)}$$

Where $\Delta_1(P_{si}/Q)$ indicates the change in P_{si}/Q over one log cycle of t .

5.3 Recovery Tests

5.3.1 Test Description and Basic Procedures

A recovery test is usually carried out in conjunction with a discharge test. Following the discharge test, the time is recorded (t), and the valve is again shut. This will allow the formation pressure to recover, with the relationship of time vs pressure recorded for this test.

The following procedures outline the basic test set-up:

1. Locate drillbit and packer assembly as in an injection test;
2. Close flow valve at top of drill rods and monitor pressure;
3. After pressure has equilibrated (steady reading for at least 3 minutes), record shut-in pressure;
4. Start timer and record pressure vs. time logarithmically (i.e.: 0.5, 1.0, 1.5, 2.0, 2.5, 3.0, 3.5, 4.0, 4.5, 5.0, 6, 7, 8, 9, 10, 12, 14, 16, 18, 20, 25, 30, 35, 40, 50, 60, 80, 100, 120, 150, 200, etc. minutes);
5. Plot data as Psi/Q vs. log₁₀t (see below for parameter list).

5.3.2 Data Analysis

The pressure readings are plotted against log₁₀(*t/t'*), the log₁₀ ratio of the time since the discharge test started (*t*) over the time since the recovery test has started (*t'*). The apparent transmissivity of the test interval can be estimated using the Cooper-Jacob method:

$$T = \frac{2.30 \bar{Q}}{4 p \left(\frac{\Delta P_r}{\Delta \log_{10}(t/t')} \right)}$$

where:

- T* = transmissivity (m²/day);
 \bar{Q} = average discharge rate during the discharge period (m³/day);
 ΔP_r = change in recovery pressure (m).
t = elapsed time since start of discharge test (min); and
t' = elapsed time since valve closed (min);

Similarly to the plot for the discharge test, the analysis is simple if the change in recovery pressure is taken over one log cycle of *t/t'* (where, again, the term log₁₀(*t/t'*) equals 1. In this case, the first equation can be simplified to:

$$T = \frac{0.183 \bar{Q}}{\Delta_1(P_r)}$$

Where $\Delta_1(P_r)$ indicates the change in recovery pressure over one log cycle of *t*.

6.0 TESTING TROUBLE SHOOTING

6.1 Test QA/QC

To ensure that the data collected during the test is accurate, and more importantly, representative of the zone of interest, the tester must verify that the test assembly is not leaking. Leaks through the supply line or rods, or past the packers will have the effect of apparently increasing the permeability of the test zone. This is because water pumped during the test will be assumed to be flowing into the test zone, but will instead be a combination of zone uptake and leakage. This will become more significant as permeability of the zone decreases and/or the injection pressure increases.

Potential Areas where Leaks can occur

- a) Packers (bypass);
- b) Injection pipe joints;
- c) Drill rods

6.2 Packer Bypass Leakage

A common area where a leak can occur is past the packer, between the expanded gland and the drillhole wall. Incomplete inflation, irregularities on the drillhole wall, tears in the outer gland material, etc are likely reasons for this to happen. Leakage of this type is difficult to assess as flow past the packer and that into the zone cannot be distinguished at surface. In order to determine if the packers are sealing properly, various information is available to the operator:

1. Check for a drop in packer inflation pressure during the test. A drop in pressure will indicate that the packer is deflating (and it or a supply line is probably leaking);
2. Check for bubbles if using a pneumatic system and the water level is visible at the top of the drill rods; and
3. Note unexpected flow vs. pressure performance either within a single test or as compared to other test zones of similar rock (as determined from the drill core). This may indicate that more water is being “taken” by the zone, whereas it is in fact leakage.

It will probably be necessary to remove the packer assembly, test it, and re-run the test in order to verify that the data collected is representative and accurate. This will be time consuming, but overestimating the zone K due to poor data collection could have serious consequences on later engineering design considerations.

6.3 Drill Rods Leaks

The joints in the drill rods should be “wicked” in order to reduce leakage. Wicking consists of wrapping a string or wicking material around the rods threads prior to connecting rods. The leakage may be greatly reduced, but may still have a significant effect when the cumulative leakage is taken into account. To test for the apparent leakage, it is recommended that a “blind” packer assembly is lowered to just above the bit and inflated. Water is then pumped into the rods and the flow vs. pressure response is recorded. If it is assumed that the packers are sealing the rods, and that water is not flowing through the bit, then any flow will be the cumulative joint leakage. The pump pressure should correspond to the expected test pressures, with a 150% increase in order to test the system (note: do not exceed 80% of packer inflation pressure as this will potentially force water past the gland, regardless of proper inflation or not.)

6.4 Supply Pipe Leaks

Testing an independent supply line can be done on surface. The only modification required is to block the water injection pipe at the bottom of the upper packer using a plug threaded to fit. Testing pressures should be the same, except that allowance for packer inflation pressure is not required.

7.0 REFERENCES

Jacob, C.E. and S.W. Lohman 1952. Non-steady flow to a well of constant drawdown in an extensive aquifer. Trans. Amer. Geophys. Union, Vol. 33, pp. 559-569.

Thiem, G. 1906. Hydrologische Methoden. Gebhardt, Leipzig, 56 pp.

Cooper, H.H. and C.E. Jacob 1946. A generalized graphical method for evaluating formation constants and summarizing well field history. Amer. Geophys. Union Trans. Vol. 27, pp. 526 - 534.