Packer Testing Program Design and Management

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Abstract Hydraulic testing using wireline deployed water-inflated packers is becoming a common practice for groundwater characterization at mining sites. Packers, designed for diamond drilling, allow for faster, deeper, and more accurate types of testing conducted concurrently with existing coring programs. Designing and managing these testing programs requires planning, flexibility, and consideration of available methods and equipment options. This presentation explores and provides critical examination of advantages and disadvantages of the following options: 1) single or straddle packer testing, 2) injection, shut-in, withdrawal or falling head techniques, 3) discrete interval or cumulative testing, and discusses design consideration for planning a testing program.

Keywords IMWA 2013, packer testing, hydrogeology, Lugeon, wire-line packer system

Introduction

Characterizing groundwater flow systems in a modern hard rock mining environment is a complex and challenging task. The hydrogeology of many mineral deposits typically comprises complex lithology and alteration zones which can be dominated by multiple fracture sets acting as flow barriers or conduits. Many mining projects are located in complex geological environments and are pushing depth limits below the capabilities of traditional field methods. As the economic, engineering and environmental constraints of mine design become increasingly restrictive, the demand for advanced types of testing to supporting these designs increases. Increasingly, mine designs are now including pore water pressure decay determinations, advanced dewatering techniques, and modes of integrating sustainable environmental practices as required by regulatory agencies, lending entities, and as best management practices at the corporate level. The costs, time and resources budgeted to generate advanced mine design data sets are also limited. This current environment necessitates innovative tools and field techniques that "do more with less." Wireline hydraulic packer testing embodies this by facilitating discrete interval hydrogeological data acquisition as a programmatical addition to existing or planned core drilling programs.

Methods

Basic packer testing techniques are discussed in Nielsen (1991). Unlike traditional pumping tests, packer testing generates a series of discrete interval permeability values along the length of a borehole, which typically decrease with depth. Defining the relationship between permeability and depth in a statistically meaningful manner allows this relationship to be projected across the site to support mine dewatering and refilling, impacts assessment, and groundwater or geotechnical modeling efforts.

Core drilling programs are one of the principle means of collecting a variety of data types at deeper depths in a modern mining operation. Packer testing during core drilling operations can be performed with a variety of different equipment types. Optimized for core drilling, wireline hydraulic packers deploy through the drill rods without inflation lines or cables, are removed using the rig's wireline, and operate using the rigs water pump. Wireline hydraulic packers are also inflated with water, which greatly increases the depth capabilities over systems that require compressed gasses to inflate.

Single Element Testing Typical packer tests are conducted using a single packer element. The testing interval using a single packer system is bounded by the bottom of the borehole and the packer seated just below the drill bit above the bottom of the hole. To conduct the test the packer is lowered and inflated, water is either injected or withdrawn from the interval while flow rates and pressures are recorded, the packer deflated and removed, and then drilling of the next interval commences. This process is repeated until the entire borehole is tested in a series of discrete tests. Limitations to this method include the need to test immediately after the drilling a targeted test interval, which requires the packer testing team to standby while drilling takes place. This is also called "concurrent testing" as it is conducted during the drilling process.

Double Element Testing Wireline packer systems can also be deployed as a double or straddle packer system where two inflatable elements are used and separated by a series of extension pipes that allow both packers to be inflated. Testing is performed on the interval between the two packer elements by injection or withdrawal (Fig. 1). Typically, straddle packer systems are used to characterize discrete intervals at the completion of a borehole by running a series of tests across selected zones of interest in the borehole, or across the entire borehole length in a series of sequential tests. One major risk is having unstable holes collapse on the lower packer causing equipment to be damaged or stuck.

Cumulative Testing Single packer tests performed at borehole completion are termed "cumulative tests", and are performed by placing the packer at various depths either starting at the top or bottom of the borehole. Cumulative tests always use the bottom of the borehole as the lower boundary of the test interval and the packer as the upper boundary. Since the test intervals are a series of overlapping zones, these tests are not considered discrete and resulting data must be mathematically processed to determine unique permeability values and remove the overlap effect. The major limitation to this approach is that zones of higher permeability at depth can mask the permeability determinations for the upper

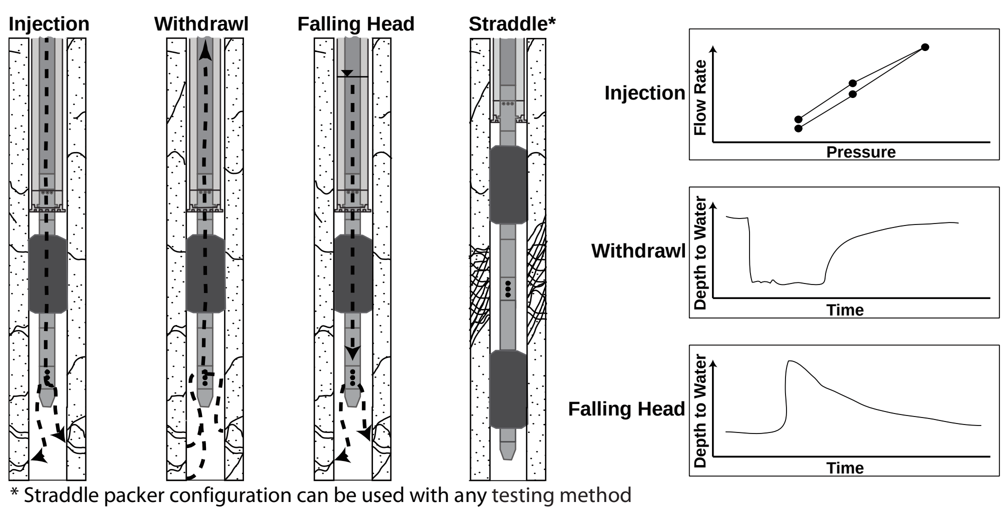

***Fig. 1**. Example of testing types and data results*

tests. Cumulative tests performed at hole completion and are sequential unlike concurrent tests which requires less standby time.

Types of Hydraulic Tests

The main types of hydraulic tests performed with the packer are: 1) injection or Lugeon, 2) withdrawal or airlift, 3) shut-in, and 4) falling head (Fig. 1). Each of these tests has the same net goal of determining permeability; however, the type of test to be performed is dependent on the estimated permeability, equipment availability and logistics, and data objectives. Each type of test has advantages and disadvantages, accuracy limitations, and time constraints. The decision on what type of test to perform can be made in the planning stages or as a situational decision by the field team. A conservative approach is to design a program that has the capabilities and flexibility to perform all types of tests; however, this can be logistically challenging and expensive. An expedient approach is to assume testing will be performed via a single method, although this may sacrifice data quality.

Injection Testing Injection tests are the most commonly conducted type of packer test. These tests are performed by injecting water at a constant pressure and recording the flow rate. If several pressure steps are used, the procedure is termed a Lugeon test (Lugeon 1933). Varying the pressure over several steps is relatively simple and adds a qualitative understanding of the downhole conditions, particularly in a fracture flow setting. The pressures used during an injection or Lugeon test must be high enough to induce flow, but low enough to ensure that hydraulic fracturing or dilation of existing fractures (hydro-jacking) does not occur, as this artificially increases the formation permeability. Typically, hydrofracturing or hydro-jacking does not occur in deeper tests, but may be a major limitation in shallow, fragile or soft formation conditions. Furthermore, if testing is performed in boreholes filled with cuttings or drill fluids such as polymer or bentonite drill muds, a rapid plugging response can occur which can lead to an underestimate of the permeability. Before starting injection testing, the borehole is usually flushed with clean water for a period of time to remove drill fluids from the testing interval. Both pressure and fluid flow rates are measured at the surface during the test on regular intervals; however, downhole pressure transducers can be used to accurately determine true interval pressures and increase accuracy. Advantages of injection testing are that the tests can be performed and analyzed relatively quickly, and require relatively basic packer testing equipment. These types of tests are limited in accuracy by the upper and lower values of the test interval transmissivity. In lower transmissivity intervals, accuracy is reduced due to potential system leakage and the inability to accurately measure very low flow rates. In higher transmissivity intervals, accuracy is constrained by frictional loss across the packer, and the inability to build sufficient testing pressures. In situations where high interval transmissivities limit injection testing accuracy, the test interval can be shortened or the type of testing can be changed to withdrawal tests.

Withdrawal Tests Withdrawal tests with the packer system consist of rapidly removing and measuring water from the test interval for a period of time and then observing the resulting recovery of the interval water level to near static conditions. This type of test is performed in intervals that have transmissivities that are too high for injection testing, such as open fracture zones, or highly fractured zones in the shallow portions of a borehole. This method is also called an airlift test when the method of water removal is compressed air. This type of test is essentially a rising head test because the analysis involves observing head recovery data after fluid removal is completed. One advantage of withdrawal tests is that they can be completed in borehole fluids other than water, such as bentonitic mud, polymers and brine, as the method removes these fluids during the test. In situations where a heavy mud has been used and significant borehole skin conditions occur, withdrawal tests may be the best method, even in moderate or low permeability intervals. However, airlift tests can cause borehole instability because of the removal of bentonite from the borehole walls. Since these tests require the analysis of a water level recovery curve, higher accuracy results are obtained when recovery is greater than 90 % of static conditions which can take significant time. Logistically, airlift withdrawal tests also require more resources such as a high capacity air compressor, airlift discharge heads, downhole air pipe, and transducers. However, since high permeability zone data is usually important project data, such measures are generally warranted.

Falling Head Tests Falling head tests are performed in a packer isolated interval by charging the rods with water and measuring the resulting water level decline until a near-static condition is observed. This test is typically done immediately after the injection test. These tests are the most simple of all types of packer tests in terms of equipment, as only a packer, pressure transducer or water level probe is required. However, in low transmissivity conditions, falling head tests can take a significant amount of time to complete, which requires drill rig standby expenses. Additionally, it may not be possible to run a falling head test in zones with a naturally high interval water level, as there may not be enough room in the rods to induce sufficient driving head for a good-quality falling head test. Finally, falling head tests through drill mud and cuttings may induce a plugging response that could result in an underestimate of the permeability of that zone. In high transmissivity conditions, a falling head test may not work efficiently due to the inability to rapidly vent air from the drill rods as water is initially placed. Falling head data can also be gathered after an injection test as a back-up or secondary means of analysis, as the drill rods are already charged with water and data acquisition is simple if a downhole transducer has been deployed.

Shut-in Tests In intervals with very low permeability or artesian conditions, shut-in type tests can be useful. A shut-in test is performed by pressurizing the testing zone, activating downhole or up-hole shut-in valve, and then monitoring the pressure decay using an up-hole gauge or a downhole transducer. Since this test is essentially a zero flow test, it can remove accuracy error related to low flow measurements obtained in injection tests and from borehole storage effects. As with withdrawal tests, shut-in tests require more time to complete and are thus more expensive considering drill rig standby rates. Although these tests bypass flow measurement related error, they can also be affected by apparatus leakage error, particularly if an uphole shut in system is used. Typically, the range of permeabilities quantified by this method is below that of concern at most mining operations; however quantification of extremely low permeabilities may be required for some project objectives. New equipment has allowed Shut-in tests to be done easier and with more accuracy than ever before (Adams and Richards 2012).

Testing Program Design

Data Objectives Detailed planning for a packer testing program is probably the most important and cost-effective activity. Table 1 shows some guidelines for packer program design. The primary consideration in performing a packer testing program is having detailed data objectives and a clear end goal for the program, which surprisingly, is often overlooked. If the packer testing campaign is in support of a groundwater or geotechnical model for example, then a preliminary model using historically available data should be constructed in order to refine and optimize the overall program objectives. The data objectives should be defined by the modeling team and the end users of the data. Data objectives include items such as assessment of the data density needs, including both vertical and horizontal distributions of tests. In an ideal program, the data needs drive the location, depths, type and

		Advantages	Limitations
Packer Configuration	Single Element	Logistical and operational simplicity allows quicker testing	Bottom of test interval constrained by borehole base
		Longer testing intervals possible - not limited by spacer pipe	Requires less accurate cumulative methods if testing at borehole completion
	Double Element	Allows discrete zone tests after borehole completion Can be done at any tme while rig is on the hole	Logistically and operationally complex, slower operation - requires addional crew training and experience
		Control of bottom test interval placement	Unecessary for testing concurent with drilling Testing interval limited by available spacer pipe segments
Test Scheduling	Concurent with Drilling	Most accurate and reliable method Requires least amount of delay of drilling operations Requires less crew expertise	Testing timing dictated by drilling progress Significant standby for crew between tests Slows down drilling operations
	Completion of Borehole	No testing crew during drilling, mobilize to rig after borehole completion	Single element completion testing must be done cumulatively - lower accuracy
		Flexible scheduling and minimizes testing crew time on rig	Discrete testing requires use of double element packer equipment
Types of Testing	Injection or Lugeon	Simplest type of test to perform Supplies both quantitative and qualitative hydrogeological data Test is quickly performed and requires less equipment	Plugging response if testing through drill mud/additives Accuracy is limited for very high and very low transmissivity test intervals
	Withdrawal	Higher accuracy in high transmissivty test intervals Can be performed through heavy drill mud	Requires more time to set-up and run Logistically complex - requires air compressor and other equipment
	Falling Head	Can be performed in conjunction with injection tests Requires the least amount of equipment Good back-up test if pump or flow manifold gear fails	May take a significant amount of time to complete Requires a use of a down hole pressure transducer Plugging response if performed through drill mud
	Shut-in	Good for very low permeability material or artesian head conditions Yields more types of data, higher accuracy	Requires a down hole shut-in valve for best accuracy. Very low permeability quantification may be unnecessary

***Table 1**. Program Design ConsiderationsControl*

number of tests to be performed; an overabundance of data is an unnecessary expenditure. Similarly, a statistically inconclusive data set may require retesting – a major setback if drill rigs and key equipment and personnel are demobilized. Often the data objectives are set by a third party, such as a regulatory body, third party reviewer, or a stakeholder representative; in these cases it is recommended that all parties come to an agreement on data objective prior to the design of the program and initiation of field activities.

Design Considerations Once the data objectives for a packer testing program are defined, the packer testing program planning can begin. Elements to consider are: 1) the type, number and capabilities of the drilling equipment intended to be used; 2) the depth, location, inclination and diameter of each borehole to be drilled; 3) timing and scheduling of the packer testing; 4) staffing as well as training plans for the personnel performing the testing; 5) expectations regarding equipment, including procurement, logistics, and transportation; 6) other hydrogeological activities, such as well installations, water level monitoring, transducer installations.

There are several different approaches to executing a packer testing campaign. Typically, packer testing is an activity that is added on to an existing exploration or geotechnical design program, thus certain portions of the campaign may already be fixed, such as the drilling locations and hole angles. Other times, constraints such as limited drill rig availability, key staff availability, weather or access issues may come into play. Based on these constraints, the packer testing program may be designed as a short but intensive campaign consisting of multiple drill rigs and a large testing crew, other times the program may be a long duration operation, where sporadic tests and a single drill rig are used.

Generally, the best results occur when packer testing is performed concurrently with drilling and when using a single packer configuration. Since this type of testing is relatively fast, a typical experienced packer testing crew can handle two to three drill rigs, moving gear between them, and testing as time allows. Occasional delays may occur but these are small in comparison to the advantages. Smaller capacity drill rigs in under-developed countries typically average 20 to 40 m of core drilling per day, when conditions such as mechanical breakdowns and logistical delays are factored in. A highly trained packer crew can typically perform two injection tests per shift, or one airlift test. In such a setting, with three operating drill rigs, it is reasonable to assume that testing could take place on 30 m intervals in each borehole. Since one drill rig is usually moving, installing casing, under maintenance, or drilling in rock that is outside the data objectives; it is reasonable to assume that a single packer kit plus a day and night testing crew could handle up to three drill rigs. If other activities are required of this crew, such as well installation, data analysis, access, equipment and supply sourcing; the maximum number of rigs drops considerably.

Staffing and Scheduling Staffing of packer testing programs is a key issue requiring careful planning. Packer testing can be performed by external consultants, specially trained drill crews, or by in-house staff after receiving training. Some packer testing crews consist of a single experienced individual, while others crews may have two or three inexperienced or junior people. Typical drilling operations and packer testing campaigns are a 24/7 continuous operations, so both a day and night crew is usually required. Crew duration is typically 3 to 5 weeks; even the most seasoned field crew member become ineffectual after this period of time. Generally, the most cost effective mix of personnel for a packer testing campaign is a blend of lower cost juniors, some locally sourced laborers, and at least one highly experienced individual that can troubleshoot and supervise staff. In many instances, when dealing with consultants, it is more efficient to have the project manager on-site so that planning and logistical difficulties are rapidly resolved. Packer testing, while simple in concept, can be exacting work that requires an experienced operator to supervise and troubleshoot issues that junior or inexperienced operators may have trouble managing. Underestimating this may result in poor data quality as well as potentially long rig standby times and associated costs.

Conclusions

Recent innovations in packer systems has reduced cost and increased accessibility for versatile, deep testing equipment. Incorporating a wireline hydraulic packer testing program into a core drilling program is advantageous in that it enables the acquisition of discrete interval hydraulic testing during exploration, geotechnical, infill or other core drilling operations. Although it does require some additional equipment and personnel, the cost advantages of including this type of testing into an existing core drilling campaign far outweigh those associated with a standalone, dedicated hydrogeological drilling and testing program.

The types of testing, packer configuration and test scheduling are flexible program design elements. In designing a packer testing program, these elements must be optimized to both meet the data objectives of the program and minimize overall budget. It is important to get the advice of a packer testing expert familiar with this type of testing to help design a successful program.

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