86mm Hydraulic Fracture Testing (HFT) Method Statement

Testing from a Rotary Drilling Rig via rods

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1.0 Equipment

86mm ('H') sized Hydraulic Stimulation (HS) equipment suitable for 101mm diameter test pockets. 100m lengths of water injection hose. 100m lengths of air inflation/data hose. Water Injection Manifold (WIM). High flow water pump & petrol driven powerpack, air powered water pump and a high pressure hand pump. Electronic interface unit (EIU) and cables. High Pressure Control Panel (HPCP) and pneumatic hoses. Compressed air regulator. Petrol driven breathing air compressor. 1.5m BW rod and sub, 2 x 12l air cylinder, site tools, 12 Volt vehicle battery and site laptop.

Emergency First Aid kit (normally stored inside work vehicle), plant nappy/drip tray for petrol driven air compressor and emergency fire extinguisher suitable for petrol/diesel fires (normally stored in work vehicle) and instrument handling A frame with pipe vice (work frame).

1.1 System Diagram

All units are millimetres and Pascals. Overall length is indicative only as sketch is not to scale. Assembled length depends on final sub arrangement. Please enquire for more details.

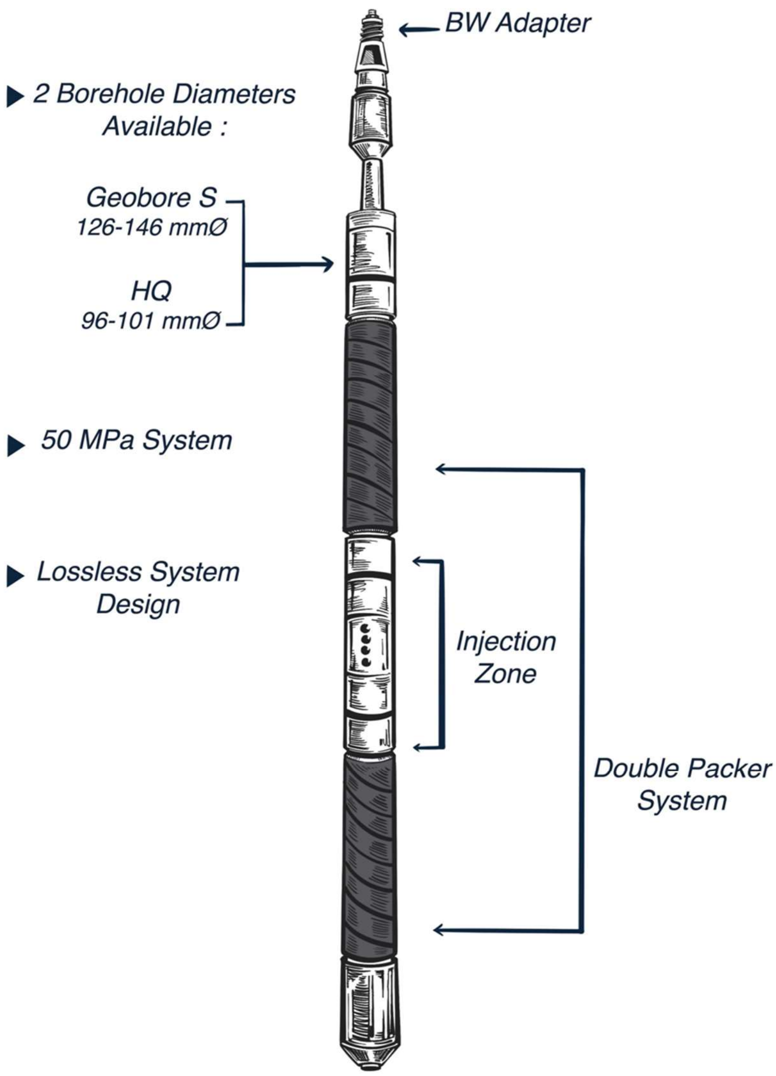

Figure 1.0. Sketch of the Hydraulic Fracture Equipment assembly.

2.0 Drilling Requirements

1. The 'H' sized HS equipment is normally placed in a pocket between 98 and 101mm diameter drilled at the foot of a larger borehole which must be cased as necessary to ensure borehole stability. In competent material where there is no risk of material falling in from the borehole wall on top of the instrument a continuous borehole all at the same diameter can be considered.

2. The pockets will be produced by the main contractor and should be between 3.0 and 6.0 metres in length. 6.0m long pockets are preferred and allow for multiple tests to be carried out if required.

3. The correct core barrel is to be supplied by the main contractor, the most commonly used core barrel type is T6101, T6H or HWF. The minimum casing size for the 95 HPD is P size. H size casing cannot be used with the 95 HPD as the instrument will not fit through a casing of this size.

4. The instrument should be lowered on the rods used by the rotary rig, but wireline deployment may be used by prior agreement. The sub necessary to adapt these rods to our instrument will be supplied by Cambridge Insitu Ltd. Our HFT equipment ends in a BW pin thread at the top and we have subs to NWY, to HWY and to 2⅜" API Regular. Other threads will require the use of an appropriate sub which may have to be specially made. We must be consulted about this as soon as possible after the award of contract.

5. It is very desirable that we discuss the working procedure with the actual drilling sub-contractor before the contract starts and arrangements should be made for us to do this as soon as possible after the award of the contract.

3.0 Mobilisation of Hydraulic Fracture (HFT) Equipment

1. Prior to the project, the HFT equipment is calibrated. This includes transducer calibrations for water pressure and flow rate (where necessary). The Instruments pre-project calibrations and any other calibrations undertaken will be included in the report.

2. The HFT and the associated equipment shall be brought to site (normally in a van) ready for testing. If four-wheel drive is essential, it can be provided but we must be consulted before agreeing prices. The van must be parked as close as possible to the drilling rig, if this is not possible then we must be consulted before hand to make other arrangements.

3. The HFT equipment is to be assembled on-site on the supplied A-frame, with electronic interface unit (EIU), High Pressure Control Panel for packer inflation, water injection system (consisting of high-pressure manifold and a combination of water pumps), and operators site laptop set up in a sheltered and dry location. Once assembled, the HFT system will be tested in an aluminum cylinder to ensure that everything is sealed and operating correctly.

4. Following successful set up and testing of the equipment on site, the testing procedure can then be followed as detailed in the below section.

4.0 Methodology for Operating Hydraulic Fracture Testing (HFT) Equipment

4.1 Testing Procedure Overview

1. The borehole or test pocket must first be logged using an acoustic imaging probe. The data record from the acoustic imaging probe is inspected to ensure that at the intended test depth the cavity is of regular size without gross discontinuities. This is confirmed by inspection of the core. Ideally an unfractured piece of rock of approximately 1.2 metre/4 ft length is required, but a test can be carried out in rock with a few tight joints given appropriate circumstances.

2. Before testing starts the downhole tool and calibrated system are checked to ensure that all transducers are working, and the packers are holding pressure. The logging system is turned on and recording starts from ground level.

3. The downhole probe and umbilical are then lowered on rods until the perforated section is aligned with the area identified as suitable for testing.

4. The packers are inflated to a nominal value, typically 5MPa using compressed air. During the test this pressure is raised to keep the packer pressure about 2MPa above the fracture pressure.

5. Once the packers are inflated the test section is then pressurised to about 3MPa. This requires the system to be filled and uses a relatively large volume of water. Invariably this stage of pressurising is done with the hand pump. The test section is locked off and the decay of pressure against time monitored for about 5 minutes. This gives an indication of the suitability of the test zone for Hydraulic Fracture and the data can also be used to estimate the permeability of the rock.

6. Assuming all is well (relatively small decline over the observed period) then pressurising the test section continues, the rate of increase being adjusted to give a brisk rate of increase of hydraulic pressure in the test section. Typically the material fractures within two minutes, the fracture pressure being called P_I. This stage could be done with the hand pump or the automatic pump, depending on the natural permeability of the rock.

7. Once fracture occurs the increased volume causes the pressure to fall. The test section is locked off and the water pressure in the test section monitored until it flattens out. The rate of decay of this part of the test can be analysed to discover the stress at which the crack closes, the so called ‘shut-in’ pressure, P_S.

8. When sufficient dissipation has been observed the pressure in the test section is reduced to ambient conditions and the procedure described above repeated. Usually, the automatic pump is used for subsequent pressurisations of the test zone. Because the material is now cracked the magnitude of the pressure rise is less than that previously seen and the flattens out when the crack reopens at a pressure P_R lower than P_I. The test section is locked off and the pressure allowed to fall until the ‘shut in’ pressure is reached. This step is repeated until an unambiguous value for P_R and the shut-in pressure P_S is achieved. Note that the initial fracture may not extend far enough (at least 5 borehole diameters) so that the first shut-in pressure may be high. When re-opening the fracture, pumping can be continued for a short time (maximum 1 minute) to ensure a sufficiently long fracture and correspondingly lower shut-in pressure. Assuming that the Hydraulic Fracture equipment does not intersect existing open joints or cause a hydraulic short circuit around the packers then an approximately consistent shut-in pressure will be achieved.

9. The test is then terminated, the pressure in the packers is vented and the probe is removed from the borehole or lowered to the next test position as appropriate.

10. Note that the flow is monitored in order to ensure that over the test the rate is the same. The absolute value is not important. Tensile strength is not a constant parameter and varies (amongst other things)

with loading rate. At times the slope of the pressure:time record is used to identify precisely when a crack reopens, and this is only possible if the rate of loading is reasonably consistent.

11. A line of data representing the output of all transducers is logged every second.

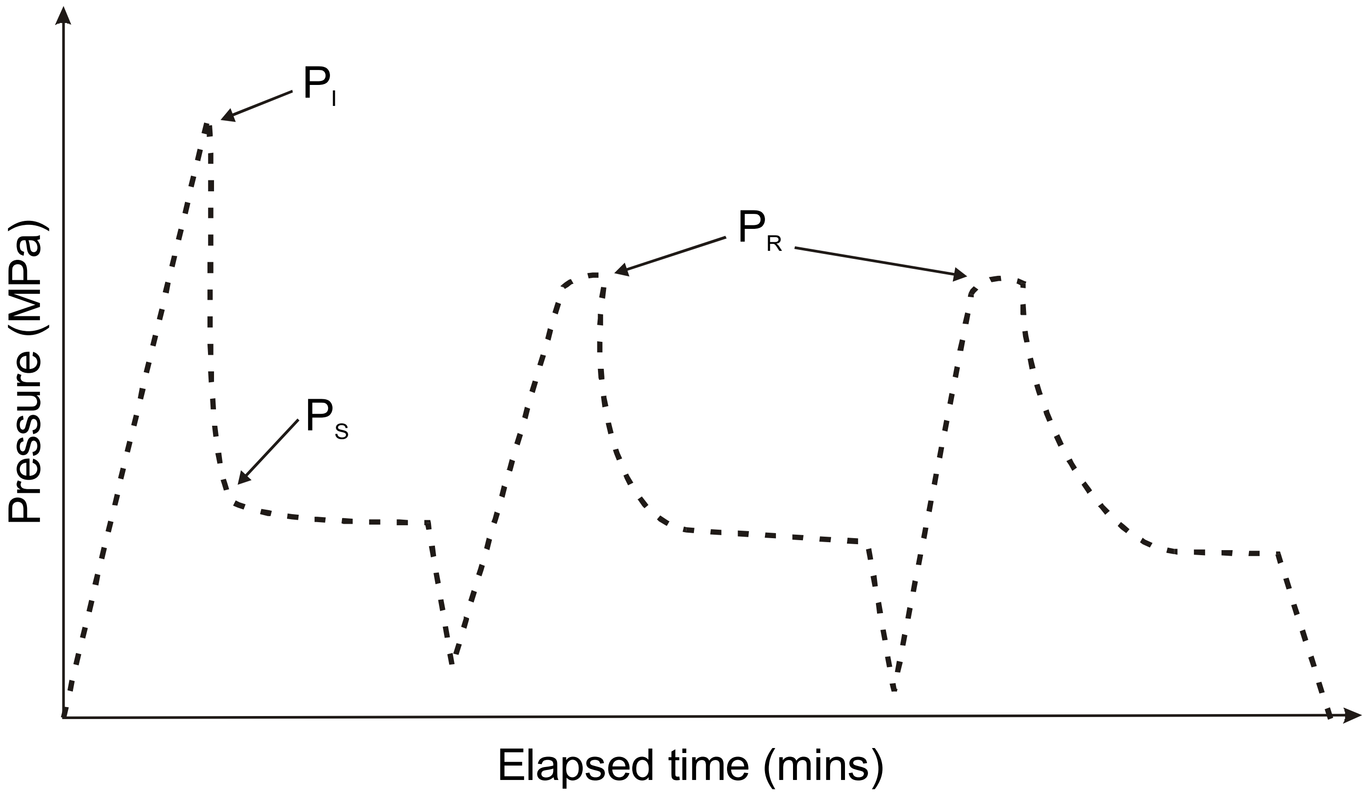

Figure 2.0. A typical plot from a Hydraulic Fracture Test.

4.2 Identifying the induced fracture strike and bearing

An acoustic televiewer should be made available to inspect the post-frac test section and confirm the strike and bearing of the induced fracture. If for whatever reason a televiewer cannot be used, then an impression packer system may be considered, but this requires prior discussion.

If tests have been carried out in smaller ~101mm diameter test pockets, then it is often beneficial for these to be over-drilled in a larger diameter (such as 150mm Geobor S) before the entire borehole is logged with an acoustic televiewer again. These additional televiewer plots often show newly extended fractures which may not be seen in the smaller diameter plots.

5.0 Post Processing

Following completion of a successful test, the graph as seen in figure 3.0 is processed using the 'FRAC' software (Cambridge Insitu Limited in-house analytical software). An example of a typical test being analysed can be seen in this section. (Note: these graphs are examples of these analyses only and not a comprehensive list).

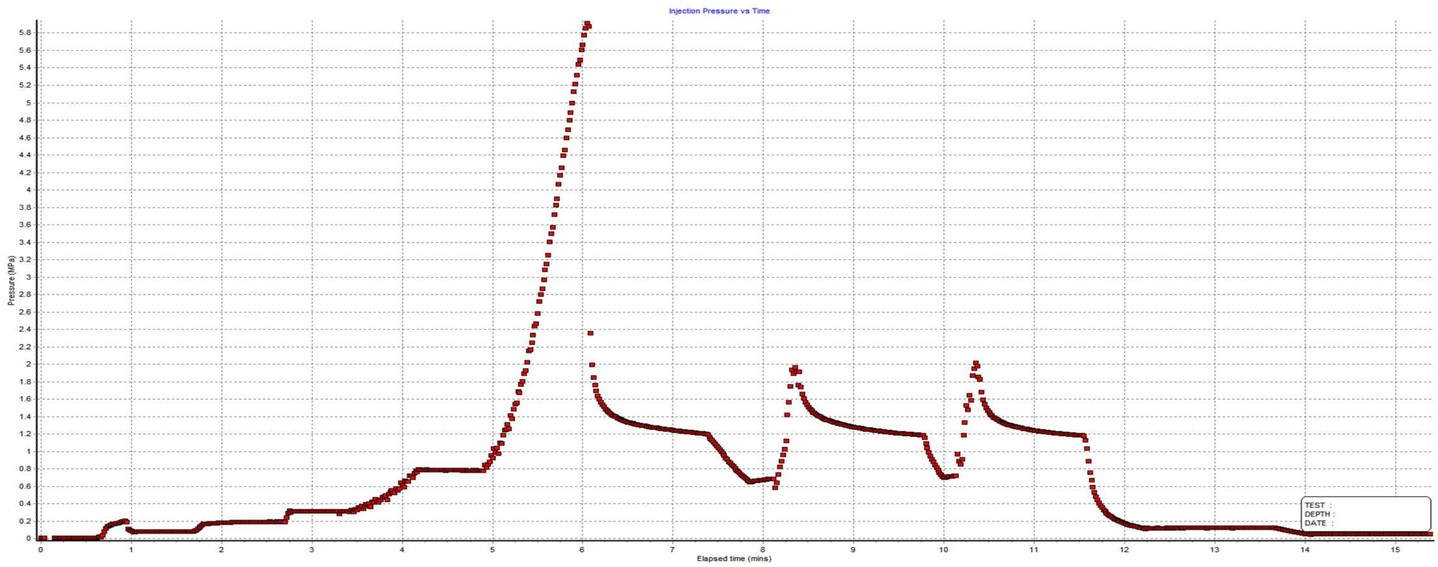

Figure 3.0. Data set collected from a Hydraulic Fracture Test.

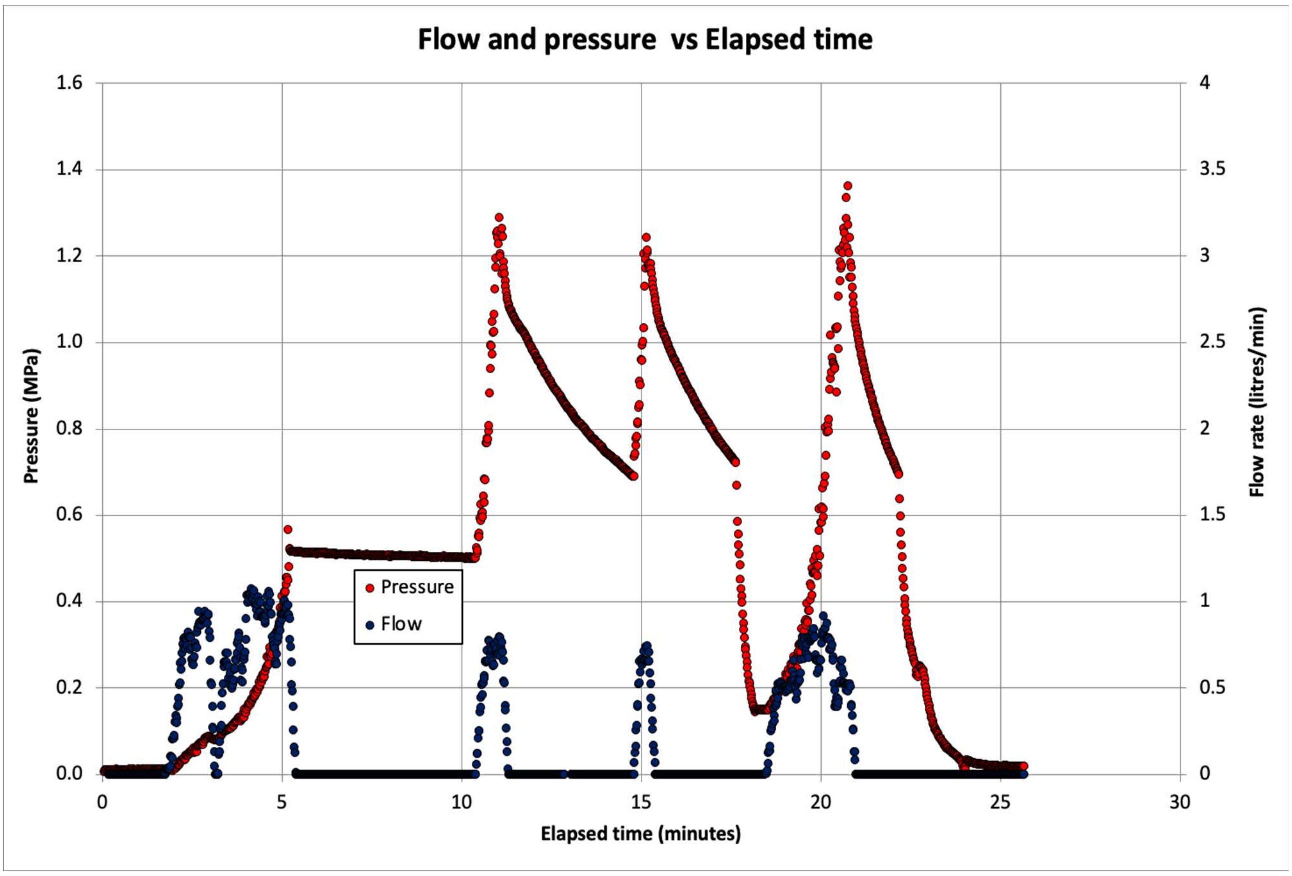

Figure 4.0. Data set collected from a Hydraulic Fracture Test, this graph shows the flow and pressure, vs elapsed time.

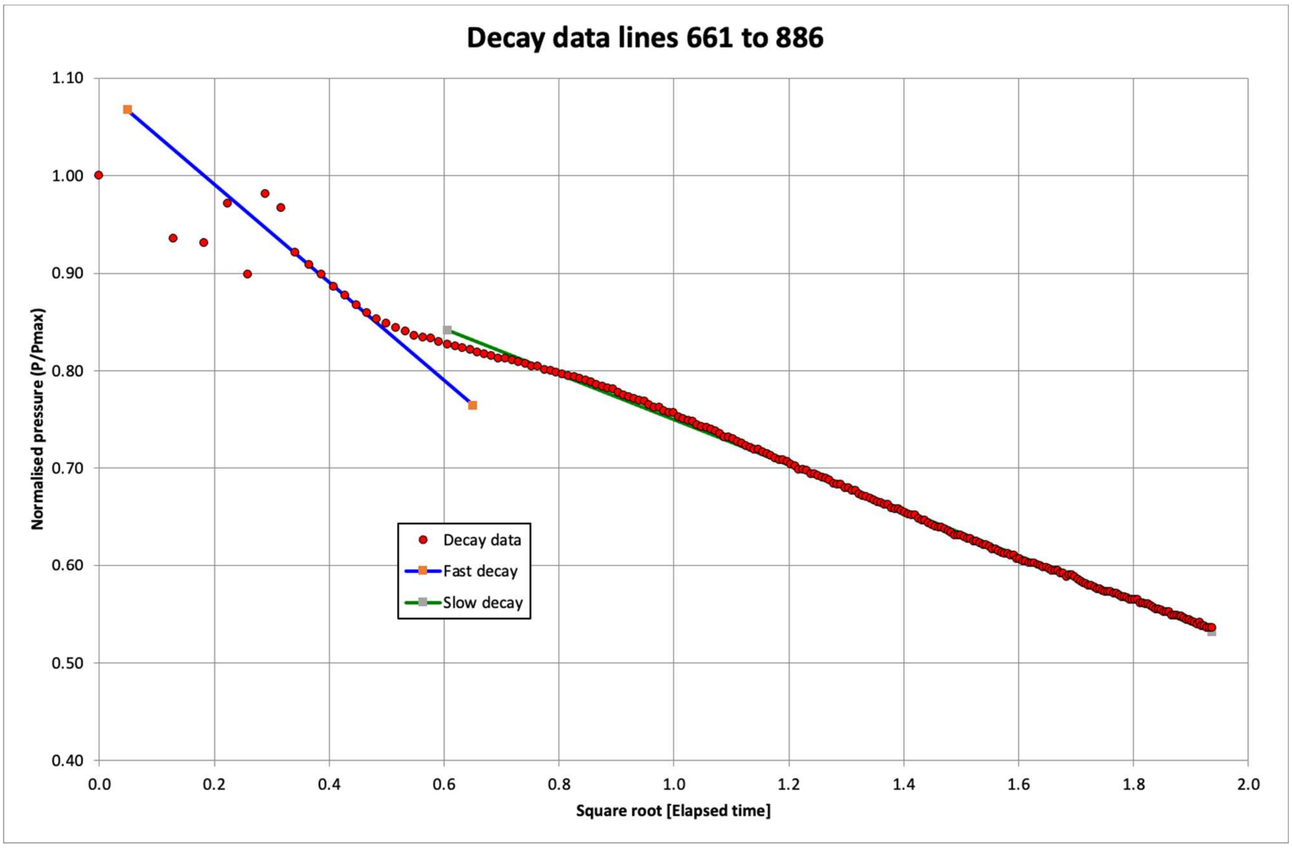

Figure 5.0. Data set collected from a Hydraulic Fracture Test, this graph shows the decay data.

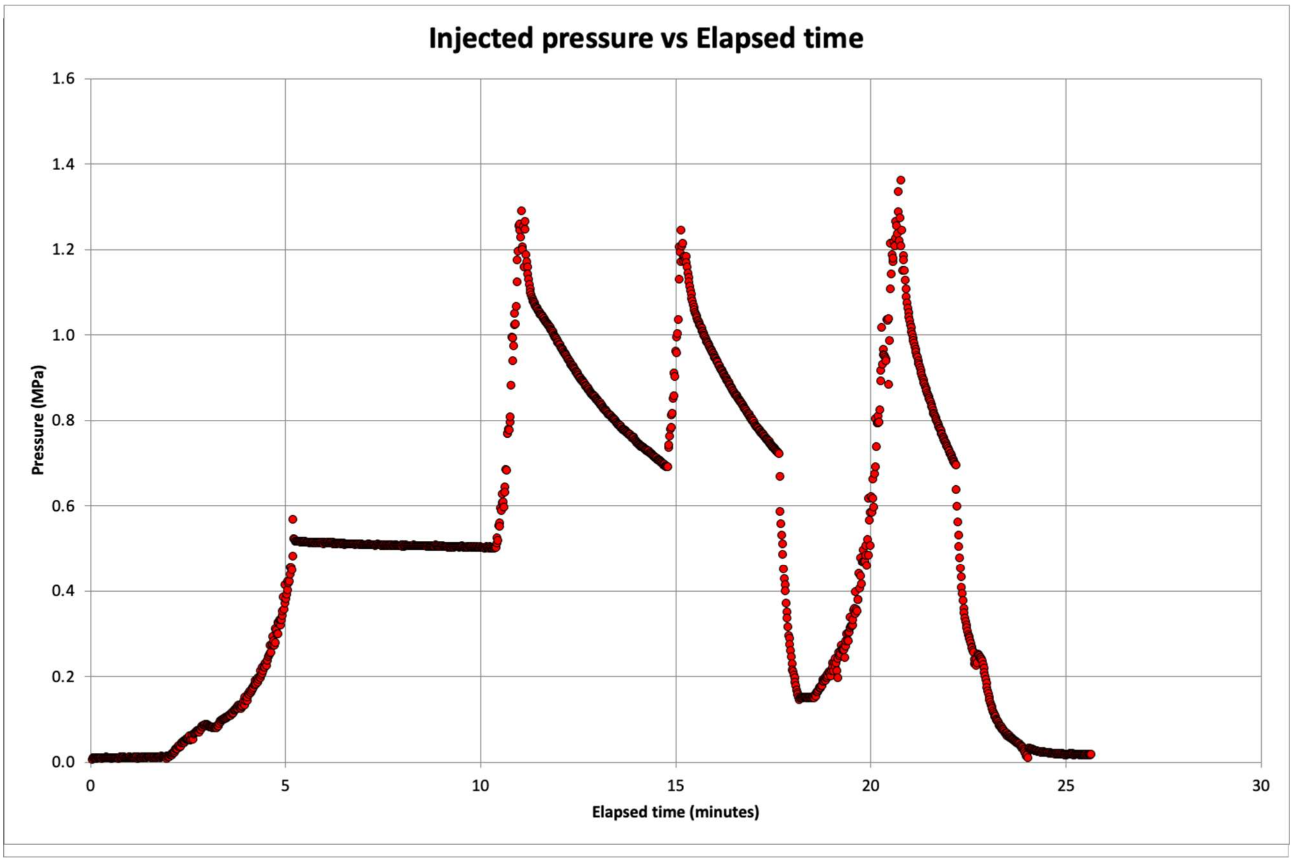

Figure 6.0. Data set collected from a Hydraulic Fracture Test, this graph shows the injected pressure vs elapsed time.

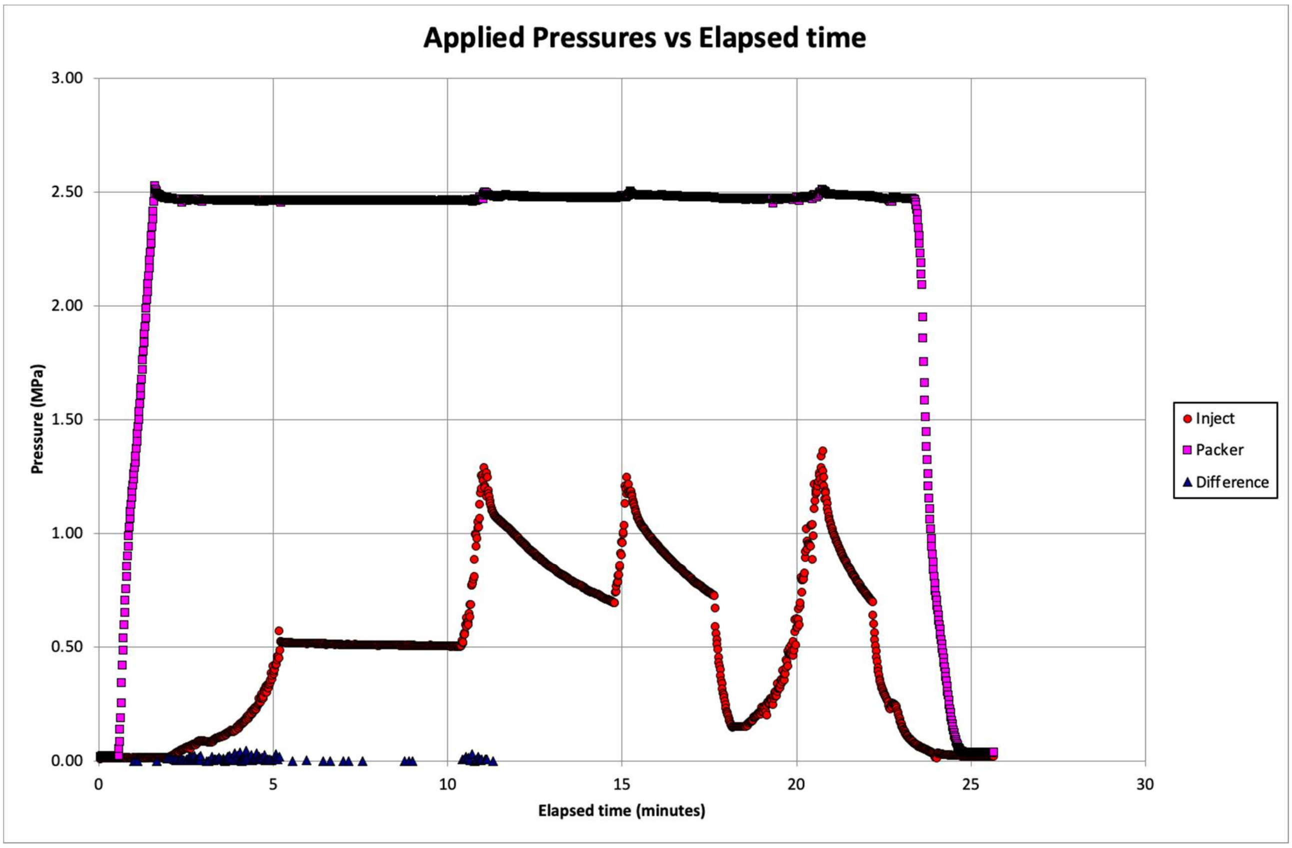

Figure 7.0. Data set collected from a Hydraulic Fracture Test, this graph shows the applied pressure, vs elapsed time.

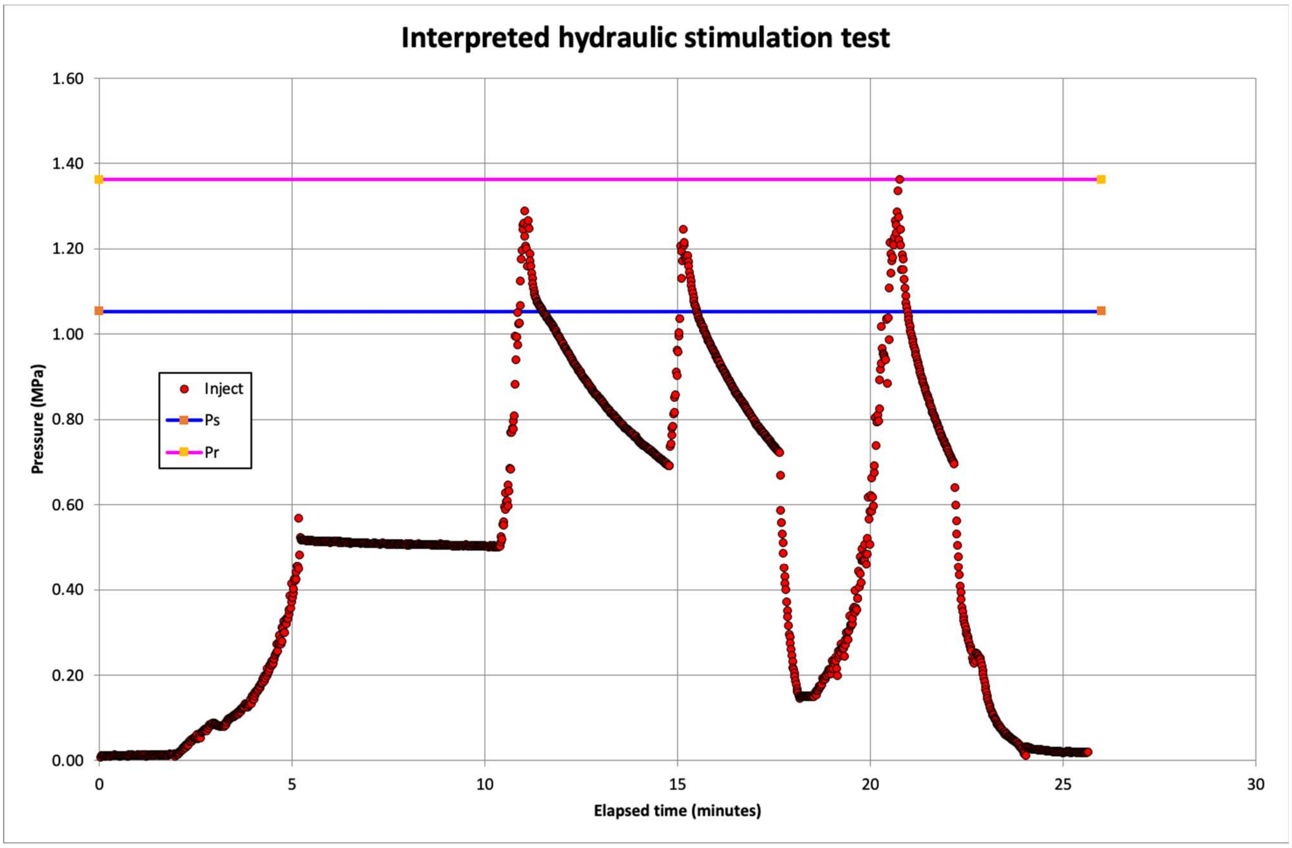

Figure 8.0. Data set collected from a Hydraulic Fracture Test, this graph shows an interpreted Hydraulic Fracture Test.

6.0 Methodology for Operating Air Compressor and Air Cylinder

It is often necessary whilst undertaking Pressuremeter testing to charge/recharge the 12l air cylinder used to supply the compressed air to the probe during testing.

6.1 Equipment

Electric compressor Unit (44kg, Max Pressure 33MPa, 230V/50Hz – power requirements may vary depending on project). 2 x 12l air cylinders (17kg, Max Pressure 30MPa).

Note: Always follow manufacturers instruction manual when operating compressor.

6.1.1 Storage of Compressor and Air Cylinders

Both the air cylinders and compressor must be stored in a cool, dry place. Air cylinders must also be stored, strapped securely into place with a ratchet-strap standing up.

6.2 Charging Operation

6.2.1 Preparation/Pre-operation Checks (Air Compressor)

1. Check compressor for valid PAT test certificate and conduct visual check for damage of wires/cables, pneumatic hoses, plugs, valves, gauges, compressor housing and plastic casing.
2. Check compressor dipstick for sufficient oil level. Top up if required.
3. Check all valves on compressor are shut off completely.
4. Locate suitable location for charge, ensure position is protected from any rainfall or surface water and has a safe/reliable source of electrical power, as well as being away from people eg. away from main gangway/walkway/rest areas (Ask site manager for assistance if necessary).

6.2.2 Setup of Air Compressor

5. Position compressor in chosen location. This should be a two-person lift (compressor weighs 44kg, see Risk Assessment).
6. Connect compressor to Electrical power supply.
7. Ensure physical check that electrical plug connections are sound.

6.2.3 Preparation/Pre-operation Checks (Air Cylinders)

8. Check air cylinder's valve is shut off completely.
9. Check air cylinder has valid in-date inspection certificate and conduct visual check for corrosion/damage to cylinder, valve and rubber protective mesh/base.
10. Position air cylinder in reach of compressor pneumatic hose. Cylinder position must be strapped securely into place with a ratchet-strap standing up.

6.2.4 Charging

11. Connect compressor's pneumatic hose to air cylinder. Conduct physical check (twisting and pulling motion on pneumatic hose to ensure connection is secure.

    At this point the air cylinder is now ready to be charged following the manufacturer's instructions.

12. During charging regularly inspect pressure gauge to ensure max pressure of cylinder is not exceeded.

    NOTE: The air cylinders have a max pressure of 30MPa.

6.3 Post-Charging

Once the air cylinder is at the desired pressure as measured by the pressure gauge on the pneumatic hose, the operator needs to safely disconnect the cylinder from the compressor.

6.3.1 Disconnecting Air Cylinder

1. Shut cylinder valve off.
2. Open bleed valve on pneumatic hose (this will bleed the air pressure from the gauge-cylinder section of the hose, thus allowing the hose to be safely unscrewed/disconnected from the air cylinder).
3. Unscrew hose from cylinder.

6.4 Replacing Air Cylinders

When the pressure in a cylinder drops below a usable amount, the air cylinder must be replaced. This does not make the cylinder 'empty', and in some cases, there may still be up to 10MPa air pressure in the cylinder. This replacement process requires residual pressure to be bled from the system for it to be safe, and can be completed either mid-test or after/before a test.

6.4.1 Disconnecting Air Cylinder

1. Shut off HPCP valve, thus preventing air flow and pressure from the regulator to the HPCP output/probe. This will maintain the pressure in the probe, but obviously makes it impossible to increase the pressure.

2. The air cylinder valve can now be shut off completely, further isolating the system. This now only leaves the pneumatic hose (between HPCP and air cylinder) and the regulator section of the HPCP being left to bleed to be able to make a safe disconnection.

3. Both the pneumatic hose and the HPCP have bleed valves that can be used to bleed the system. Typically, the HPCP input bleed valve is the preferred option. Open this valve and the pressure in the hose and the regulator section of the HPCP will equalize to atmospheric pressure.

4. The hose can now be unscrewed from the air cylinder. The inadequately filled cylinder can now be refilled (see section 1.0 Methodology for Operating Air Compressor and Air Cylinder).

6.4.2 Connecting a New Air Cylinder

5. Take a full air cylinder and once strapped and secured upright screw the pneumatic hose into the cylinder valve. Ensure all the bleed valves are shut and hose connection is sound.

6. Open cylinder valve, slowly at first to ensure that the air pressure transferring from the bottle to the hose does not escape through a leak caused by an inadequate connection or similar fault. Once the system is secure, open the valve fully. This fully pressurizes the regulator section of the HPCP and the gauge pressure (on the HPCP) should reflect what quantity of pressure is now available to the system.

7. Open the HPCP valve, allowing air flow and pressure to transfer from the regulator to the probe. Continue testing as normal.