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Oskarshamn site investigation

Hydraulic injection tests in borehole KSH03A, 2004

Sub-area Simpevarp

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December 2004

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Keywords: Site/project, Hydrogeology, Hydraulic tests, Injection test, Hydraulic parameters, Transmissivity.

Abstract

Hydraulic injection tests have been performed in Borehole KSH03A at the Simpevarp peninsula, Oskarshamn. The tests are part of the general program for site investigations and specifically for the Simpevarp sub-area. The hydraulic testing programme has the aim to characterise the rock with respect to its hydraulic properties of the fractured zones and rock mass between them. Data is subsequently delivered for the site descriptive model.

This report describes the results and primary data evaluation of the hydraulic injection tests in borehole KSH03A performed between 10^{th} February and 12^{th} of February 2004.

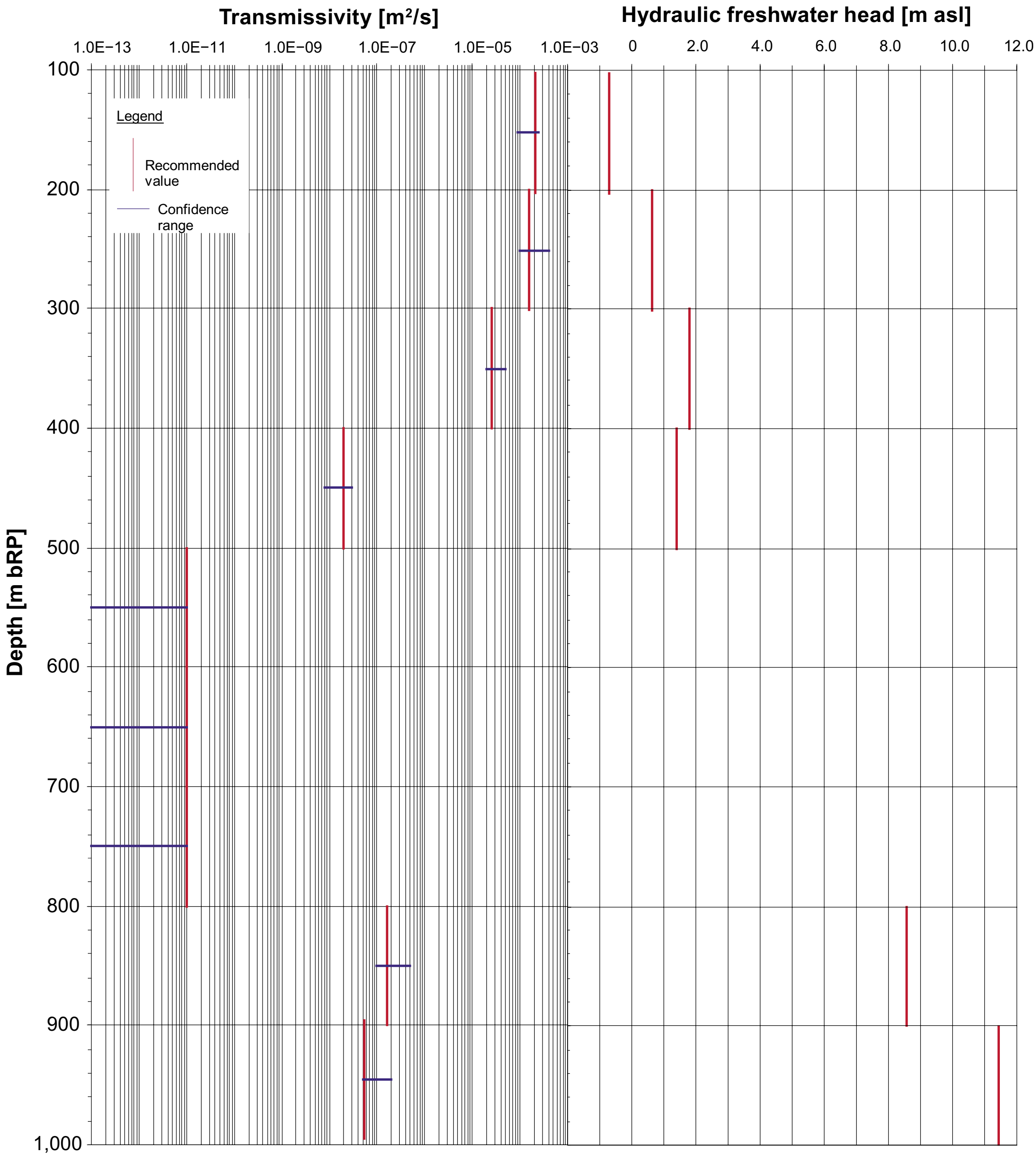
The objective of the hydrotests was to describe the rock around the borehole with respect of hydraulic parameters, mainly transmissivity (T) and hydraulic conductivity (K) at different measurement scales of 100 m sections. Transient evaluation during flow and recovery period provided additional information such as flow regimes, hydraulic boundaries and cross-over flows. Constant pressure injection tests were conducted between 102.5–995 m below ToC. The results of the test interpretation are presented as transmissivity and hydraulic freshwater head.

Sammanfattning

Injektionstester har utförts i borrhål KSH03A i delområde Simpevarp området, Oskarshamn. Testerna är en del av SKB:s platsundersökningar. Hydraultestprogrammet där injektions-testerna ingår har som mål att karakterisera berget med avseende på dess hydrauliska egenskaper av sprickzoner och mellanliggande bergmassa. Data från testerna används vid den platsbeskrivande modelleringen av området.

Denna rapport redovisar resultaten och utvärderingar av primärdata från de hydrauliska injektionstesterna i borrhål KSH03A. Testerna utfördes mellan den 10 februari till den 12 februari 2004.

Syftet med hydrotesterna var framförallt att beskriva bergets hydrauliska egenskaper runt borrhålet med avseende på hydrauliska parametrar, i huvudsak transmissivitet (T), hydraulisk konduktivitet vid olika mätskalor av 100 m sektioner. Transient utvärdering under injektions- och återhämtningsfasen gav ytterligare information avseende flödesgeometri, hydrauliska gränser och sprickläckage. Injektionstester utfördes mellan 102.5–995 m borrhålslängd. Resultaten av test utvärderingen presenteras som transmissivitet, hydraulisk konduktivitet och grundvattennivå uttryckt i ekvivalent nivå sötvattenpelare (freshwater head).



Borehole KSH03A – Summary of results.

Contents

1 Introduction

A general program for site investigations presenting survey methods has been prepared /SKB, 2001a/, as well as a site-specific program for the investigations in the Simpevarp area /SKB, 2001b/. The hydraulic injection tests form part of the site characterization program under item 1.1.5.8 in the work breakdown structure of the execution programme, /SKB, 2002/.

Measurements were carried out according in borehole KSH03A during 10th and 12th of February 2004 following the methodology described in SKB MD 323.001 and in the activity plan AP PS 400-03-065 (SKB internal controlling documents). Data and results were delivered to the SKB site characterization database SICADA.

Borehole KSH03A is situated on the Simpevarp peninsula 0.5 km east of the Block 3 of the nuclear power plant at Simpevarp, Figure 1-1. The borehole was drilled in 2003 at 1,000.7 m depth with an inner diameter of 76 mm. The upper 101.4 m is cased with large diameter telescopic casing ranging from diameter 200–100 mm. The borehole is inclined with 59.254°.

***Figure 1-1.** The investigation area Simpevarp, Oskarshamn with location of borehole KSH03A.*

2 Objective

The objective of the hydrotests in borehole KSH03A is to describe the rock around the borehole with respect to hydraulic parameters, mainly transmissivity (T) and hydraulic conductivity (K). This is done at 100 m sections. Among these parameters transient evaluation during the flow and recovery period provides additional information such as flow regimes, hydraulic boundaries and cross-over flows.

Originally, further tests in subsequent sections of 20 m were planned but by pulling out the 100 m section tool, this tool got stuck in the borehole at a depth of 206 m below TOC (depth of top of tool). When several tries to free the equipment failed, it was agreed by SKB to perform the 20 m section tests in a future phase of hydrotests in the borehole KSH03A.

A comparison with the results of the previous televiewer logging and core description is also possible. Finally the results provide a database for statistical analysis of the hydraulic conductivity distribution along the borehole at the different measurement scales and also transmissivity distribution from the borehole and out in the rock mass.

3 Scope of work

The scope of work consisted of preparation of the PSS2 tool, which included calibration and functional checks, injection tests of 100 m and 20 m (rescheduled after stuck of tool) test sections, analysis and reporting.

Preparation for testing was done according to the Quality plan. This step mainly consists of functions checks of the equipment to be used, the PSS2 tool. Calibration checks and function checks were documented in the daily log and/or relevant documents.

The following test programme was performed.

Table 3-1. Performed test programme at borehole KSH03A.

No of injection tests	Interval	Positions	Time/test	Total test time
9	100 m	102.5–995 m	125 min	18.75 hrs
			Total:	18.75 hrs

3.1 Boreholes

The borehole is telescope drilled with specifications on its construction according to Table 3-2. The reference point in the boreholes is the centre of top of casing (ToC), given as Elevation in the table below. The Swedish National coordinate system (RT90) is used in the x-y direction and RHB70 in the z-direction. Northing and Easting refer to the top of the boreholes at the ground surface. The borehole diameter in Table 3-2 refers to the final diameter of the drill bit after drilling to full depth.

Table 3-2. Information about KSH03A (from SICADA 2004-02-04).

Title	Value				
Borehole length (m)	1,000.700				
Drilling Period(s)	From date	To date	Secup (m)	Seclow (m)	Drilling type
	2003-08-13	2003-09-03	0.000	101.400	Percussion drilling
	2003-09-11	2003-11-07	100.000	1,000.700	Core drilling
Starting point coordinate	Length (m)	Northing (m)	Easting (m)	Elevation (masl)	Coord Sys.
(centerpoint of TOC)	0.000	6366018.632	1552711.204	4.067	RT90-RHB70
Angles	Length(m)	Bearing Inclination		(– = down)	
	0.000	125.088 –59.254			

Borehole diameter:	Secup (m)	Seclow (m)	Hole diam (m)	
	0.000	11.620	0.347	
	11.620	100.055	0.248	
	100.055	100.060	0.169	
	101.400	1,000.700	0.076	
Casing diameter	Secup (m)	Seclow (m)	Case in (m)	Case out (m)
	0.000	100.035	0.200	0.208
	0.000	11.620	0.265	0.273
	96.750	97.050	0.195	0.100
	97.050	101.400	0.100	0.080
	100.055	100.060	0.169	0.208
Grove milling	Length (m)	Trace detectable		
	110.000	YES		
	150.000	YES		
	200.000	YES		
	250.000	YES		
	300.000	YES		
	350.000	YES		
	400.000	YES		
	450.000	YES		
	500.000	YES		
	550.000	YES		
	600.000	YES		
	650.000	YES		
	700.000	YES		
	750.000	YES		
	800.000	YES		
	850.000	YES		
	900.000	YES		
	950.000	YES		

3.2 Tests

Injection tests were conducted according to the Activity Plan AP PS 400-03-065 (SKB internal document). Tests were done in 100 m test sections between 102.5–995 m below ToC. The criteria for performing following injection tests in 20 m test sections, is a measurable flow of Q > 0,001 L/min (see Figure 3-1). The measurements were performed with SKB's custom made equipment for hydraulic testing called PSS2.

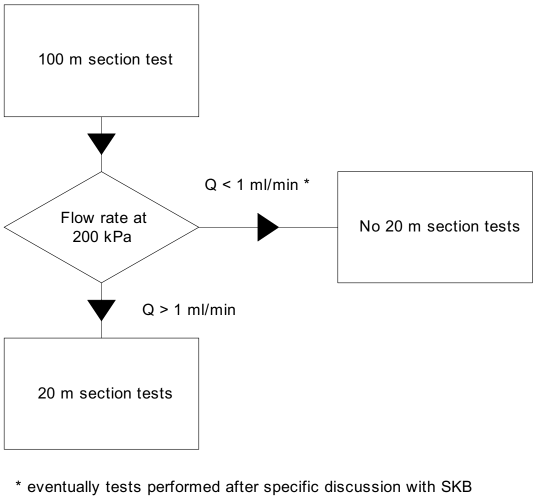


Figure 3-1. *Flow chart for test sections.*

Table 3-3. Tests performed.

Bh ID	Test section (m)	Test type[1]	Test no	Test start Date, time (yyyy-mm-dd hh:mm:ss)	Test stop Date, time (yyyy-mm-dd hh:mm:ss)
KSH 03A	102.5–202.5	3	2	2004-02-10 10:58:56	2004-02-10 12:44:56
KSH 03A	201–301	3	1	2004-02-10 14:10:06	2004-02-10 16:23:46
KSH 03A	300–400	3	1	2004-02-10 18:00:08	2004-02-11 05:28:36
KSH 03A	400–500	3	1	2004-02-11 09:50:49	2004-02-11 12:31:16
KSH 03A	500–600	3	1	2004-02-11 14:19:08	2004-02-11 15:37:07
KSH 03A	600–700	3	1	2004-02-11 17:11:15	2004-02-11 18:30:08
KSH 03A	700–800	3	1	2004-02-12 10:22:29	2004-02-12 11:41:53
KSH 03A	800–900	3	1	2004-02-12 13:52:48	2004-02-12 16:58:16
KSH 03A	895–995	3	1	2004-02-12 18:14:52	2004-02-13 06:15:32

3: Injection test.

No other additional measurements except the actual hydraulic tests and related measurements of packer position and water level in annulus of borehole KSH03A were conducted.

3.3 Control of equipment

Control of equipment was mainly performed according to the Quality plan. The basis for equipment handling is described in the "Mätssystembeskrivning" SKB MD 345.101–123 which is composed of two parts 1) management description, 2) drawings and technical documents of the modified PSS2 tool.

Function checks were performed before and during the tests. Among these pressure sensors were checked at ground level and while running in the hole calculated to the static head. Temperature was checked at ground level and while running in. Leakage at joints in the pipe string was done at least every 100 m of running in.

Any malfunction was recorded, and measures were taken accordingly for proper operation. Approval was made according to SKB site manager, or Quality plan and the Mätssystembeskrivning.

4 Equipment

4.1 Description of equipment

The equipment called PSS2 (Pipe String System 2) is a highly integrated tool for testing boreholes at great depth (see conceptual drawing in the next figure). The system is built inside a container suitable for testing at any weather. Briefly, the components consists of a hydraulic rig, down-hole equipment including packers, pressure gauges, shut-in tool and level indicator, racks for pump, gauge carriers, breakpins, etc. shelfs and drawers for tools and spare parts.

There are three spools for a multi-signal cable, a test valve hose and a packer inflation hose. There is a water tank for injection purposes, pressure vessels for injection of packers, to open test valve and for low flow injection. The PSS2 has been upgraded with a computerized flow regulation system. The office part of the container consists of a computer, regulation valves for the nitrogen system, a 24 V back-up system in case of power shut-offs and a flow regulation board.

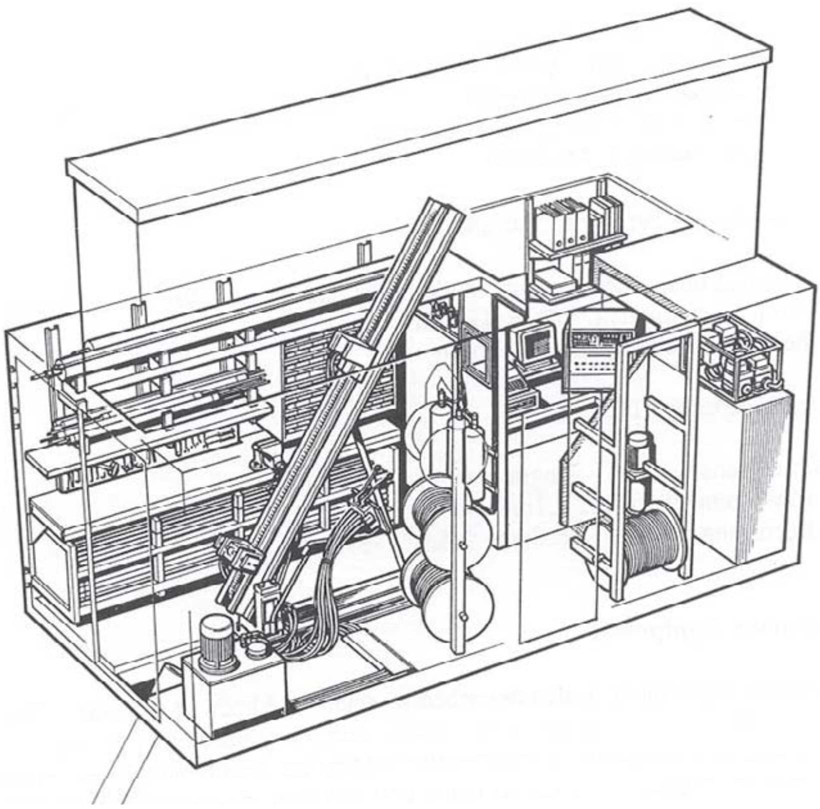


Figure 4-1. *A view of the layout and equipment of PSS2.*

PSS2 is documented in photographs 1–6.

Photo 1. *Hydraulic rig.*

Photo 2. *Rack for pump, down-hole equipment, workbench and drawers for tools.*

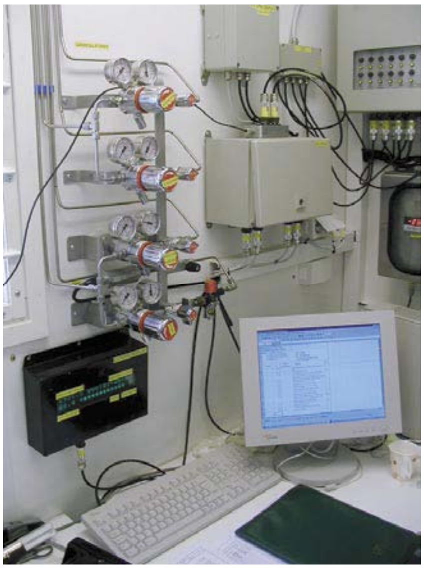


Photo 3. *Computer room, displays and gas regulators.*

Photo 4. *Pressure vessels for test valve, packers and injection.*

Photo 5. *Positioner, bottom end of down-in-hole string.*

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The down-hole equipment consists from bottom to top of the following equipment:

- Level indicator – SS 630 mm pipe with OD 73 mm with 3 plastic wheels connected to a Hallswitch.
- Gauge carrier – SS 1.5 m carrying bottom section pressure transducer and connections from positioner.
- Lower packer – SS and PUR 1,5 m with OD 72 mm, stiff ends, tightening length 1.0 m, maximum pressure 6.5 MPa, working pressure 1.6 MPa.
- Contact carrier – SS 1,0 m carrying connections for sensors below.
- Pop joint – SS 1.0 or 0.5 m with OD 33 mm and ID 21 mm, double O-ring fittings, trapezoid thread, friction loss of 3 kPa/m at 50 L/min.
- Pipe string – SS 3.0 m with OD 33 mm and ID 21 mm, double O-ring fittings, trapezoid thread, friction loss of 3 kPa/m at 50 L/min.
- Gauge carrier with breakpin – SS 2.0 m carrying test section pressure transducer, temperature sensor and connections for sensors below. Breakpin with maximum load of 47.3 (± 1.0) kN.
- Upper packer – SS and PUR 1.5 m with OD 72 mm, fixed ends, seal length 1.0 m, maximum pressure 6.5 MPa, working pressure 1.6 MPa.
- Breakpin – SS 250 mm with OD 33.7 mm. Maximum load of 47.3 (± 1.0) kN.
- Pipe gauge carrier – SS 2.0 m carrying top section pressure transducer, connections from sensors below. Flow pipe is double bent at both ends to give room for sensor equipment.
- Shut-in tool (test valve) – SS 1.0 m with a OD of 48 mm, Teflon coated valve piston, friction loss of 11 kPa at 10 L/min (260 kPa–50 L/min). Working pressure 2.8–4.0 MPa.

The tool scheme is presented in Figure 4-2.

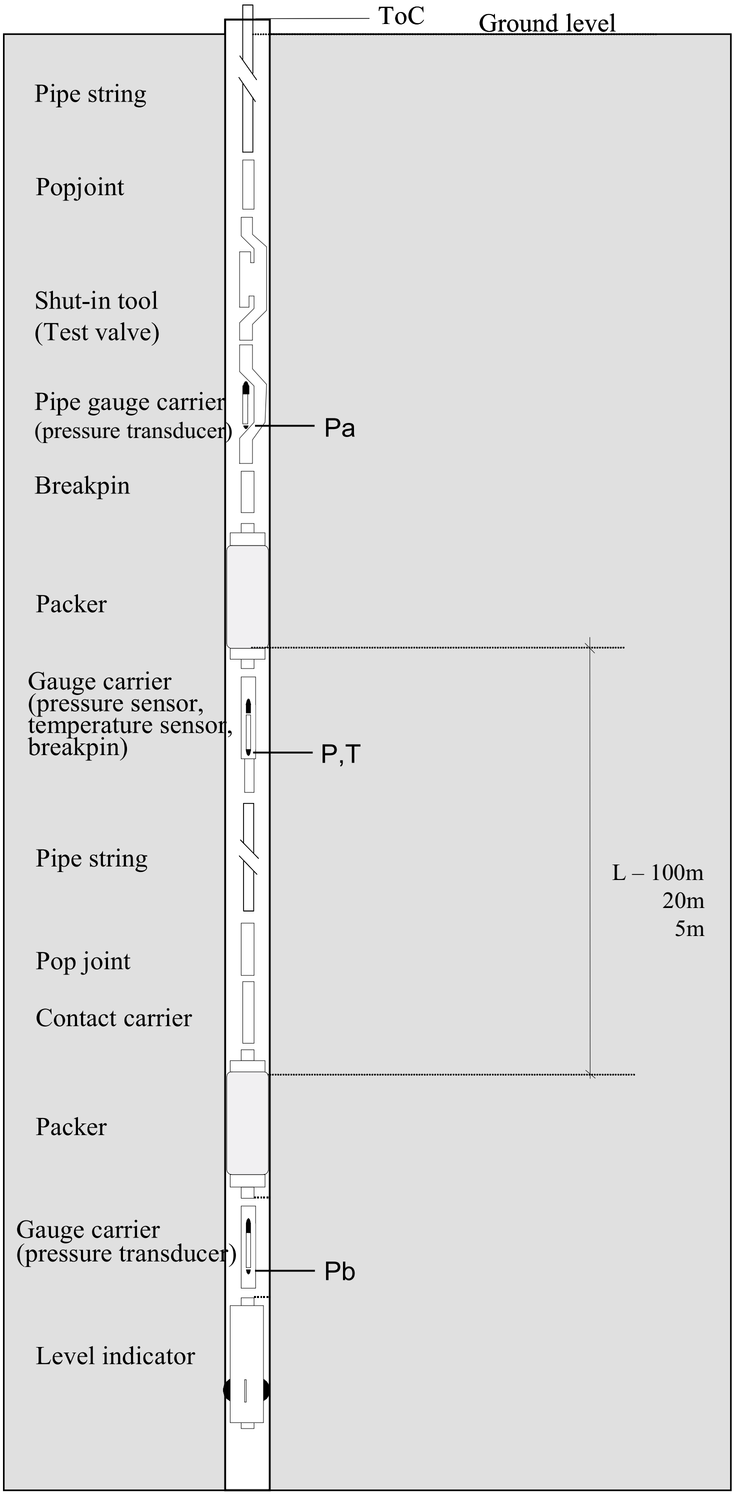

Figure 4-2. *Schematic drawing of the down-hole equipment in the PSS2 system.*

4.2 Sensors

Table 4-1. Technical specifications of sensors.

Keyword	Sensor	Name	Unit	Value/range	Comments
$P_{sec,a,b}$	Pressure	Druck PTX 162–1464abs	9–30 4–20 0–13.5 Resolution accuracy	VDC mA MPa % of FS	
$T_{sec,surf,air}$	Temperature	BGI	18–24 4–20 0–32 0.1	VDC mA °C °C	
Q_{big}	Flow	Micro motion Elite sensor	0–100 ± 0.1	kg/min %	Massflow
Q_{small}	Flow	Micro motion Elite sensor	0–1.8 ± 0.1	kg/min %	Massflow
P_{air}	Pressure	Druck PTX 630	9–30 4–20 0–120 ± 0.1	VDC mA KPa % of FS	
P_{pack}	Pressure	Druck PTX 630	9–30 4–20 0–4 ± 0.1	VDC mA MPa % of FS	
$P_{in,out}$	Pressure	Druck PTX 1400	9–28 4–20 0–2.5	VDC mA MPa	

Table 4-2. Sensor positions and wellbore storage (WBS) controlling factors.

Borehole information			Sensors		Equipment affecting WBS coefficient		
ID	Test section (m)	Test no	Type	Position (m fr ToC)	Position	Function	Outer diameter (mm)
KSH03A	102.5–202.5	2	P_a P T P_b	100.0 103.75 104.0 204.5	Test section	Signal cable Pump string Packer line	9.1 33 6

4.3 Data acquisition system

The data acquisition system in the PSS2 container contains a stationary PC with the software Orchestrator, pump- and injection tests parameters such as pressure, temperature and flow are monitored and sensor data collected. A second laptop PC is connected to the stationary PC through a network containing evaluation software, FlowDim. While testing, data from previously tested section is converted with IPPlot and entered FlowDim for evaluation.

The data acquisition system starts and stops the test automatically or can be disengaged for manual operation of magnetic and regulation valves within the injection/pumping system. The flow regulation board is used for differential pressure and valve settings prior testing and for monitoring valves during actual test. An outline of the data acquisition system is outlined in Figure 4-3.

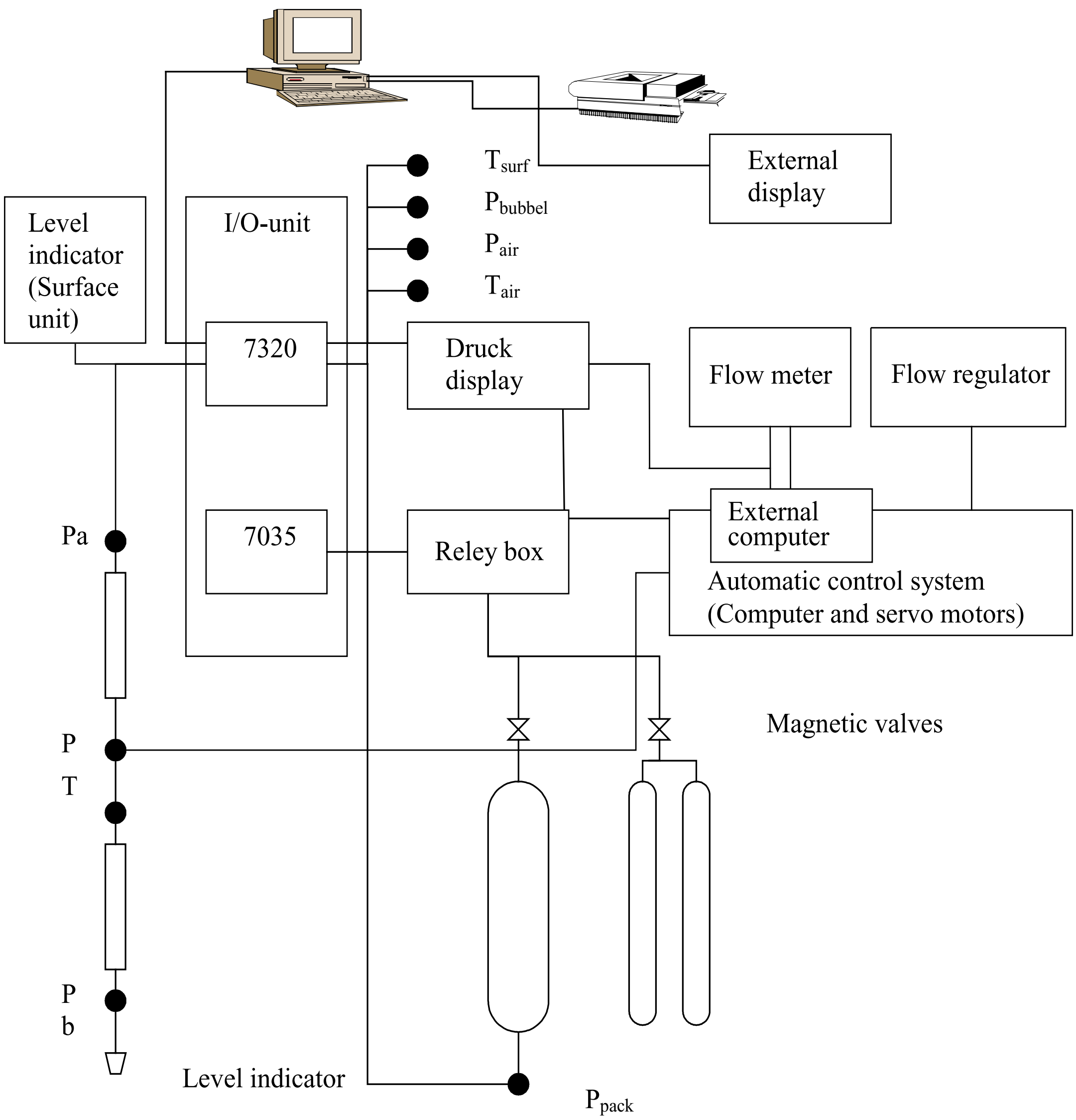

***Figure 4-3.** Schematic drawing of the data acquisition system and the flow regulation control system in PSS2.*

5 Execution

5.1 Preparations

Following preparation work and functional checks were conducted prior to starting test activities:

- Placing the container above the borehole.
- Connecting the container to power supply and to nitrogen supply, installation of computer systems.
- Lifting the rigg into position according to the inclination of the borehole
- Cleaning of all in-hole equipment with hot steam.
- Filling injection tank with 2″pump.
- Filling the packer inflation and test valve hoses and pressure vessels with water.
- Function check of shut-in tool both ends, overpressure by 1MPa, leak detected on lower side close to valve. Discarded. Replace shut-in tool. Check new shut-in tool
- Synchronize clocks on all computers.
- Check pressure gauges against atmospheric pressure and than on test depth against column of water.
- Check functionality of level indicator – works well with 77 mm ring.
- Translate all protocols into English.
- Filling buffer tank with water.
- Filling packers with water and de-air.
- Measure and assemble test tool.

5.2 Execution of tests/measurements

5.2.1 Test principle

The tests were conducted as constant pressure injection (CHi phase) followed by a shut-in pressure recovery (CHir phase). In some cases, when the test section transmissivity was too low (typically lower than 1E–9 m^2/s) no measurable flow could be registered during the CHi phase ($Q < 1$ mL/min). Due to the very low test section transmissivity, the packer compliance period (PSR phase) lasted very long (typically several hours). As agreed with SKB, a test was skipped when there was no indication for a pressure stabilisation within 45 min (see Figure 5-1). In such cases there was no active test conducted, the behaviour of the compliance period being taken as a proof of very low section transmissivity (lower than 1E–11 m^2/s).

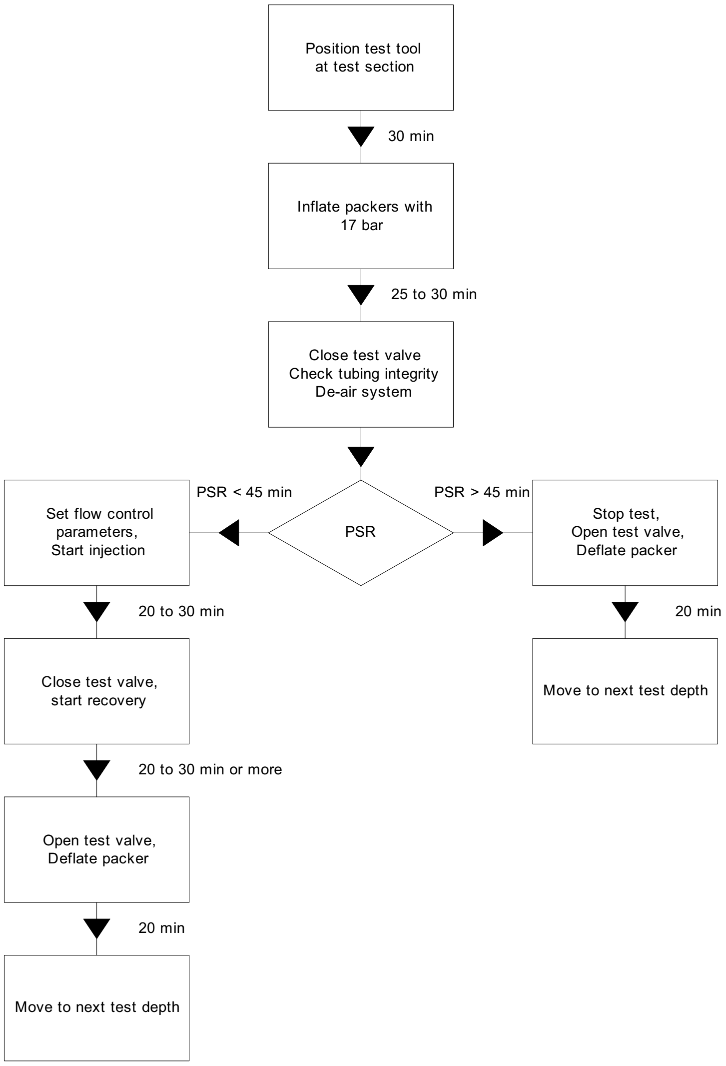

Figure 5-1. *Flow chart for test performance (PSR: packer compliance period).*

5.2.2 Test procedure

A test cycle includes the following phases: 1) Transfer of down-hole equipment to the section; 2) Packer inflation; 3) Pressure stabilisation; 4) Constant head injection; 5) Pressure recovery; 6) Packer deflation. The injection tests in KSH03A has been carried out by applying a constant injection pressure of ca 200 kPa (20 m water column) above the static formation pressure in the test section. Before start of the injection tests, approximately stable pressure conditions prevailed in the test section. Following the injection period, the pressure recovery in the section was measured.

The planned duration for each phase is presented in Table 5-1, the durations of the full test cycles performed is presented in Table 3-3.

In some cases injection and recovery phases were prolonged. This was due to testing zones of high interest for example high flow zones or low flow zones.

Table 5-1. Durations for packer inflation, pressure stabilisation, injection and recovery phase and packer deflation in KSH03A.

Position test tool to new test section (evtl correct position using the borehole markers)	Approx 30 min
Inflate packers with 17 bar	30 min
Close test valve	2 min
Check tubing integrity with 8.5 bar	5 min
De-air system	2 min
Set automatic flow control parameters	5 min
Injection	30 min
Close test valve, start recovery	30 min or more
Open test valve	2 min
Deflate packers	25 min
Move to next test section depth	…

5.3 Data handling

The data handling followed several stages. The data acquisition software (Orchestrator) produced an ASCII raw data file (*.ht2) which contains the data in voltage and milliampere format plus calibration coefficients. The *.ht2 files were processed to *.dat files using the SKB program called IPPlot. These files contain the time, pressure, flow rate and temperature data. The *.dat files were synthesised in Excel to a *.xls file for plotting purposes of the Karthesian plot. Finally, the processed test data to be delivered to SKB were exported from Excel in *.csv format. These files were also used for the subsequent test analysis with FlowDim.

5.4 Analyses and interpretation

5.4.1 Analysis software

The tests were analysed using a type curve matching method. The analysis was performed using Golder's test analysis program FlowDim. FlowDim is an interactive analysis environment allowing the user to interpret constant pressure, constant rate and slug/pulse tests in source as well as in observation boreholes. The program allows the calculation of type-curves for homogeneous, dual porosity and composite flow models in variable flow geometries from linear to spherical.

5.4.2 Analysis approach

Constant pressure tests are analysed using a rate inverse approach. The method initially known as the /Jacob and Lohman, 1952/ method was further improved for the use of type curve derivatives and for different flow models.

Constant rate and pressure recovery tests are analysed using the method described by /Gringarten, 1986/ and /Bourdet et al. 1989/ by using type curve derivatives calculated for different flow models.

5.4.3 Analysis methodology

Each of the relevant test phases is subsequently analyzed using the following steps:

- Identification of the flow model by evaluation of the derivative on the log-log diagnostic plot. Initial estimates of the model parameters are obtained by conventional straight-line analysis.
- Superposition type curve matching in log-log coordinates. A non-linear regression algorithm is used to provide optimized model parameters in the latter stages.
- Non-linear regression in semi-log coordinates /superposition HORNER plot; Horner, 1951/. In this stage of the analysis, the static formation pressure is selected for regression.

The test analysis methodology is best explained in /Horne, 1990/.

5.4.4 Steady state analysis

In addition to the type curve analysis, an interpretation based on the assumption of stationary conditions was performed as described by /Moye, 1967/.

5.4.5 Flow models used for analysis

The flow models used in analysis were derived from the shape of the pressure derivative calculated with respect to log time and plotted in log-log coordinates.

In several cases the pressure derivative suggests a change of transmissivity with the distance from the borehole. In such cases a composite flow model was used in the analysis.

In other cases, the use of a homogeneous flow model led to very large skin factors (e.g. 20). In these cases, in addition to the homogeneous flow model analysis an analysis using a composite flow model was conducted. In these cases the skin was represented explicitly as inner composite zone.

The flow dimension displayed by the test can be diagnosed from the slope of the pressure derivative. A slope of 0.5 indicates linear flow, a slope of 0 (horizontal derivative) indicates radial flow and a slope of –0.5 indicates spherical flow. The flow dimension diagnosis was commented for each of the tests. However, in all cases it was possible to achieve to acceptable analysis results (good match quality) by using radial flow geometry (flow dimension of 2).

5.4.6 Calculation of the static formation pressure an equivalent freshwater head

The static pressure measured at transducer depth, was derived from the pressure recovery (CHir) following the constant pressure injection phase by using straight line or type curve extrapolation in the Horner plot.

The equivalent freshwater head (expressed in meters above sea level) was calculated from the static formation pressure, corrected for atmospheric pressure measured by the surface gauge and corrected for the vertical depth considering the inclination of the drillhole, by assuming a water density of 1,000 kg/m^3 (freshwater). The equivalent freshwater head is the static water level an individual test interval would show if isolated and connected to the surface by tubing full of freshwater. Figure 5-2 shows the methodology schematically.

The freshwater head in meters above sea level is calculated as following:

$$h = \frac{(p_i - p_{atm})}{\rho \cdot g}$$

which is the P_i value expressed in a water column of freshwater.

With consideration of the elevation of the reference point (RP) and the gauge depth (Gd), the freshwater head is

$$head = RP_{elev} - Gd + \frac{(p_i - p_{atm})}{\rho \cdot g}$$

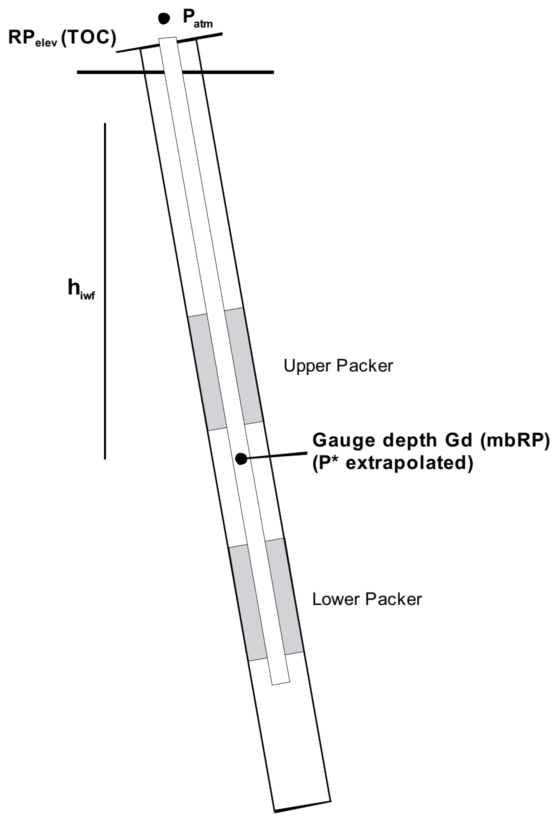

Figure 5-2. *Schematic methodologies for calculation of the freshwater head.*

5.4.7 Derivation of the recommended transmissivity and the confidence range

In most of the cases more than one analysis was conducted on a specific test. Typically both test phases were analysed (CHi and CHir) and in some cases the CHir phase was analysed using two different flow models. The parameter sets (i.e. transmissivities) derived from the individual analyses of a specific test usually differ. In the case when the differences are small (which is typically the case) the recommended transmissivity value is chosen from the test phase that shows the best data and derivative quality, which is most of the cases at the CHir phase. In cases when a composite flow model was deemed to be most representative for the hydraulic behaviour of the specific test section, than the outer zone transmissivity was selected as recommended value, because it is regarded as most representative for the large scale undisturbed formation properties.

In cases when the difference in results of the individual analyses was large (more than half order of magnitude) the test phases were compared in a normalized plot and the phase showing the best derivative quality was selected.

The confidence range of the transmissivity was derived using expert judgement. Factors considered were the range of transmissivities derived from the individual analyses of the test as well as additional sources of uncertainty such as noise in the flow rate measurement, numeric effects in the calculation of the derivative or possible errors in the measurement of the wellbore storage coefficient. No statistical calculations were performed to derive the confidence range of transmissivity.

In some cases the tests were not analysable due to the fact that the flow rates during the CHi phase were below the range of the flowmeter (< 0.5 mL/min) or because the compliance phase following packer inflation was too long, thus indicating a very low section transmissivity. In such cases the interval transmissivity was recommended to a value of 1.0E–11 m^2/s which was in the same time regarded as the upper boundary of the confidence range. This value is consistent with the observations made during the analysis of the other tests in the borehole (i.e. the transmissivity must be lower than in the cases when the test was analysable).

5.5 Non-conformities

At the performance of 100 m section injection tests, the in-the-hole equipment got stuck in the borehole at a depth of 206 m below TOC (depth of top of tool) when pulling out. SKB was informed immediately about the stuck of the tool and further action was discussed with and agreed by SKB. Several tries were made to free the equipment first by moving with the rig, later by using a percussion hammer and subsequently a stronger rig and a stronger piping. Further investigations were made using a televiewer showing hydraulic and signal cables visibly knotted on top of the shut-in-tool. Cause of the stuck equipment may be a combination of worn tape, falling rock and sliding roles at the bobbins.

When several attempts to free the equipment failed, it was agreed by SKB to cancel the 20 m section tests at this stage. It was agreed to set up specific improvements to perform hydrotesting in such deep, strongly inclined and partially fissured rock. Examples of discussed improvements are: taping of each cable at a time, weartape for protection, cable markings for control of pulling out, stronger motors and higher friction on bobbins and closer spacing between the tapes.

6 Results

In the following, results of all tests are presented and analysed. The results are given as general comments to test performance, the identified flow regimes and calculated parameters and finally the parameters which are considered as most representative are chosen and justification is given. All results are also summarised in Table 7-1 and 7-2 of the Synthesis chapter.

6.1 100 m single-hole injection tests

In the following sections the tests conducted in borehole KSH03A are presented and analysed.

6.1.1 Section 102.5–202.5 m, test no 2, injection

Comments to test

The test was composed of a constant pressure injection test phase with a pressure difference of 60 kPa, followed by a pressure recovery phase. No hydraulic connection between test interval and the adjacent zones was observed. The injection rate control during the CHi phase was good. In addition, due to the very high transmissivity, the automatic regulation system set a new target pressure of 60 kPa. The injection rate decreased from 57.6 L/min at start of the CHi phase to 44.1 L/min at the end. The recovery phase (CHir) shows no problems and is adequate for quantitative analysis.

Flow regime and calculated parameters

The flow dimension is interpreted from the slope of the semi-log derivative plotted in log-log coordinates. In case of the present test the CHi phase shows a flat derivative at late times, which is indicative of a flow dimension of 2 (radial flow). The CHir phase derivative shows a downward trend at late times indicating an increase of transmissivity at some distance from the borehole. An infinite acting homogeneous radial flow model was chosen for the analysis of the CHi phase. For the analysis of the CHir phase a radial composite flow model was chosen. The analysis is presented in Appendix 2-1. The table below presents relevant parameters with respect to the selected model.

Table 6-1. Analyses results; section 102.5–202.5 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	1.20E–4	NA	NA
T_M [m^2/s]	1.56E–4	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	1.91E–4	NA	1.03E–4
T_2 [m^2/s]	NA	NA	2.06E–4
r_1 [m]	NA	NA	2.02
S [–] (ass. approx 1E–6)	1.00E–6	NA	1.00E–6
ξ [–]	0	NA	–3.61
C [m^3/Pa]	NA	NA	1.67E–7

Selected representative parameters

The recommended transmissivity of 2.06E–4 m^2/s was derived from the analysis of the CHir phase (outer zone), which shows a good data and derivative quality. The confidence range for the interval transmissivity is estimated to be 9.0E–5 to 2.5E–4 m^2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 912.4 kPa.

The analysis of the CHi and CHir phases shows good consistency. No further analysis is recommended.

6.1.2 Section 201–301 m, test no 1, injection

Comments to test

The test was composed of a constant pressure injection test phase with a pressure difference of 9 kPa, followed by a pressure recovery phase. No hydraulic connection between test interval and the adjacent zones was observed. The injection rate control during the CHi phase was good. In addition, due to very high injection rates (very high transmissivity) the target difference pressure of 200 kPa could not be matched, instead of this the automatic regulation system set a new target pressure of 9 kPa. The injection rate decreased from 49.3 L/min at start of the CHi phase to 31.2 L/min at the end, indicating a relatively very high interval transmissivity. According to the low pressure difference, the recovery phase (CHir) shows some inaccuracies and is adequate for quantitative analysis only considering the limits of test performance.

Flow regime and calculated parameters

The flow dimension is interpreted from the slope of the semi-log derivative plotted in log-log coordinates. In case of the present test the CHi phase shows a flat derivative at late times, which is indicative of a flow dimension of 2 (radial flow). According to the low pressure difference of 9 kPa, the CHir phase derivative shows only indications for transmissivities close to the borehole. An infinite acting homogeneous radial flow model was chosen for the analysis of the CHi phase. For the analysis of the CHir phase an infinite acting homogeneous radial flow model was chosen as well. The analysis is presented in Appendix 2-2. The table below presents relevant parameters with respect to the selected model.

Table 6-2. Analyses results; section 201–301 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	5.50E–4	NA	NA
T_M [m^2/s]	7.16E–4	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	1.09E–4 (results less reliable due to low pressure difference)	1.58E–4 (results less reliable due to low pressure difference)	NA
T_2 [m^2/s]	NA	NA	NA
r_1 [m]	NA	NA	NA
S [–] (ass. approx 1E–6)	1.00E–6	1.00E–6	NA
ξ [–]	–6.73	–8.50	NA
C [m^3/Pa]	NA	6.69E–7	NA

Selected representative parameters

The recommended transmissivity of 1.58E–4 m^2/s was derived from the analysis of the CHir phase, which shows the best data and derivative quality. The confidence range for the interval transmissivity is estimated to be 1.0E–4 to 4.0E–4 m^2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 1,737.0 kPa.

The analysis of the CHi and CHir phases shows consistency only at the last parts of the phases. According to the test restrictions (the testing system could not inject with a higher flow rate to meet the target pressure difference), no further analysis is recommended.

6.1.3 Section 300–400 m, test no 1, injection

Comments to test

The test was composed of a constant pressure injection test phase with a pressure difference of 200 kPa, followed by a pressure recovery phase. No hydraulic connection between test interval and the adjacent zones was observed. The injection rate control during the CHi phase was very good. The injection rate decreased from 16.1 L/min at start of the CHi phase to 14.4 L/min at the end, indicating a relatively high interval transmissivity. The recovery phase (CHir) shows no problems and is adequate for quantitative analysis.

Flow regime and calculated parameters

The flow dimension is interpreted from the slope of the semi-log derivative plotted in log-log coordinates. In case of the present test the CHi phase shows an increasing derivative at late times (after a period of a flat derivative), which is indicative of a flow dimension of 2 (radial flow) in connection to a composite model. The CHir phase derivative shows an upward trend at late times indicating a decrease of transmissivity at some distance from the borehole. A radial composite flow model was chosen for the analysis of the CHi phase. For the analysis of the CHir phase a radial composite flow model was chosen as well. The analysis is presented in Appendix 2-3. The table below presents relevant parameters with respect to the selected model.

Table 6-3. Analyses results; section 300 –400 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	1.18E–5	NA	NA
T_M [m^2/s]	1.53E–5	NA	NA
Flow model	Radial 2 shell composite infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	4.20E–5	NA	4.49E–5
T_2 [m^2/s]	2.10E–5	NA	2.58E–5
r_1 [m]	2.28E+7	NA	5.70E+7
S [–] (ass. approx 1E–6)	1.00E–6	NA	1.00E–6
ξ [–]	11.68	NA	12.84
C [m^3/Pa]	NA	NA	6.51E–9

Selected representative parameters

The recommended transmissivity of 2.6E–5 m^2/s was derived from the analysis of the CHir phase (outer zone), which shows a good data and derivative quality. The confidence range for the interval transmissivity is estimated to be 2.0E–5 to 5.0E–5 m^2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 2,567.4 kPa.

The analysis of the CHi and CHir phases shows good consistency. No further analysis is recommended.

6.1.4 Section 400–500 m, test no 1, injection

Comments to test

The test was composed of a constant pressure injection test phase with a pressure difference of 200 kPa, followed by a pressure recovery phase. No hydraulic connection between test interval and the adjacent zones was observed. The injection rate control during the CHi phase was not good at the middle and late times of the injection phase. The analysis results of the Chi phase should be regarded as order of magnitude only. The injection rate decreased from 41.7 mL/min at start of the CHi phase to 35.6 mL/min at the end, indicating a relatively low interval transmissivity. The recovery phase (CHir) shows no problems and is adequate for quantitative analysis.

Flow regime and calculated parameters

The flow dimension is interpreted from the slope of the semi-log derivative plotted in log-log coordinates. In case of the present test the CHi phase shows a flat derivative at late times, which is indicative of a flow dimension of 2 (radial flow). The CHir phase derivative is not reaching a flat phase, therefore no indication for a change of transmissivity at some distance of the borehole could be derived from the test evaluation. An infinite acting homogeneous radial flow model was chosen for the analysis of the CHi phase and for the CHir phase as well. The analysis is presented in Appendix 2-4. The table below presents relevant parameters with respect to the selected model.

Table 6-4. Analyses results; section 400–500 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	2.94E–8	NA	NA
T_M [m^2/s]	3.83E–8	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	2.64E–8	1.93E–8	NA
T_2 [m^2/s]	NA	NA	NA
r_1 [m]	NA	NA	NA
S [–] (ass. approx 1E–6)	1.00E–6	1.00E–6	NA
ξ [–]	0	–0.97	NA
C [m^3/Pa]	NA	4.95E–10	NA

Selected representative parameters

The recommended transmissivity of 1.9E–8 m^2/s was derived from the analysis of the CHir phase, which shows the best data and derivative quality. The confidence range for the interval transmissivity is estimated to be 8.0E–9 to 3.0E–8 m^2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 3,393.1 kPa.

The analysis of the CHi and CHir phases shows good consistency. Uncertainties due to the poor flow rate data quality during the injection phase have to be considered. No further analysis is recommended.

6.1.5 Section 500–600 m, test no 1, injection

Comments to test

After closing the shut-in tool following the packer inflation phase, the formation pressure rose steadily up by 40 kPa but did not stabilise in 45 min. Due to expected flow rates of less than 1 mL/min (sensitivity limit of the small flow meter) the test was skipped.

Flow regime and calculated parameters

The data sheet is presented in Appendix 2-5 but no analysis was performed. The table below presents relevant parameters.

Table 6-5. Analyses results; section 500–600 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	NA	NA	NA
T_M [m^2/s]	NA	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	NA	NA	NA
T_2 [m^2/s]	NA	NA	NA
r_1 [m]	NA	NA	NA
S [–] (ass. approx 1E–6)	NA	NA	NA
ξ [–]	NA	NA	NA
C [m^3/Pa]	NA	NA	NA

Selected representative parameters

The recommended transmissivity of < 1 E–11 m^2/s was derived from experience of previous tests in the boreholes KLX02 and KSH01A with flow rates of less than 1 mL/min. No further analysis is recommended.

6.1.6 Section 600–700 m, test no 1, injection

Comments to test

After closing the shut-in tool following the packer inflation phase, the formation pressure rose steadily up by 58 kPa but did not stabilise in 45 min. Due to expected flow rates of less than 1 mL/min (sensitivity limit of the small flow meter) the test was skipped.

Flow regime and calculated parameters

The data sheet is presented in Appendix 2-6 but no analysis was performed. The table below presents relevant parameters.

Table 6-6. Analyses results; section 600–700 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	NA	NA	NA
T_M [m^2/s]	NA	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	NA	NA	NA
T_2 [m^2/s]	NA	NA	NA
r_1 [m]	NA	NA	NA
S [–] (ass. approx 1E–6)	NA	NA	NA
ξ [–]	NA	NA	NA
C [m^3/Pa]	NA	NA	NA

Selected representative parameters

The recommended transmissivity of < 1 E–11 m^2/s was derived from experience of previous tests in the boreholes KLX02 and KSH01A with flow rates of less than 1 mL/min. No further analysis is recommended.

6.1.7 Section 700–800 m, test no 1, injection

Comments to test

After closing the shut-in tool following the packer inflation phase, the formation pressure rose steadily up by 43 kPa but did not stabilise in 45 min. Due to expected flow rates of less than 1 mL/min (sensitivity limit of the small flow meter) the test was skipped.

Flow regime and calculated parameters

The data sheet is presented in Appendix 2-7 but no analysis was performed. The table below presents relevant parameters.

Table 6-7. Analyses results; section 700–800 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	NA	NA	NA
T_M [m^2/s]	NA	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	NA	NA	NA
T_2 [m^2/s]	NA	NA	NA
r_1 [m]	NA	NA	NA
S [–] (ass. approx 1E–6)	NA	NA	NA
ξ [–]	NA	NA	NA
C [m^3/Pa]	NA	NA	NA

Selected representative parameters

The recommended transmissivity of < 1 E–11 m^2/s was derived from experience of previous tests in the boreholes KLX02 and KSH01A with flow rates of less than 1 mL/min. No further analysis is recommended.

6.1.8 Section 800–900 m, test no 1, injection

Comments to test

The test was composed of a constant pressure injection test phase with a pressure difference of 200 kPa, followed by a pressure recovery phase. No hydraulic connection between test interval and the adjacent zones was observed. The injection rate control during the CHi phase was very good. The injection rate decreased from 0.83 L/min at start of the CHi phase to 0.42 L/min at the end, indicating a medium interval transmissivity. The recovery phase (CHir) shows no problems and is adequate for quantitative analysis.

Flow regime and calculated parameters

The flow dimension is interpreted from the slope of the semi-log derivative plotted in log-log coordinates. In case of the present test the CHi phase shows a flat derivative at late times, which is indicative of a flow dimension of 2 (radial flow). The CHir phase derivative shows an upward trend at late times indicating a decrease of transmissivity at some distance from the borehole. An infinite acting homogeneous radial flow model was chosen for the analysis of the CHi phase. For the analysis of the CHir phase a radial composite flow model was chosen. The analysis is presented in Appendix 2-8. The table below presents relevant parameters with respect to the selected model.

Table 6-8. Analyses results; section 800–900 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	3.45E–7	NA	NA
T_M [m^2/s]	4.49E–7	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	1.47E–7	NA	4.14E–7
T_2 [m^2/s]	NA	NA	1.65E–7
r_1 [m]	NA	NA	0.97
S [–] (ass. approx 1E–6)	1.00E–6	NA	1.00E–6
ξ [–]	–4.02	NA	–2.36
C [m^3/Pa]	NA	NA	3.09E–10

Selected representative parameters

The recommended transmissivity of 1.7E–7 m^2/s was derived from the analysis of the CHir phase (outer zone), which shows the best data and derivative quality. The confidence range for the interval transmissivity is estimated to be 1.0E–7 to 5.0E–7 m^2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 6,772.3 kPa.

The analysis of the CHi and CHir phases shows good consistency. No further analysis is recommended.

6.1.9 Section 895–995 m, test no 1, injection

Comments to test

The test was composed of a constant pressure injection test phase with a pressure difference of 200 kPa, followed by a pressure recovery phase. A hydraulic connection between test interval and the bottom zone was observed. The injection rate control during the CHi phase was very good. The injection rate decreased from 0.23 L/min at start of the CHi phase to 0.15 L/min at the end, indicating a medium interval transmissivity. The recovery phase (CHir) shows no problems and is adequate for quantitative analysis.

Flow regime and calculated parameters

The flow dimension is interpreted from the slope of the semi-log derivative plotted in log-log coordinates. In case of the present test the CHi phase shows a flat derivative at late times, which is indicative of a flow dimension of 2 (radial flow). The CHir phase derivative shows an upward trend at late times indicating a decrease of transmissivity at some distance from the borehole. An radial composite flow model was chosen for the analysis of the CHi phase and of the CHir phase as well. The analysis is presented in Appendix 2-9. The table below presents relevant parameters with respect to the selected model.

Table 6-9. Analyses results; section 895–995 m.

Parameter	CHi Phase	CHir Phase	CHir Phase
Q/s [m^2/s]	1.22E–7	NA	NA
T_M [m^2/s]	1.58E–7	NA	NA
Flow model	Homogeneous infinite acting.	WBS and skin. Homogeneous infinite acting.	WBS and skin. Radial 2 shell composite infinite acting.
T_1 [m^2/s]	1.40E–7	NA	1.41E–7
T_2 [m^2/s]	8.09E–8	NA	5.47E–8
r_1 [m]	12.77	NA	14.17
S [–] (ass. approx 1E–6)	1.00E–6	NA	1.00E–6
ξ [–]	0	NA	0
C [m^3/Pa]	NA	NA	3.42E–10

Selected representative parameters

The recommended transmissivity of 5.5E–8 m^2/s was derived from the analysis of the CHir phase (outer zone), which shows a good data and derivative quality. The confidence range for the interval transmissivity is estimated to be 5.0E–8 to 2.0E–7 m^2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 7,545.4 kPa.

The analysis of the CHi and CHir phases shows good consistency. No further analysis is recommended.

7 Synthesis

The synthesis chapter summarizes the basic test parameters and analysis results. In addition, the correlation between steady state and transient transmissivities as well as between the matched and the theoretical wellbore storage (WBS) coefficient are presented and discussed.

7.1 Summary of results

Table 7-1. General test data from constant head injection tests in KSH03A (bml = below measurement limit).

Borehole secup (m)	Borehole seclow (m)	Date and time for test, start YYYYMMDD hh:mm	Date and time for test, stop YYYYMMDD hh:mm	Q_p (m^3/s)	Q_m (m^3/s)	tp (s)	t_F (s)	p_0 (kPa)	p_i (kPa)	p_p (kPa)	p_F (kPa)	Te_w (°C)	Test phases measured Analysed test phases marked bold	
102.50	202.50	20040210 10:58	20040210 12:45	7.35E–04	7.83E–04	1,800	1,800	910.0	911.6	972.1	914.4	8.8	CHi	CHir
201.00	301.00	20040210 14:10	20040210 16:23	5.04E–04	6.28E–04	1,800	1,800	1,735.8	1,736.4	1,744.1	1,738.0	8.9	CHi	CHir
300.00	400.00	20040210 18:00	20040211 05:28	2.40E–04	2.54E–04	1,800	36,000	2,565.5	2,566.0	2,764.4	2,567.7	10.0	CHi	CHir
400.00	500.00	20040211 09:50	20040211 12:30	6.00E–07	2.31E–05	1,800	1,800	3,407.8	3,426.5	3,626.5	3,420.5	11.2	CHi	CHir
500.00	600.00	20040211 14:19	20040211 15:37	–	–	–	–	4,252.9	–	–	–	12.5	–	–
600.00	700.00	20040211 17:11	20040211 18:30	–	–	–	–	5,099.6	–	–	–	13.8	–	–
700.00	800.00	20040212 10:22	20040212 11:41	–	–	–	–	5,945.0	–	–	–	15.1	–	–
800.00	900.00	20040212 13:52	20040212 16:57	6.99E–06	8.62E–06	1,800	5,400	6,788.6	6,776.5	6,978.1	6,784.2	16.4	CHi	CHir
895.00	995.00	20040212 18:14	20040213 06:15	2.48E–06	2.82E–06	1,800	36,000	7,543.0	7,546.8	7,746.8	7,538.6	17.5	CHi	CHir

#NV not analysed.

CHi: constant head injection phase.

CHir: recovery phase following the constant head injection phase.

Table 7-2. Results from analysis of constant head injection tests in KSH03A.

Interval position		Stationary flow parameters		Transient analysis													Static conditions	
				Flow regime		Formation parameters												
up	low	Q/s	T_M	Perturb phase	Recovery phase	T_{f1}	T_{f2}	T_{s1}	T_{s2}	T_T	T_{TMIN}	T_{TMAX}	C	ξ	dt_1	dt_2	p*	h_{wif}
m btoc	m btoc	m^2/s	m^2/s			m^2/s	m^2/s	m^2/s	m^2/s	m^2/s	m^2/s	m^2/s	m^3/Pa	–	min	min	kPa	masl
102.5	202.5	1.20E–04	1.56E–04	2	WBS22	#NV	1.2E–04	1.0E–04	2.1E–04	2.1E–04	9.0E–05	2.5E–04	1.67E–07	–3.6	1.1	4.4	912.4	–2.29
201	301	5.50E–04	7.16E–04	2	WBS2	#NV	1.1E–04	#NV	1.6E–04	1.6E–04	1.0E–04	4.0E–04	6.69E–07	–8.5	–	–	1,737.0	–2.88
300	400	1.18E–05	1.53E–05	22	WBS22	4.2E–05	2.1E–05	4.5E–05	2.6E–05	2.6E–05	2.0E–05	5.0E–05	6.51E–09	12.8	0.8	3.1	2,567.4	–3.32
400	500	2.94E–08	3.83E–08	2	WBS2	#NV	2.6E–08	#NV	1.9E–08	1.9E–08	8.0E–09	3.0E–08	4.95E–10	–0.97	–	–	3,393.1	–5.10
500	600	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	1.0E–11	1.0E–13	1.0E–11	#NV	#NV	#NV	#NV	#NV	#NV
600	700	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	1.0E–11	1.0E–13	1.0E–11	#NV	#NV	#NV	#NV	#NV	#NV
700	800	#NV	#NV	#NV	#NV	#NV	#NV	#NV	#NV	1.0E–11	1.0E–13	1.0E–11	#NV	#NV	#NV	#NV	#NV	#NV
800	900	3.45E–07	4.49E–07	2	WBS22	#NV	1.5E–07	4.1E–07	1.7E–07	1.7E–07	1.0E–07	5.0E–07	3.09E–10	–2.4	0.4	1.1	6,772.3	–4.41
895	995	1.22E–07	1.58E–07	22	WBS22	1.4E–07	8.1E–08	1.4E–07	5.5E–08	5.5E–08	5.0E–08	2.0E–07	3.42E–10	0.0	5.2	11.3	7,545.4	–7.25

Notes

1 T1 and T2 refer to the transmissivity(s) derived from the analysis while using the recommended flow model. In case a homogeneous flow model was recommended only one T value is reported, in case a two zones composite model was recommended both T1 and T2 are given. The recommended transmissivity T_T typically refers to the T2 value (far field transmissivity).

2 The parameter p* denoted the static formation p
extrapolation.

3 The flow regime description refers to the recomme
the flow dimension used in the analysis (1 = linear flow
was used in the analysis, if two numbers are given (WBS22 or 22) a 2 zones composite model was used.

#NV Not analysed.

The Figure 7-1 presents the hydraulic freshwater head profiles.

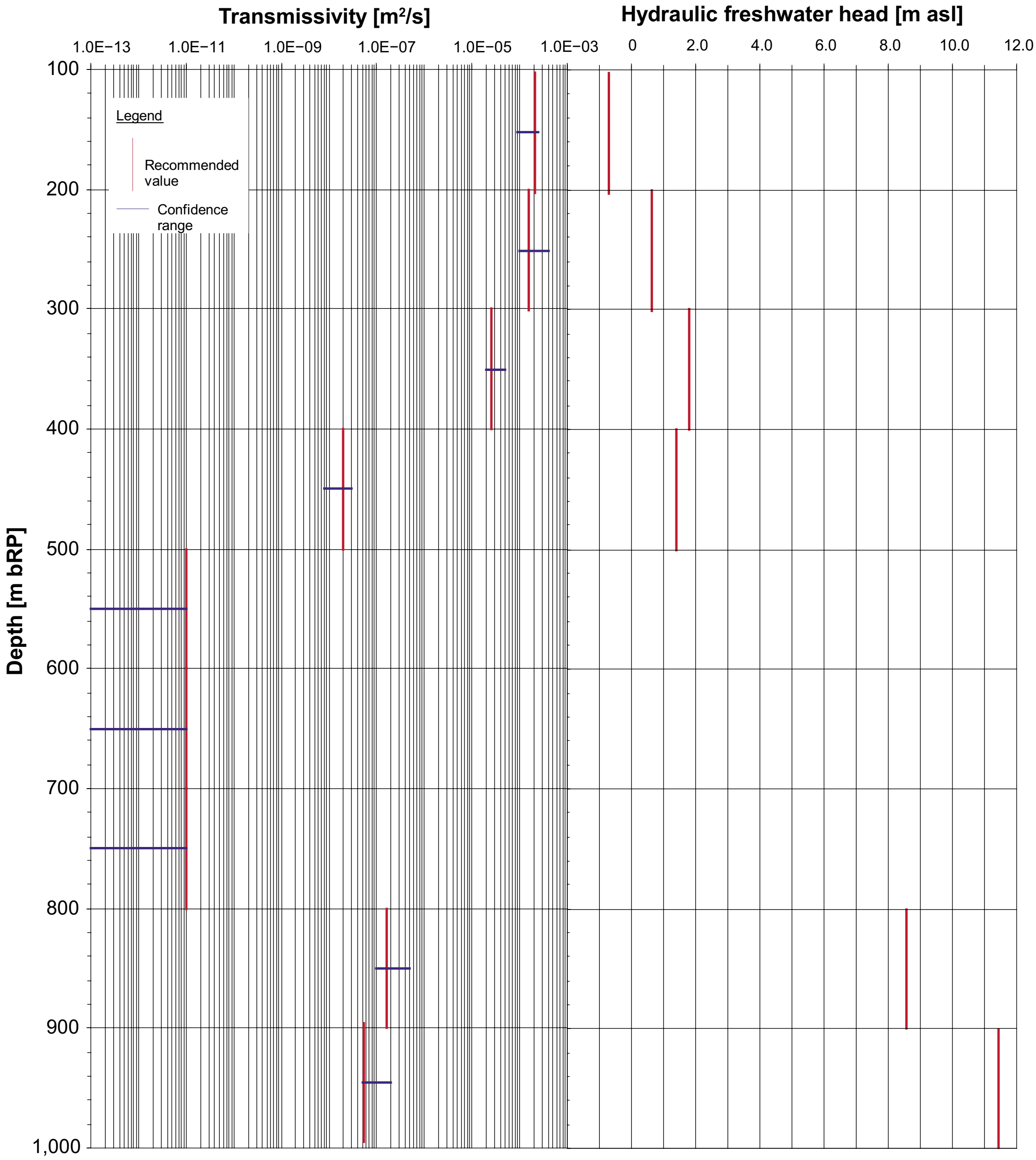

Figure 7-1. Results summary – profiles of transmissivity and equivalent freshwater head.

7.2 Correlation analysis

A correlation analysis was used with the aim of examining the consistency of results and deriving general conclusion regarding the testing and analysis methods used.

7.2.1 Comparison of steady state and transient analysis results

The steady state derived transmissivities (T_M and Q/s) were compared in a cross-plot with the recommended transmissivity values derived from the transient analysis (see following figure).

The correlation analysis shows that all of the steady state derived transmissivities differ by less than one order of magnitude from the transmissivities derived from the transient analysis.

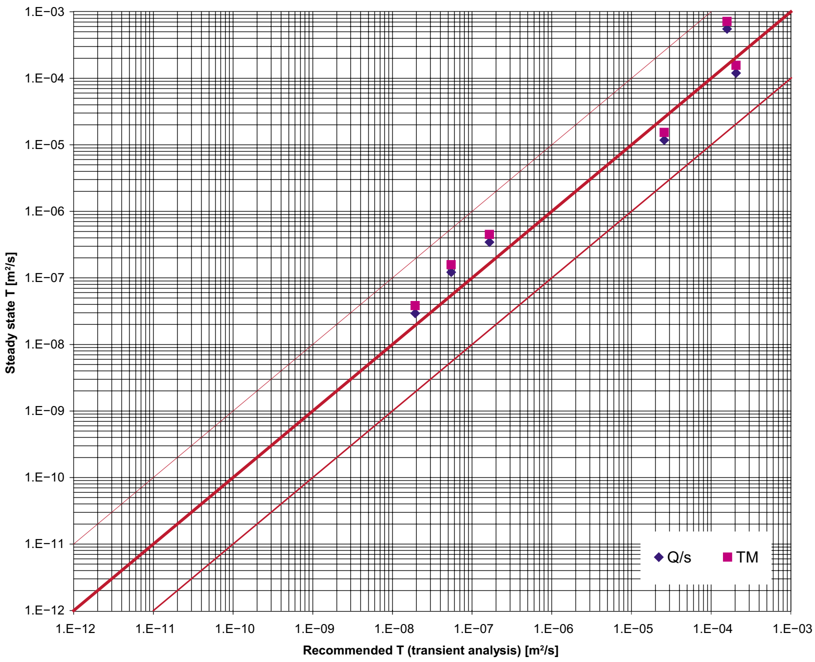

Figure 7-2. *Correlation analysis of transmissivities derived by steady state and transient methods.*

7.2.2 Comparison between the matched and theoretical wellbore storage coefficient

The wellbore storage coefficient describes the capacity of the test interval to store fluid as result to a unit pressure change in the interval. For a closed system (i.e. closed downhole valve) the theoretical value of the wellbore storage coefficient is given by the product between the interval volume and the test zone compressibility. The interval volume is calculated from the borehole radius and interval length. There are uncertainties concerning the interval volume calculation. Cavities or high transmissivity fractures intersecting the interval may enlarge the effective volume of the interval. The test zone compressibility is given by the sum of compressibilities of the individual components present in the interval (water, packer elements, other test tool components, and the borehole wall). A minimum value for the test zone compressibility is given by the water compressibility which is approx 5E–10 1/Pa. For the calculation of the theoretical wellbore storage coefficient a test zone compressibility of 7E–10 1/Pa was used. The matched wellbore storage coefficient is derived from the transient type curve analysis by matching the unit slope early times derivative plotted in log-log coordinates.

The following figure presents a cross-plot of the matched and theoretical wellbore storage coefficients.

It can be seen that the matched wellbore storage coefficients are up to three orders of magnitude larger than the theoretical values. A three orders of magnitude increase is difficult to explain by volume uncertainty. Even if large fractures are connected to the interval, a volume increase by three orders of magnitude does not seem probable. The discrepancy can be more likely explained by increased compressibility of the packer system. In order to better understand this phenomenon, a series of tool compressibility tests should be conducted in order to measure the tool compressibility and to assess to what extent the system behaves elastically.

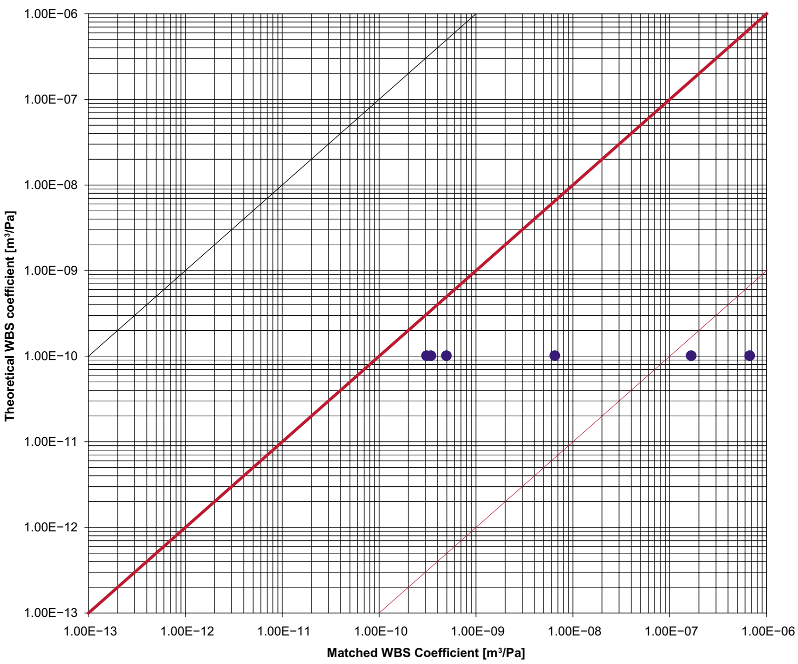

Figure 7-3. Correlation analysis of theoretical and matched wellbore storage coefficients.

8 Conclusions

8.1 Transmissivity

Figure 7-1 presents a profile of transmissivity, including the confidence ranges derived from the transient analysis. The method used for deriving the recommended transmissivity and its confidence range is described in Section 5.4.7.

Whenever possible, the transmissivities derived are representative for the "undisturbed formation" further away from the borehole. The borehole vicinity was typically described using a skin effect.

In some cases the tests were not analysable due to the fact that the flow rates during the CHi phase were below the range of the flowmeter (< 0.5 mL/min) or because the compliance phase following packer inflation was too long, thus indicating a very low interval transmissivity. In such cases the interval transmissivity was recommended to a value of 1.0E–11 m^2/s which was in the same time regarded as the upper boundary of the confidence range. This value is consistent with the observations made during the analysis of the other tests in the borehole (i.e. the transmissivity must be lower than in the cases when the test was analysable).

8.2 Equivalent freshwater head

Figure 7-1 presents a profile of the derived equivalent freshwater head expressed in meters above sea level. The method used for deriving the equivalent freshwater head is described in Section 5.4.6.

The head profile shows two distinct zones. The first zone between 102.5 m and 500 m depth shows freshwater heads between –0.5 m and 2 m asl. The second zone between 800 m and 995 m depth shows freshwater heads between 7.5 m and 11.5 m asl which is distinctly different from the heads derived from the upper zone. The freshwater heads show an increasing tendency towards greater depth. The two zones are separated by 300 m with a very low transmissivity, where no freshwater heads could be determined. A general increase of the freshwater head of approximately 1 m per 100 m depth could be derived from the freshwater head profile.

It should be noted that the head differences may be explained by salinity differences if we assume that the salinity increases with depth. In this case the freshwater heads would have to increase with depth, what the actual profile shows.

8.3 Flow regimes encountered

The flow models used in analysis were derived from the shape of the pressure derivative calculated with respect to log time and plotted in log-log coordinates.

In several cases the pressure derivative suggests a change of transmissivity with the distance from the borehole. In such cases a composite flow model was used in the analysis.

In other cases, the use of a homogeneous flow model led to very large skin factors (e.g. 20). In these cases, in addition to the homogeneous flow model analysis an analysis using a composite flow model was conducted. In these cases the skin was represented explicitly as inner composite zone.

The flow dimension displayed by the test can be diagnosed from the slope of the pressure derivative. A slope of 0.5 indicates linear flow, a slope of 0 (horizontal derivative) indicates radial flow and a slope of –0.5 indicates spherical flow. The flow dimension diagnosis was commented for each of the tests. However, in all cases it was possible to achieve to acceptable analysis results (good match quality) by using radial flow geometry (flow dimension of 2).

9 References

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APPENDIX 1

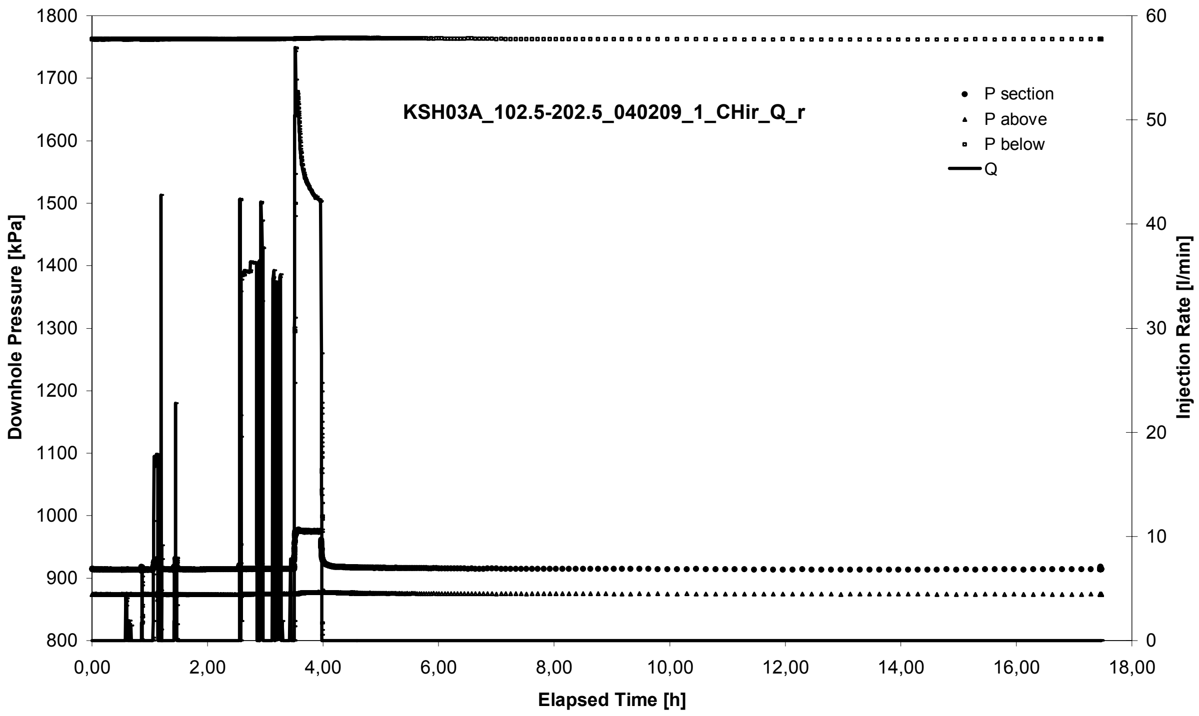
File Description Table

HYDROTESTING WITH PSS					**DRILLHOLE IDENTIFICATION NO.: KSH03A**				
TEST- AND FILEPROTOCOL					**Testorder dated : 2003-12-04**				
Teststart		Interval boundaries		Name of Datafiles		Testtype	Copied to	Plotted (date)	Sign.
Date	Time	Upper	Lower	(*.HT2-file)	(*.CSV-file)		disk/CD		
09.02.2004	11:00	102,5	202,5	__KSH03A_0897.50_200402091419.ht2	KSH03A_102.5-202.5_040209_1_CHir_Q_r.csv	Injection	18.02.2004	10.02.2004	
10.02.2004	10:58	102,5	202,5	__KSH03A_0897.50_200402101058.ht2	KSH03A_102.5-202.5_040210_2_CHir_Q_r.csv	Injection	18.02.2004	10.02.2004	
10.02.2004	14:10	201	301	__KSH03A_0201.00_200402101410.ht2	KSH03A_201-301_040210_1_CHir_Q_r.csv	Injection	18.02.2004	10.02.2004	
10.02.2004	18:00	300	400	__KSH03A_0300.00_200402101800.ht2	KSH03A_300-400_040210_1_CHir_Q_r.csv	Injection	18.02.2004	11.02.2004	
11.02.2004	09:50	400	500	__KSH03A_0400.00_200402110950.ht2	KSH03A_400-500_040211_1_CHir_Q_r.csv	Injection	18.02.2004	11.02.2004	
11.02.2004	14:16	500	600	__KSH03A_0500.00_200402111419.ht2	KSH03A_500-600_040211_1_CHir_Q_r.csv	Injection	18.02.2004	11.02.2004	
11.02.2004	17:11	600	700	__KSH03A_0600.00_200402111711.ht2	KSH03A_600-700_040211_1_CHir_Q_r.csv	Injection	18.02.2004	12.02.2004	
12.02.2004	10:22	700	800	__KSH03A_0700.00_200402121022.ht2	KSH03A_700-800_040212_1_CHir_Q_r.csv	Injection	18.02.2004	12.02.2004	
12.02.2004	13:52	800	900	__KSH03A_0800.00_200402121352.ht2	KSH03A_800-900_040212_1_CHir_Q_r.csv	Injection	18.02.2004	12.02.2004	
12.02.2004	18:14	895	995	__KSH03A_0895.00_200402121814.ht2	KSH03A_895-995_040212_1_CHir_Q_r.csv	Injection	18.02.2004	13.02.2004	

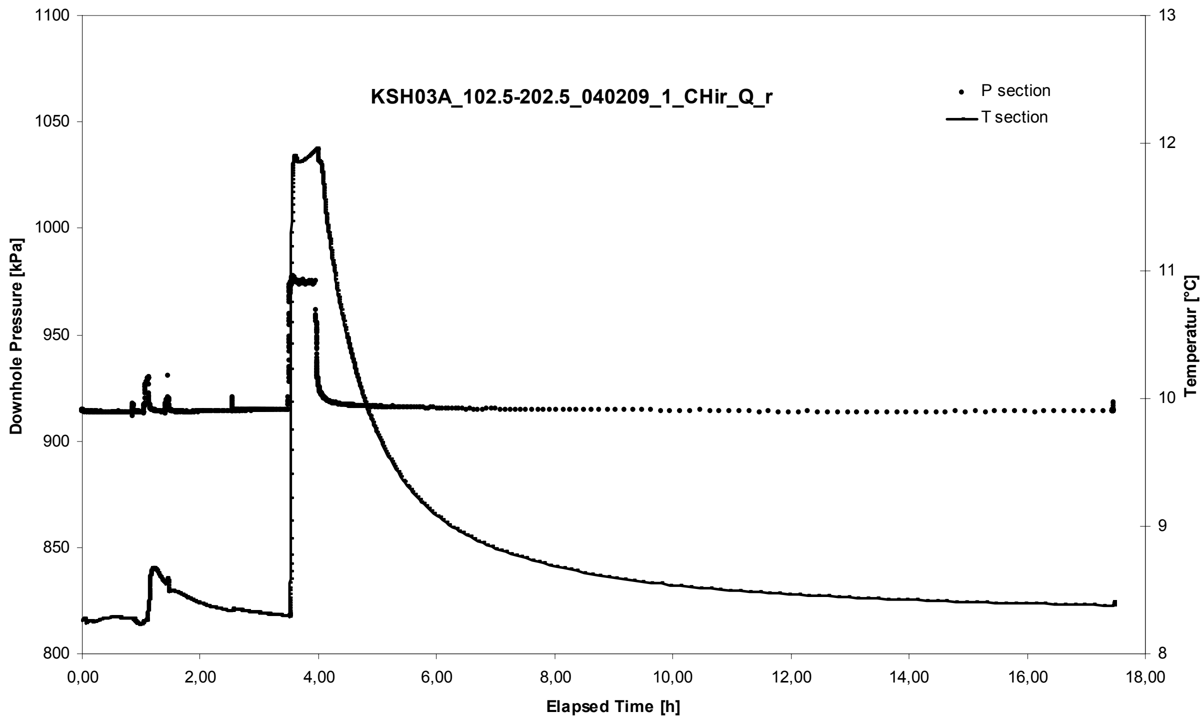
APPENDIX 2-1

Test 102,5 – 202,5 m

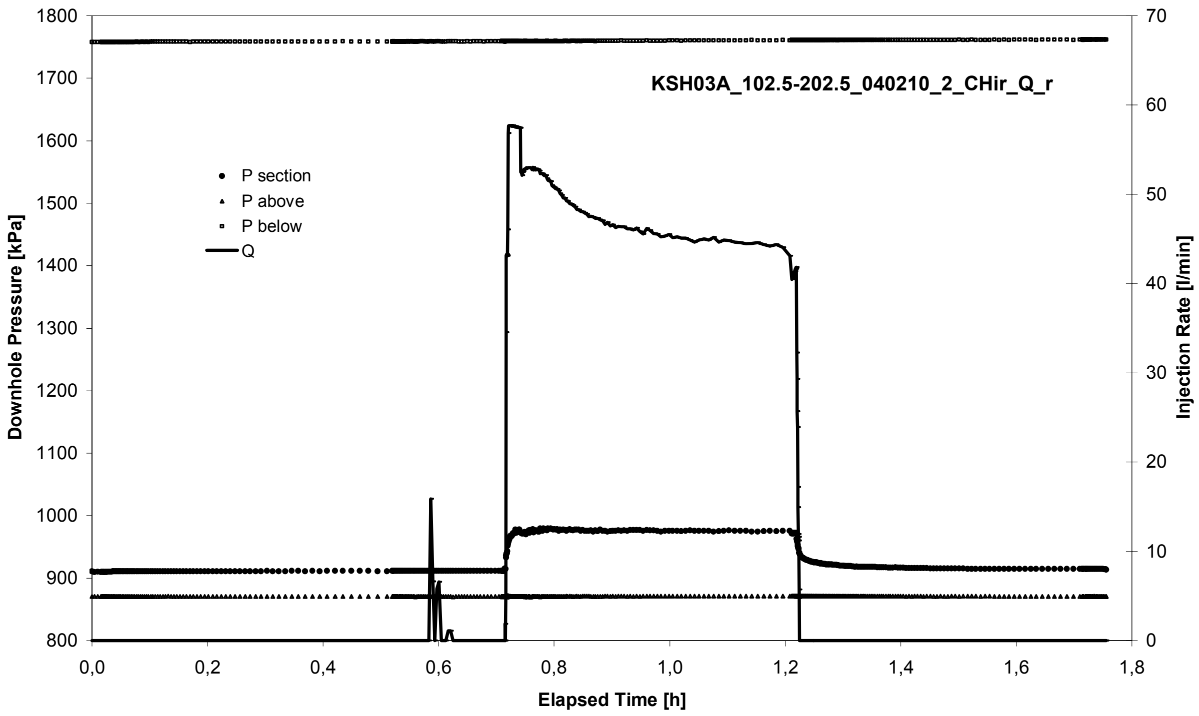
Analysis diagrams



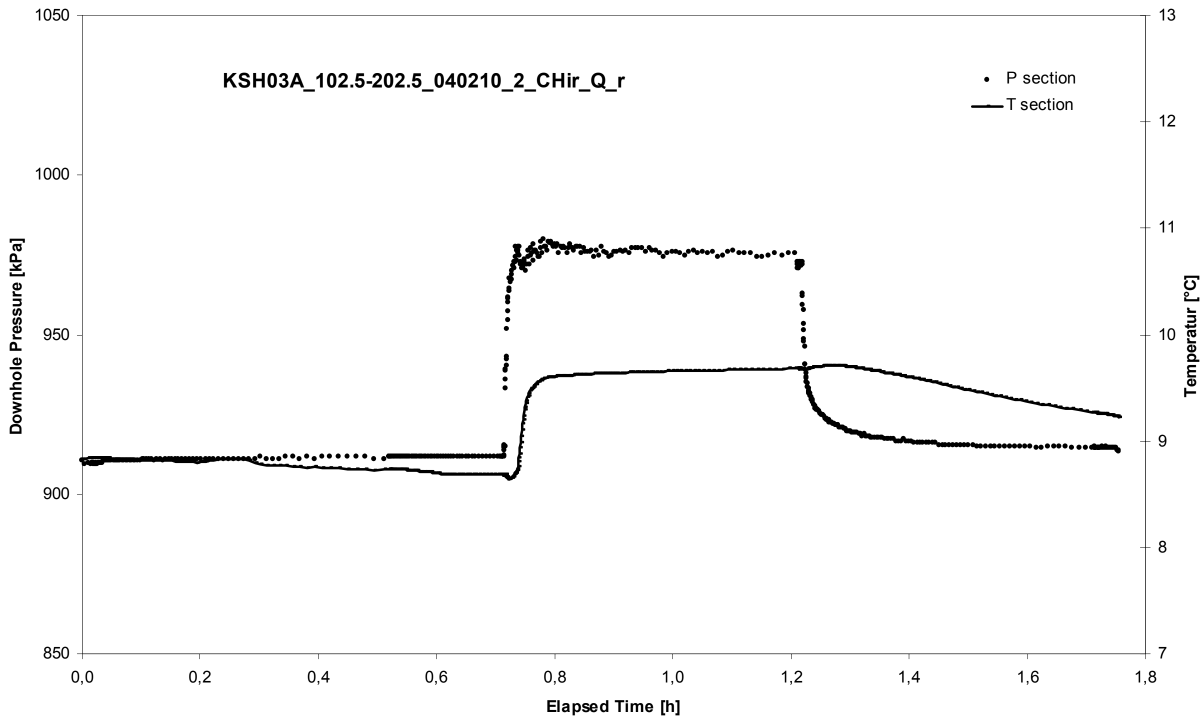
Pressure and flow rate vs. time; cartesian plot (test repeated)



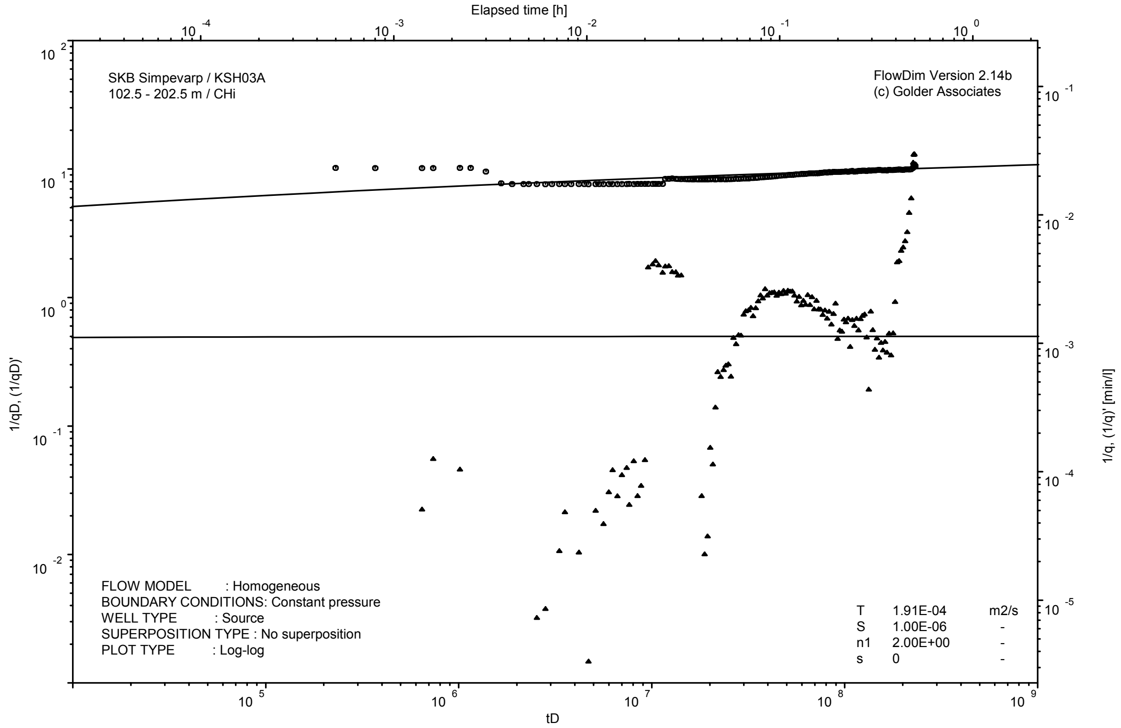
Interval pressure and temperature vs. time; cartesian plot (test repeated)



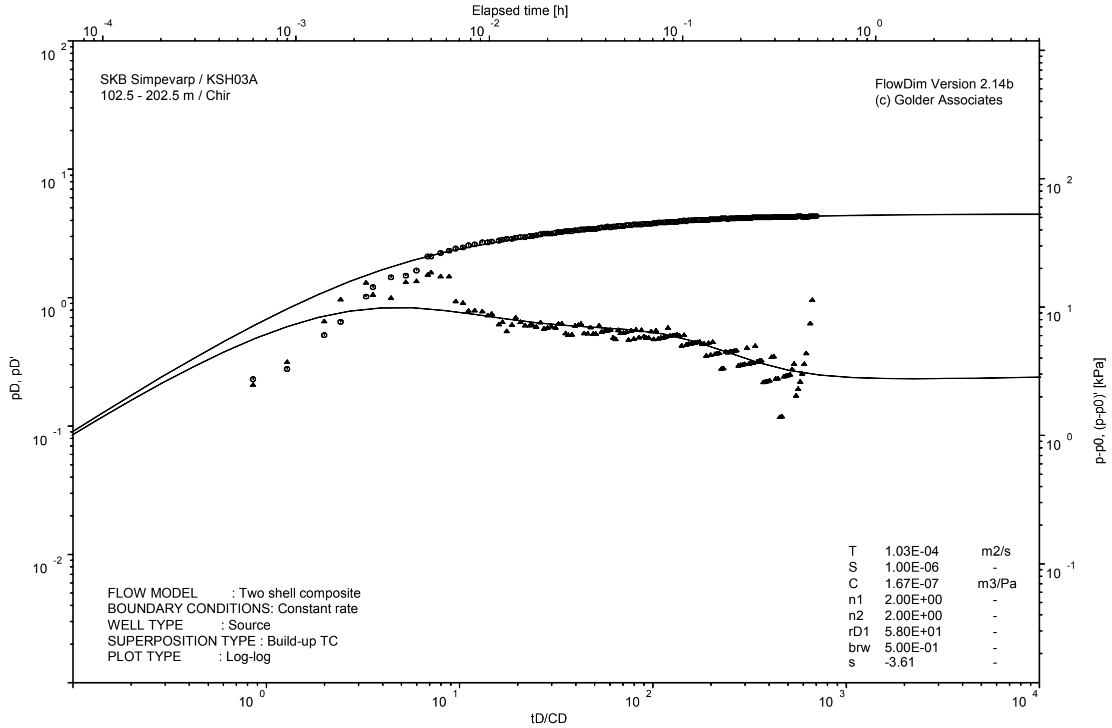
Pressure and flow rate vs. time; cartesian plot (analysed)



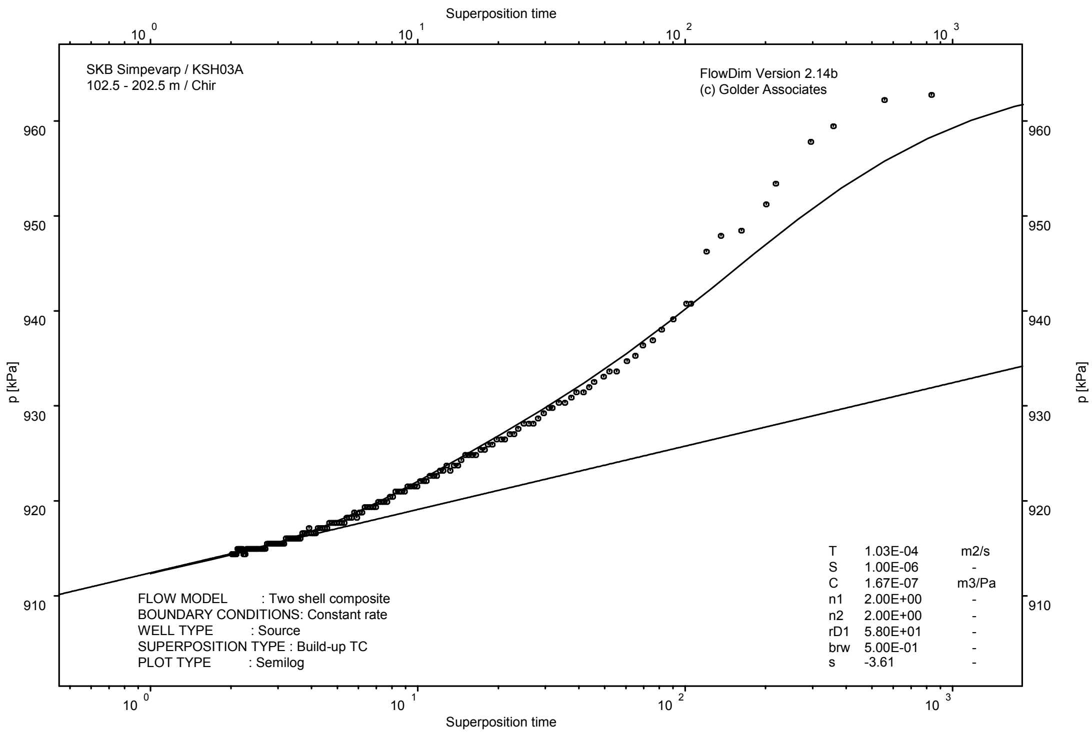
Interval pressure and temperature vs. time; cartesian plot (analysed)



CHI phase; log-log match



CHIR phase; log-log match

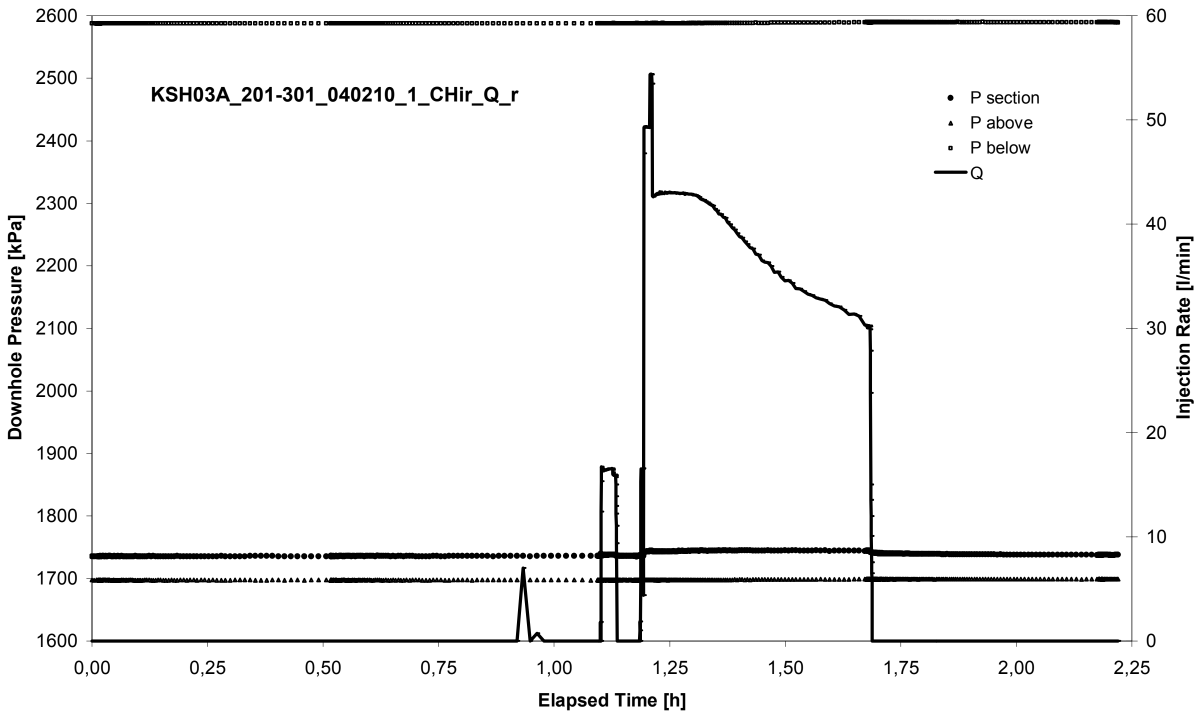


CHIR phase; HORNER match

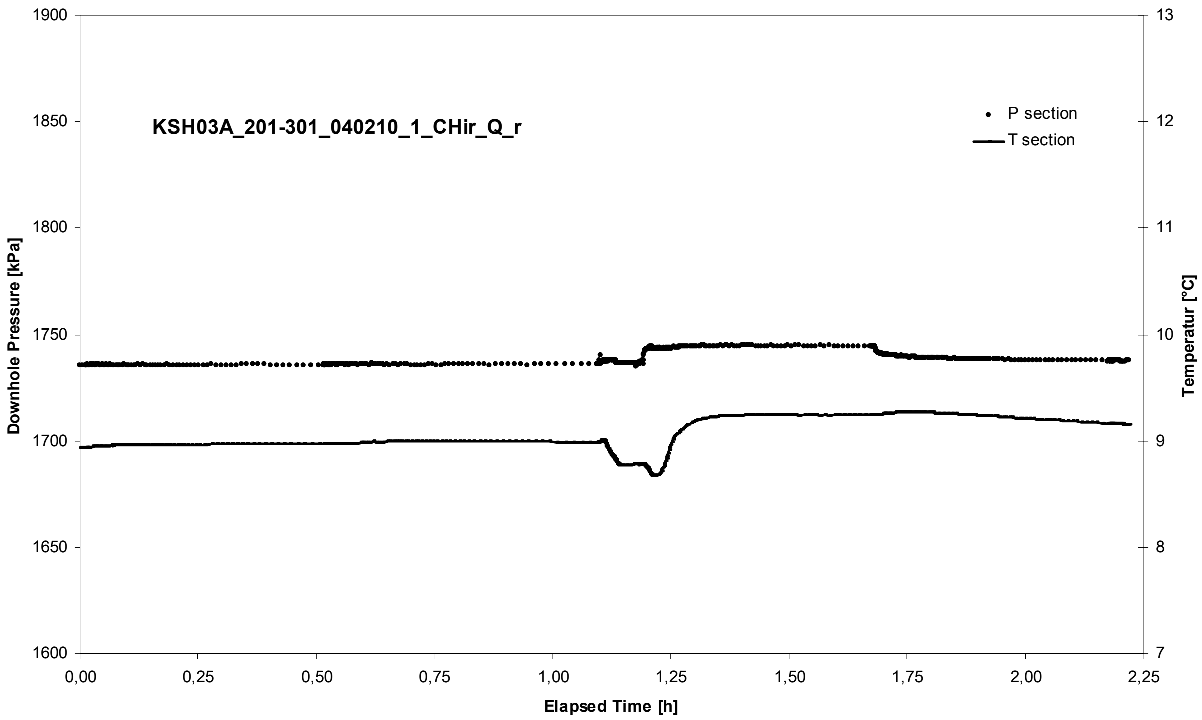
APPENDIX 2-2

Test 201 – 301 m

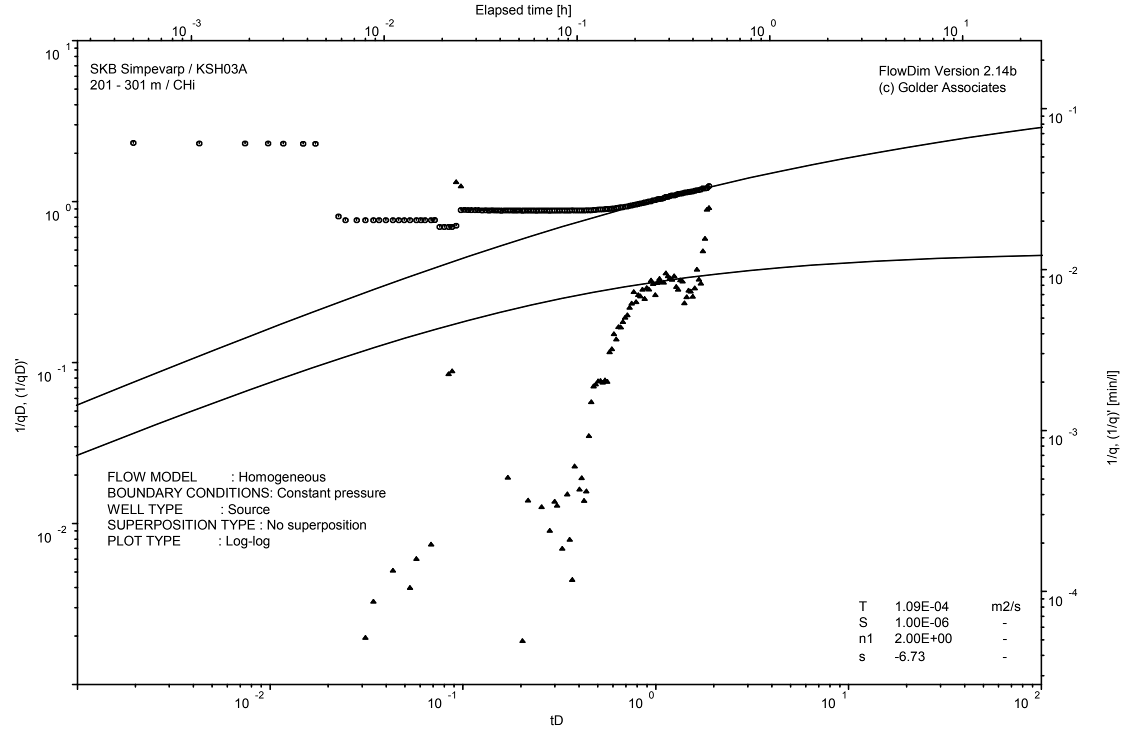
Analysis diagrams



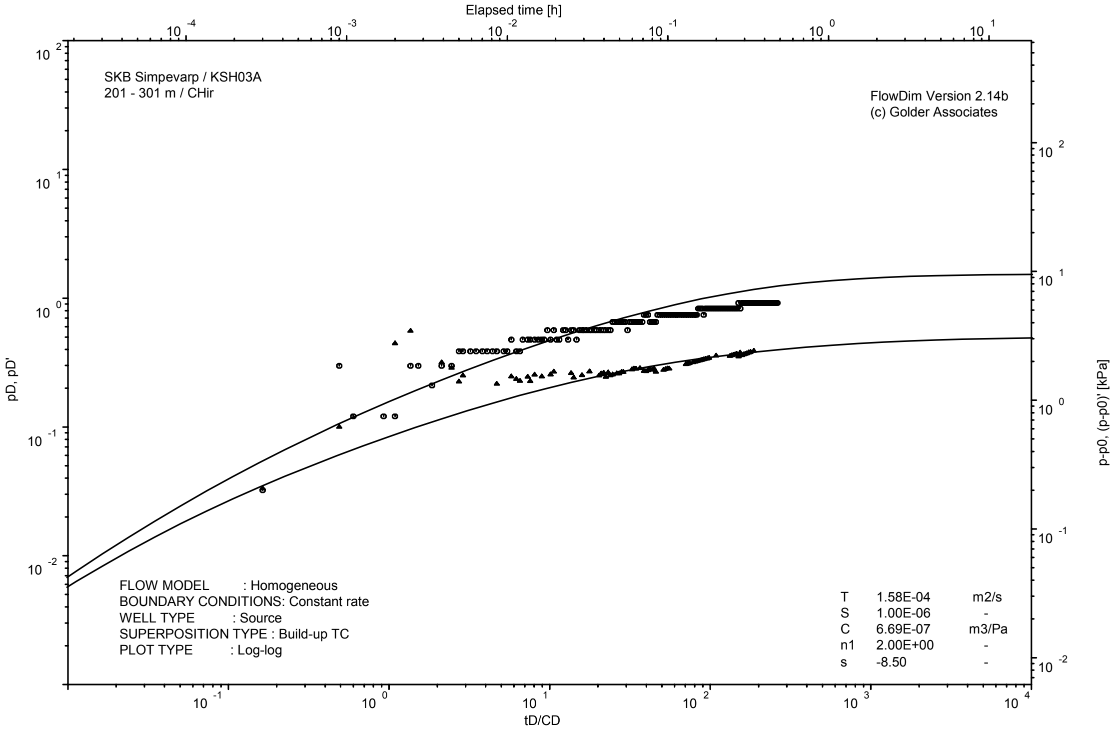
Pressure and flow rate vs. time; cartesian plot



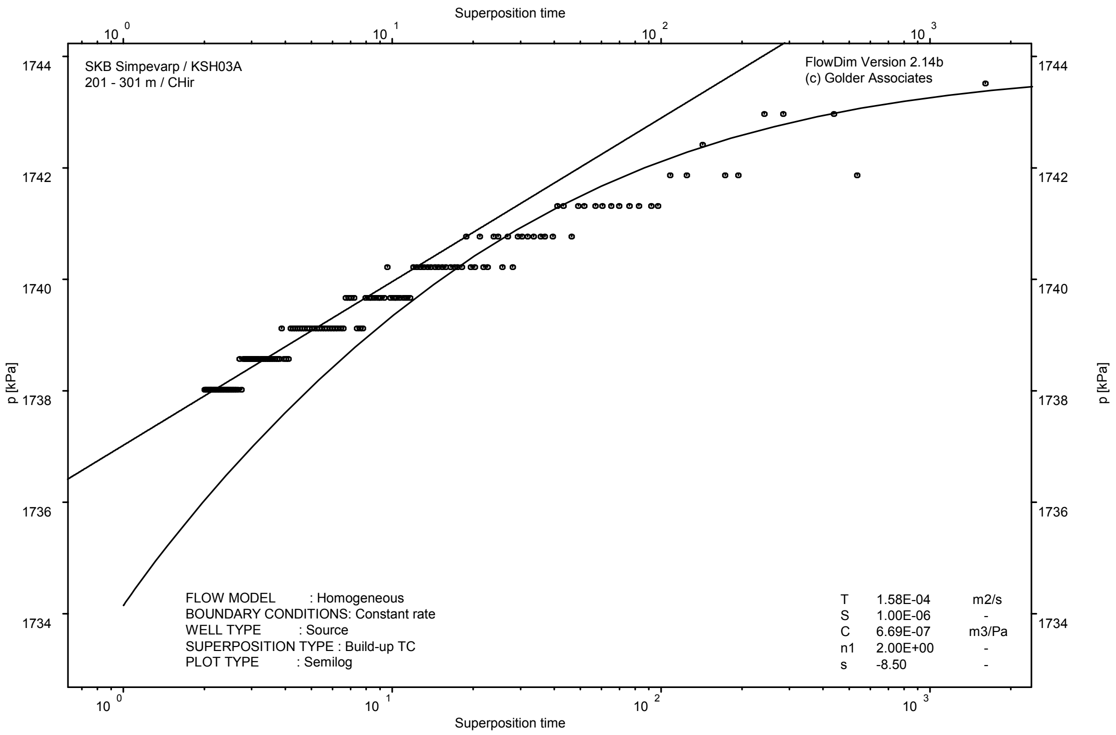
Interval pressure and temperature vs. time; cartesian plot



CHI phase; log-log match



CHIR phase; log-log match

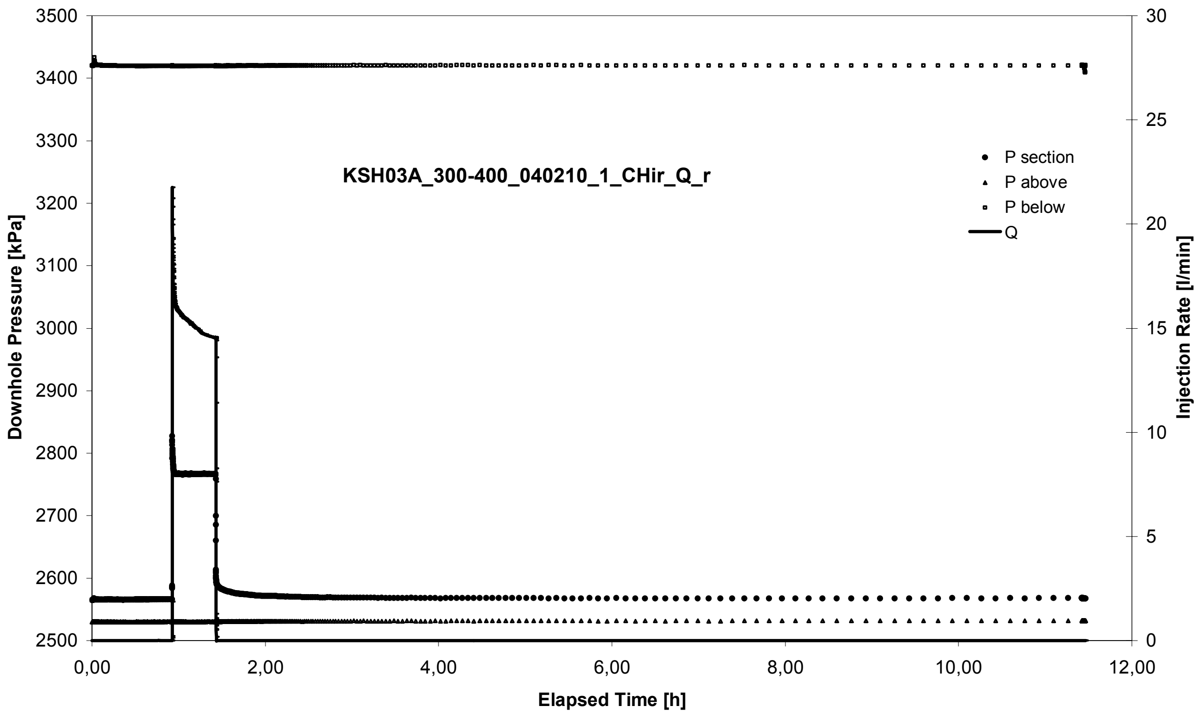


CHIR phase; HORNER match

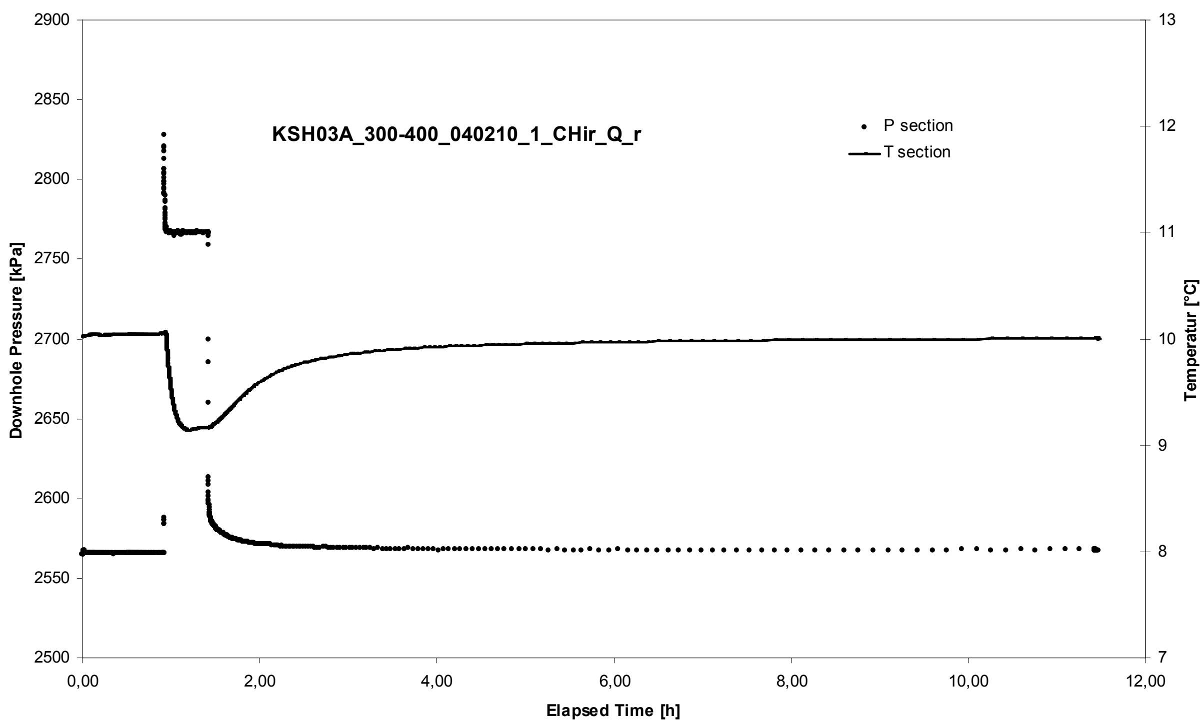
APPENDIX 2-3

Test 300 – 400 m

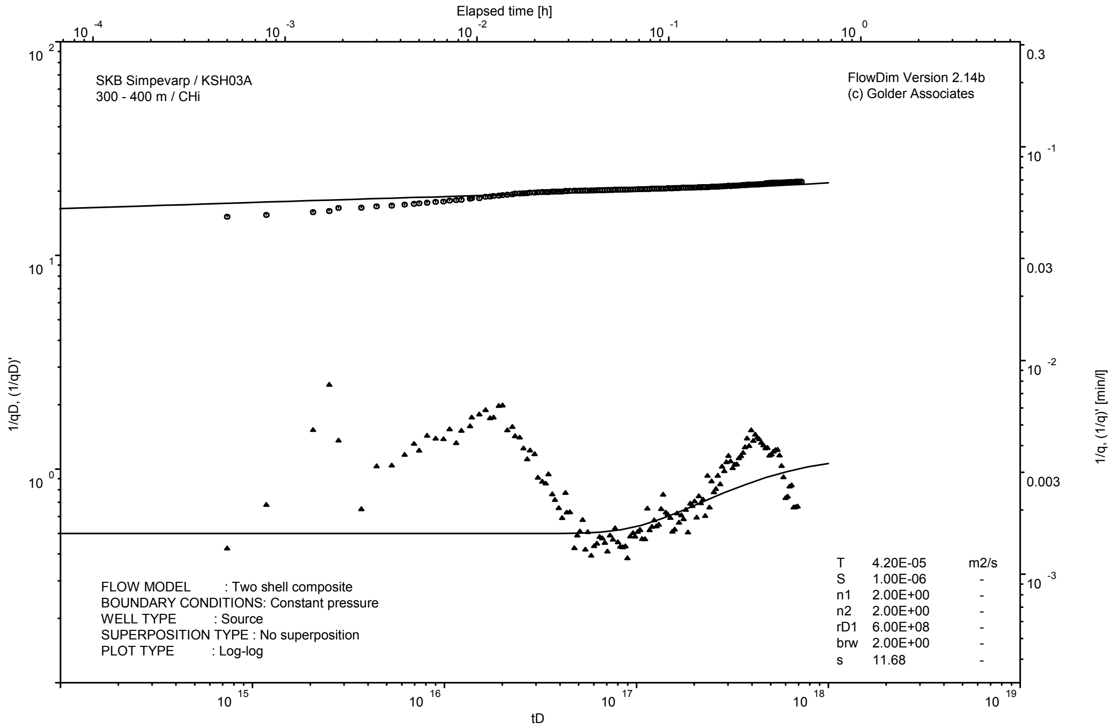
Analysis diagrams



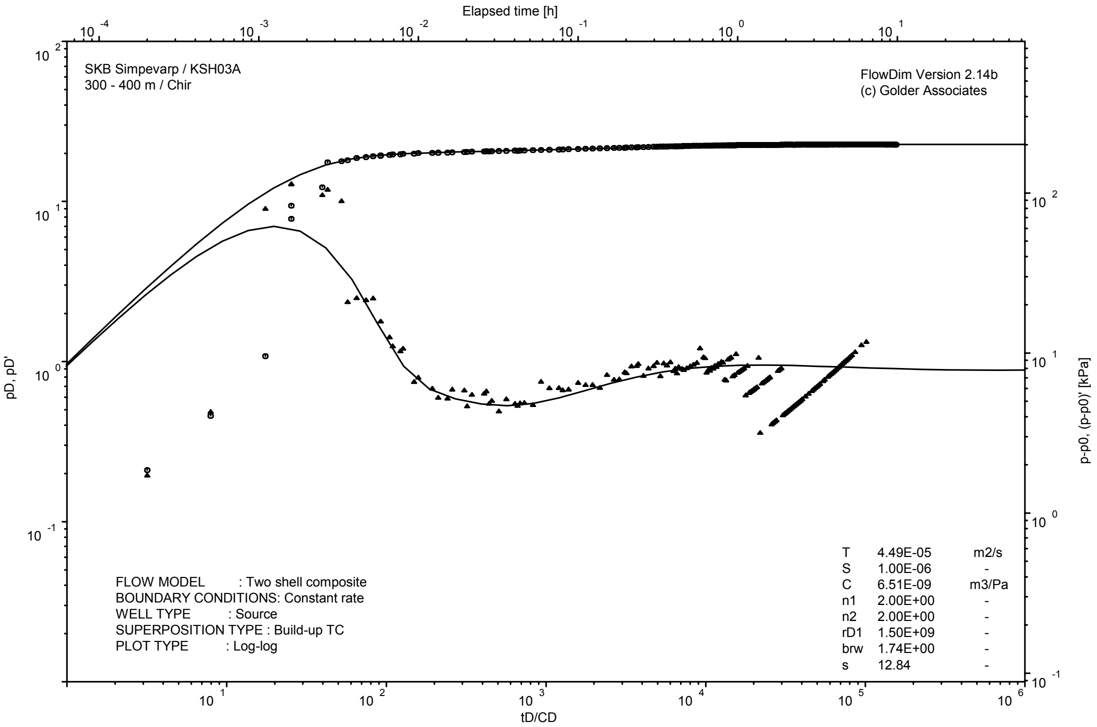
Pressure and flow rate vs. time; cartesian plot



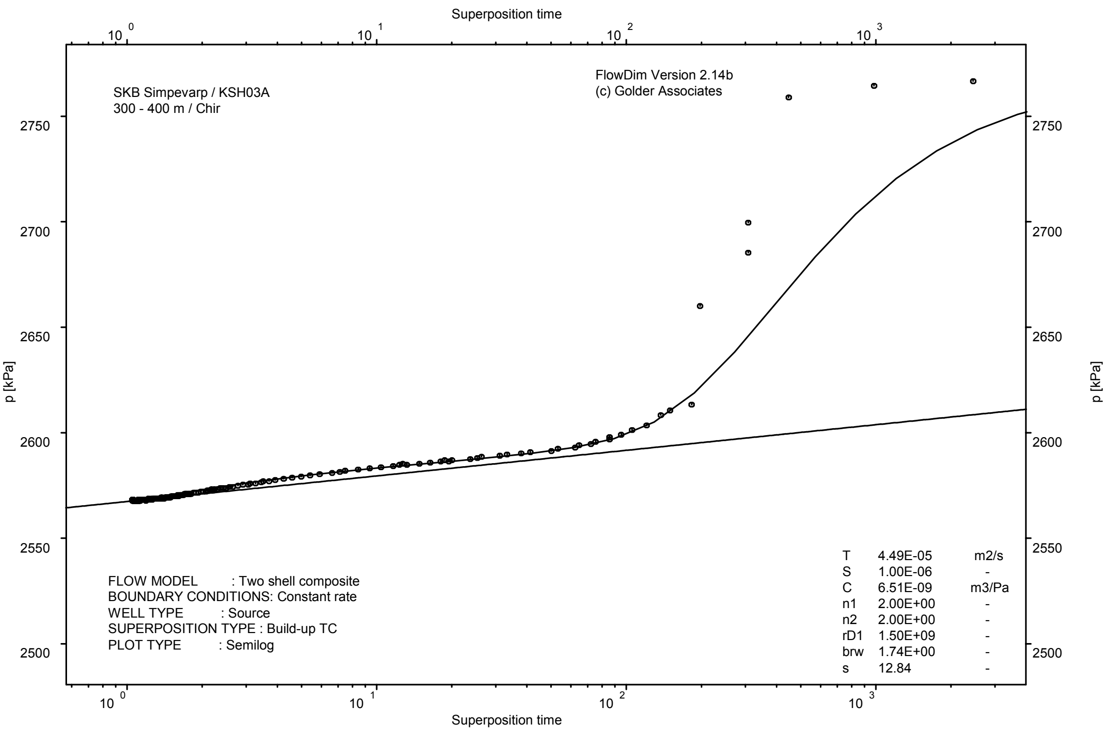
Interval pressure and temperature vs. time; cartesian plot



CHI phase; log-log match



CHIR phase; log-log match

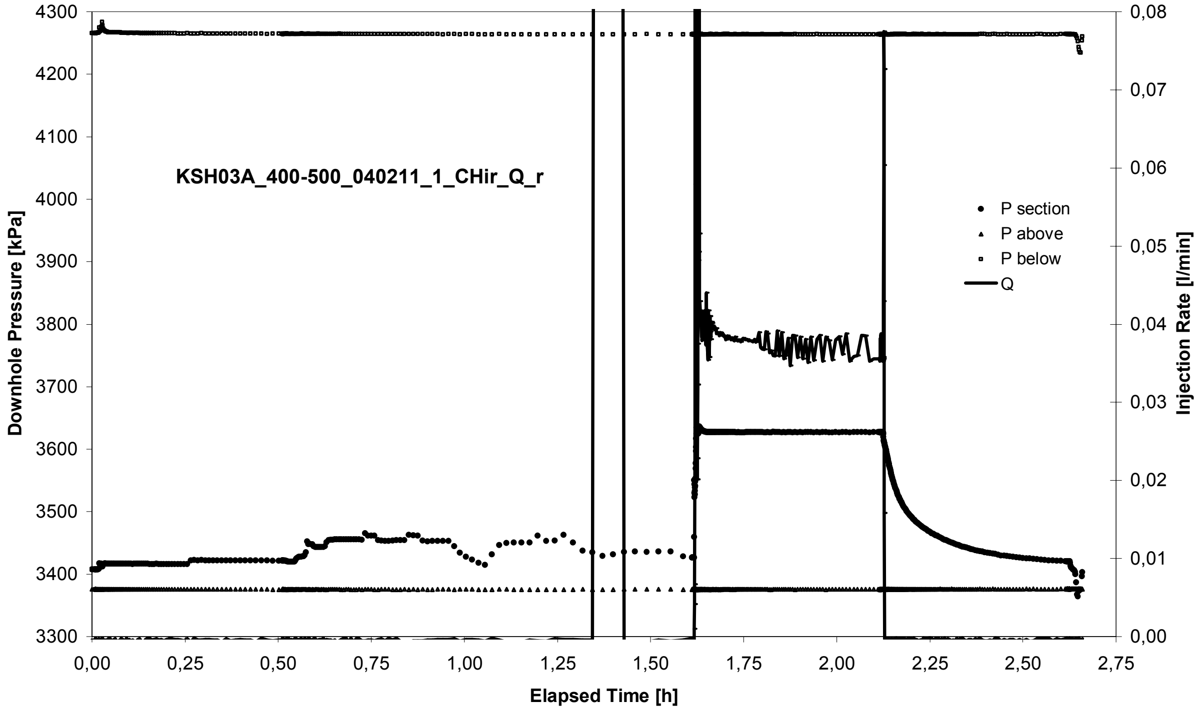


CHIR phase; HORNER match

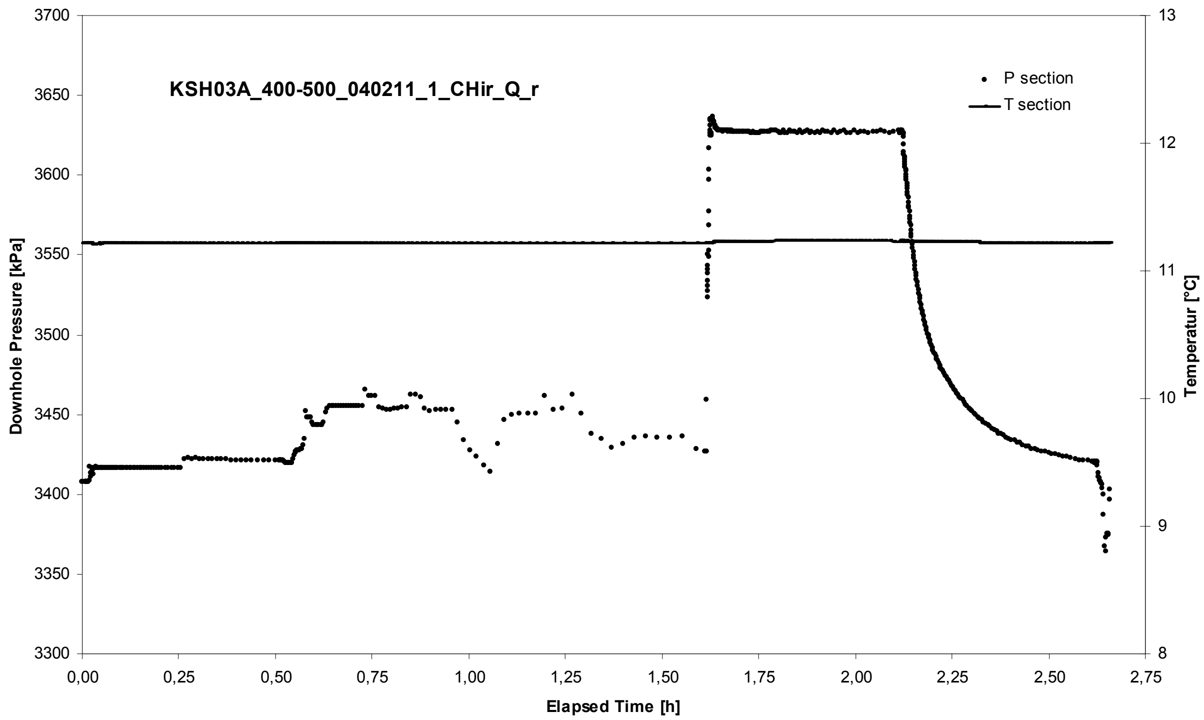
APPENDIX 2-4

Test 400 – 500 m

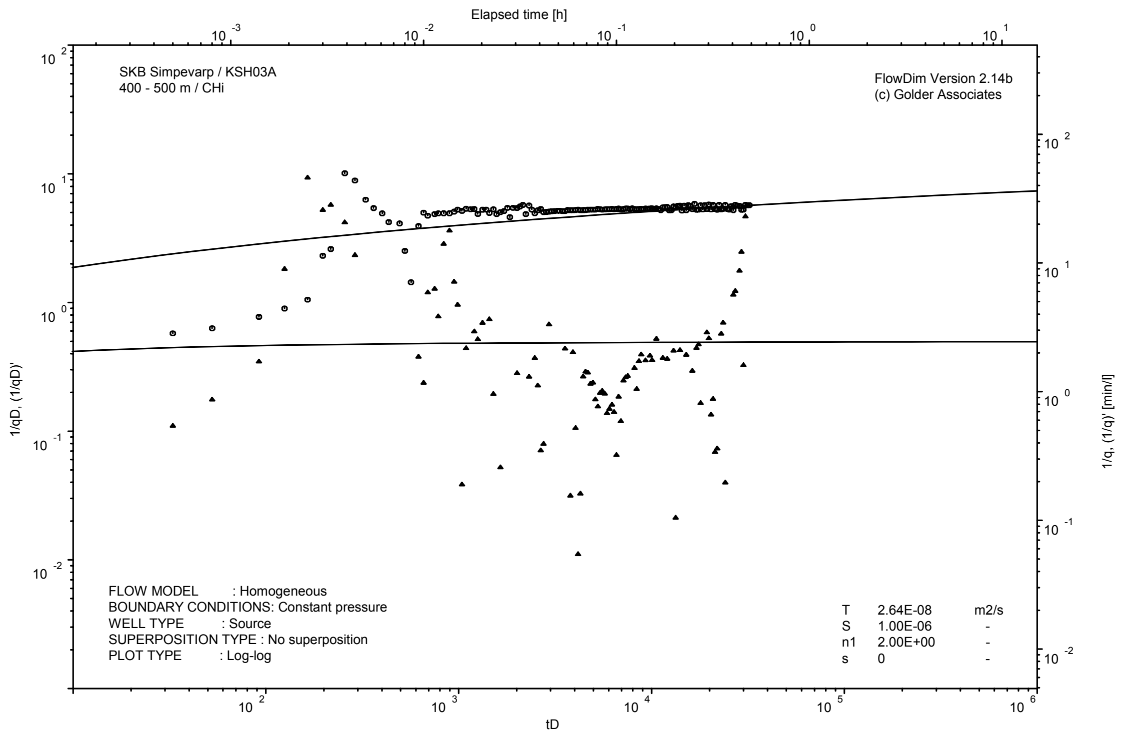
Analysis diagrams



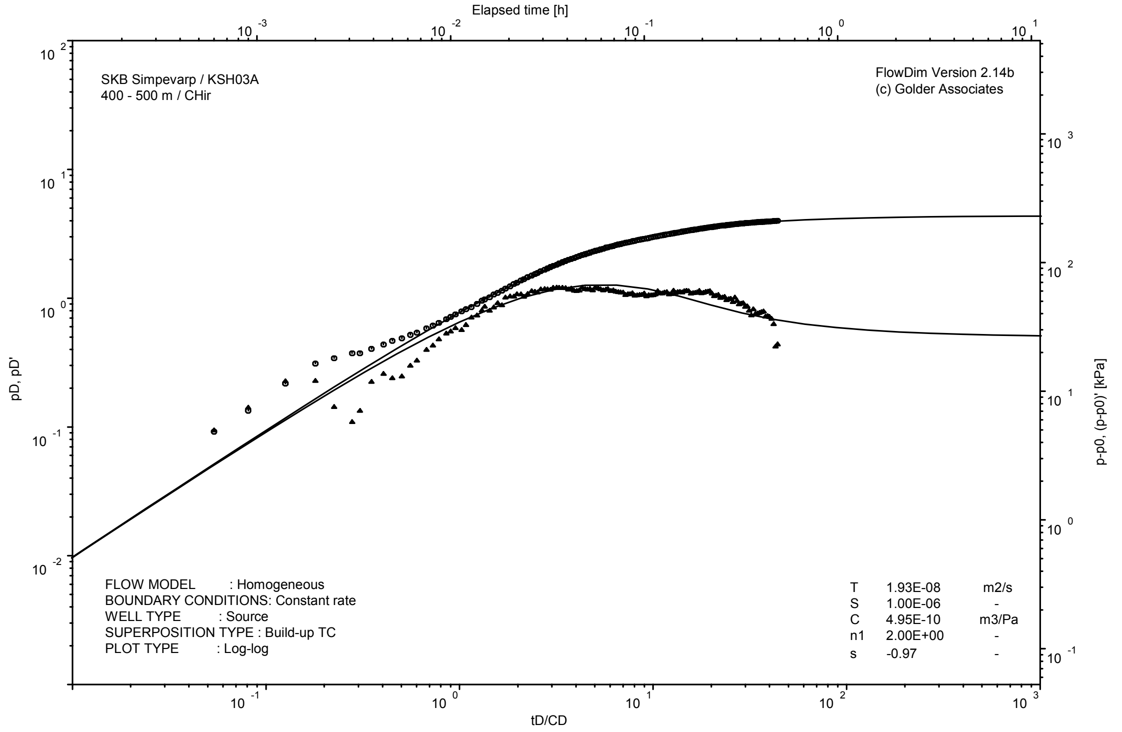
Pressure and flow rate vs. time; cartesian plot



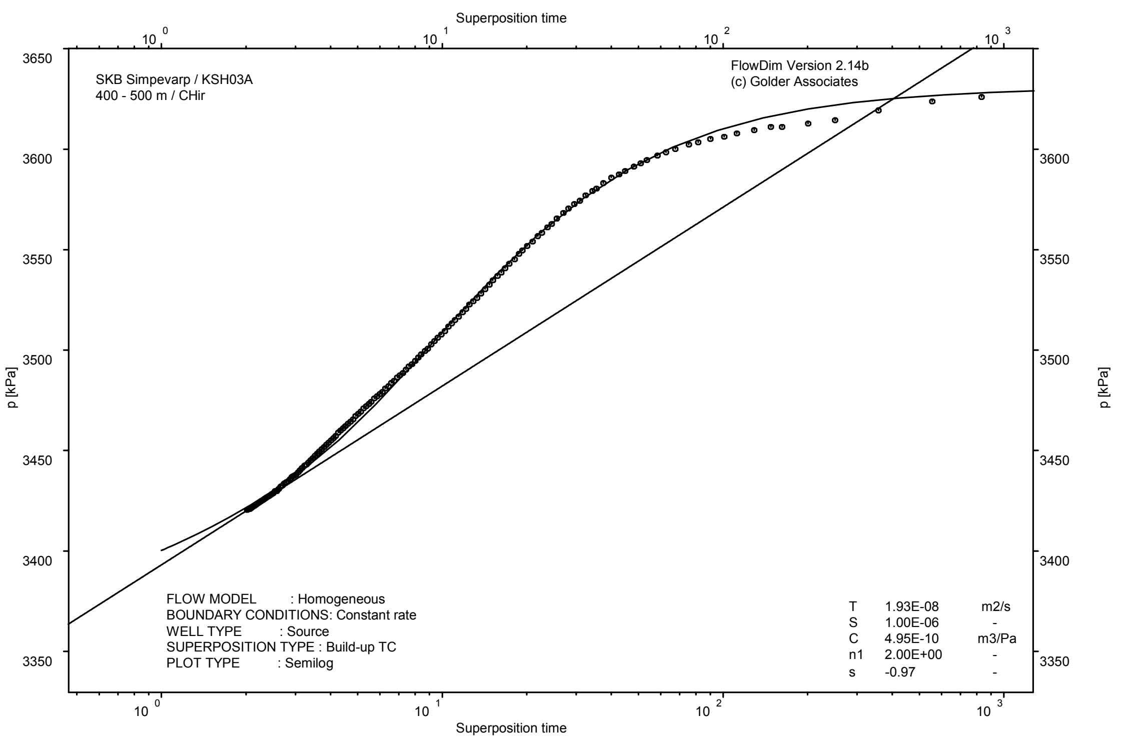
Interval pressure and temperature vs. time; cartesian plot



CHI phase; log-log match



CHIR phase; log-log match

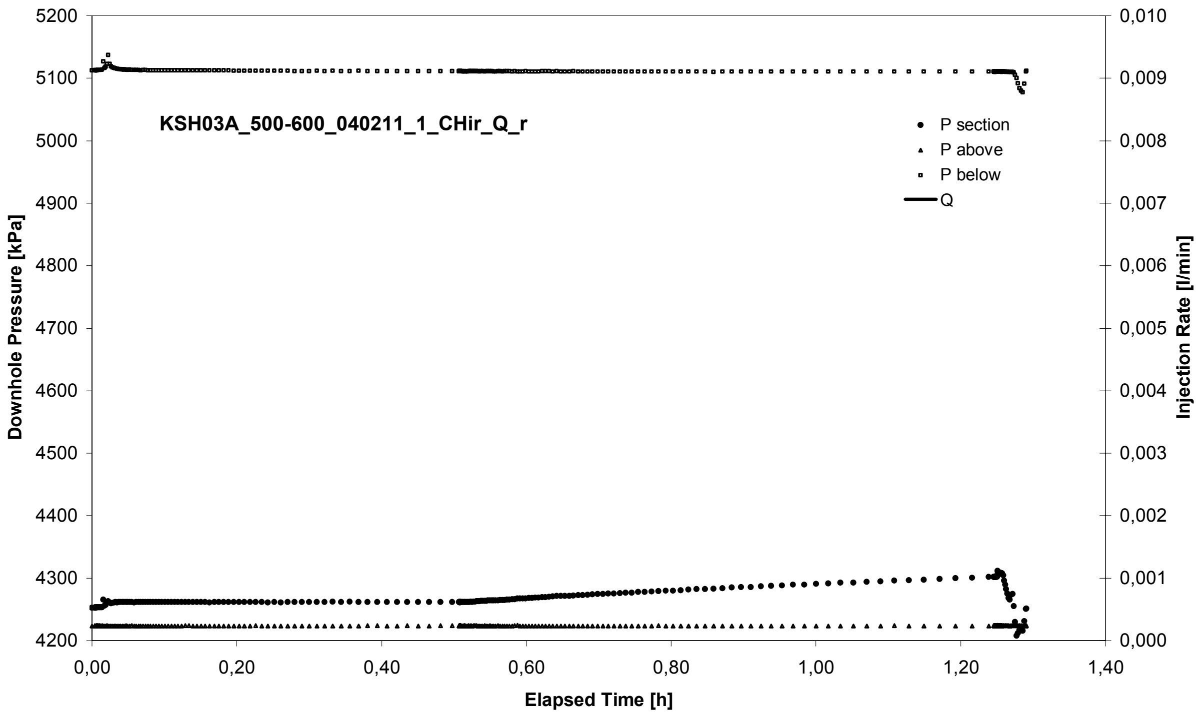


CHIR phase; HORNER match

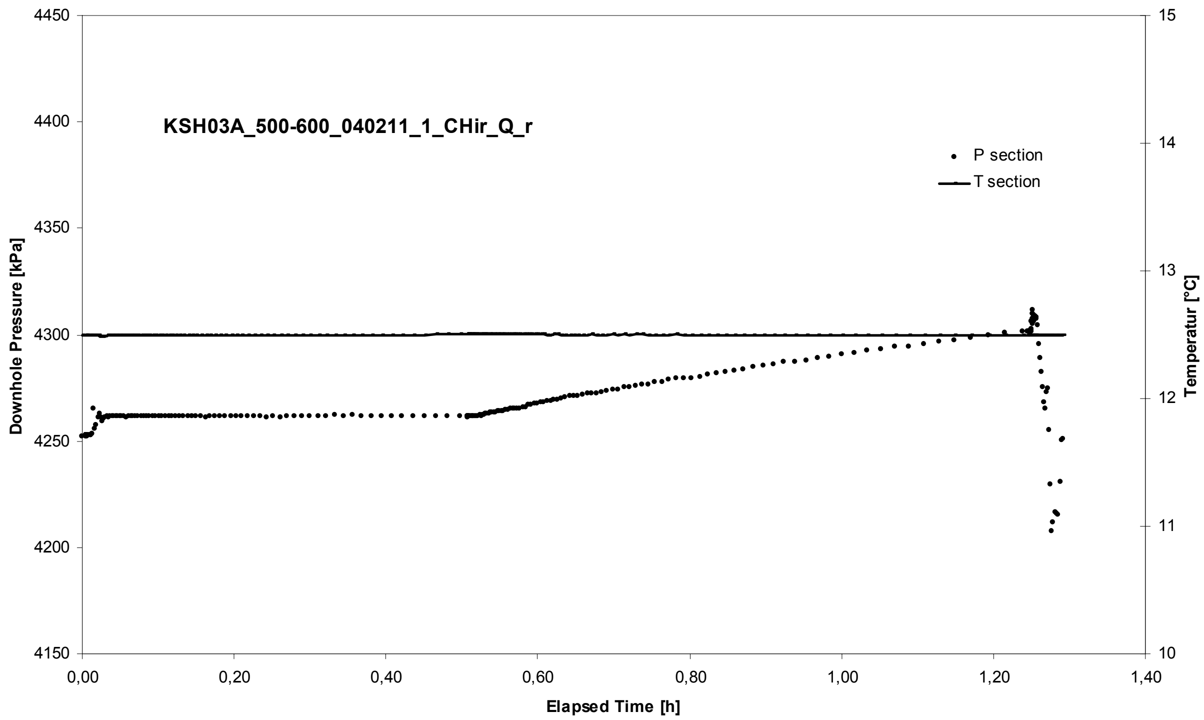
APPENDIX 2-5

Test 500 – 600 m

Analysis diagrams



Pressure and flow rate vs. time; cartesian plot



Interval pressure and temperature vs. time; cartesian plot

Not Analysed

CHI phase; log-log match

Not Analysed

CHIR phase; log-log match

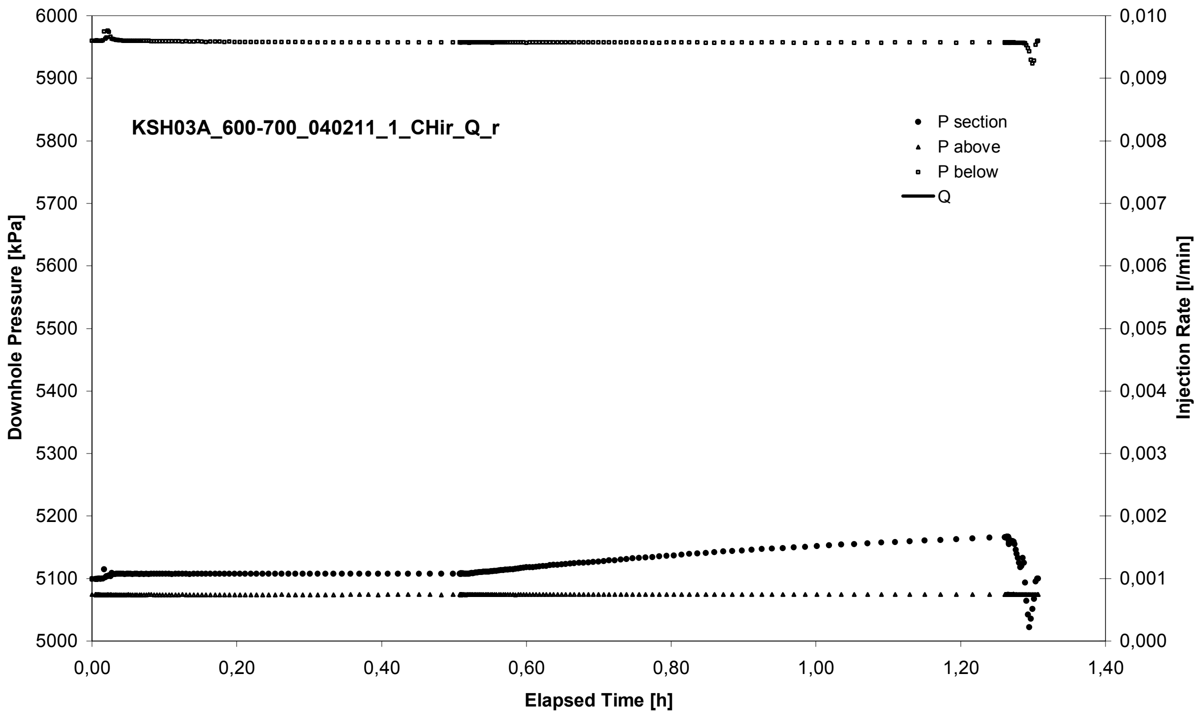
Not Analysed

CHIR phase; HORNER match

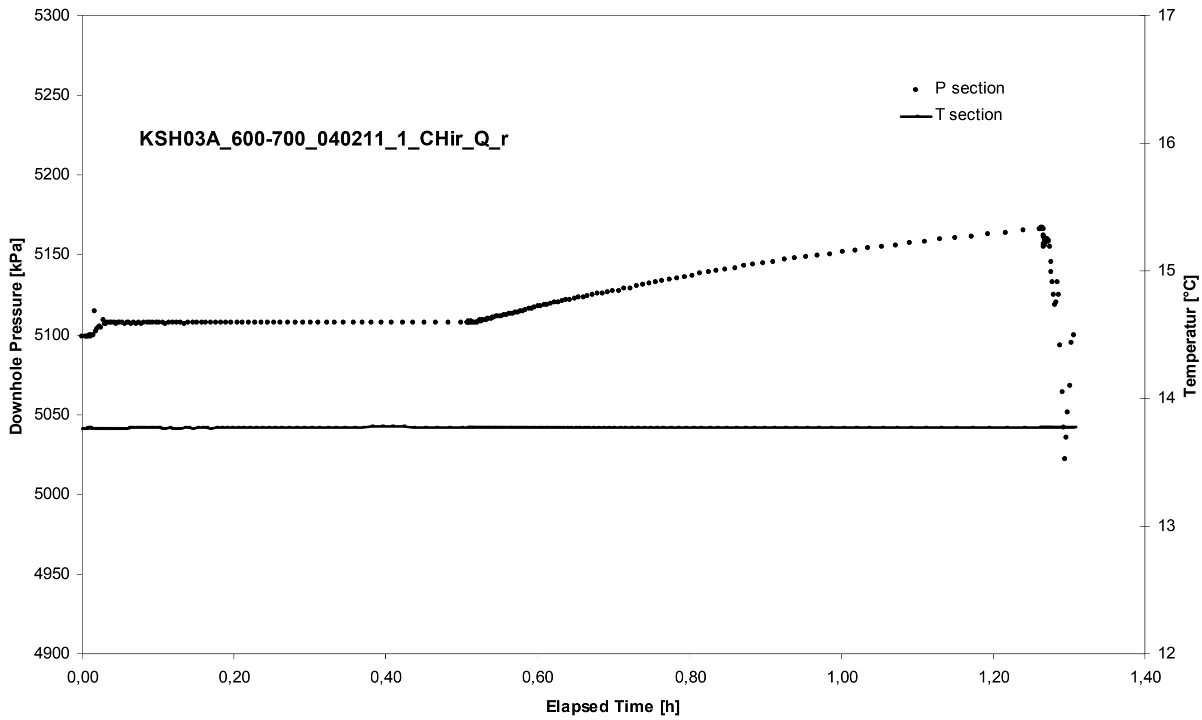
APPENDIX 2-6

Test 600 – 700 m

Analysis diagrams



Pressure and flow rate vs. time; cartesian plot



Interval pressure and temperature vs. time; cartesian plot

Not Analysed

CHI phase; log-log match

Not Analysed

CHIR phase; log-log match

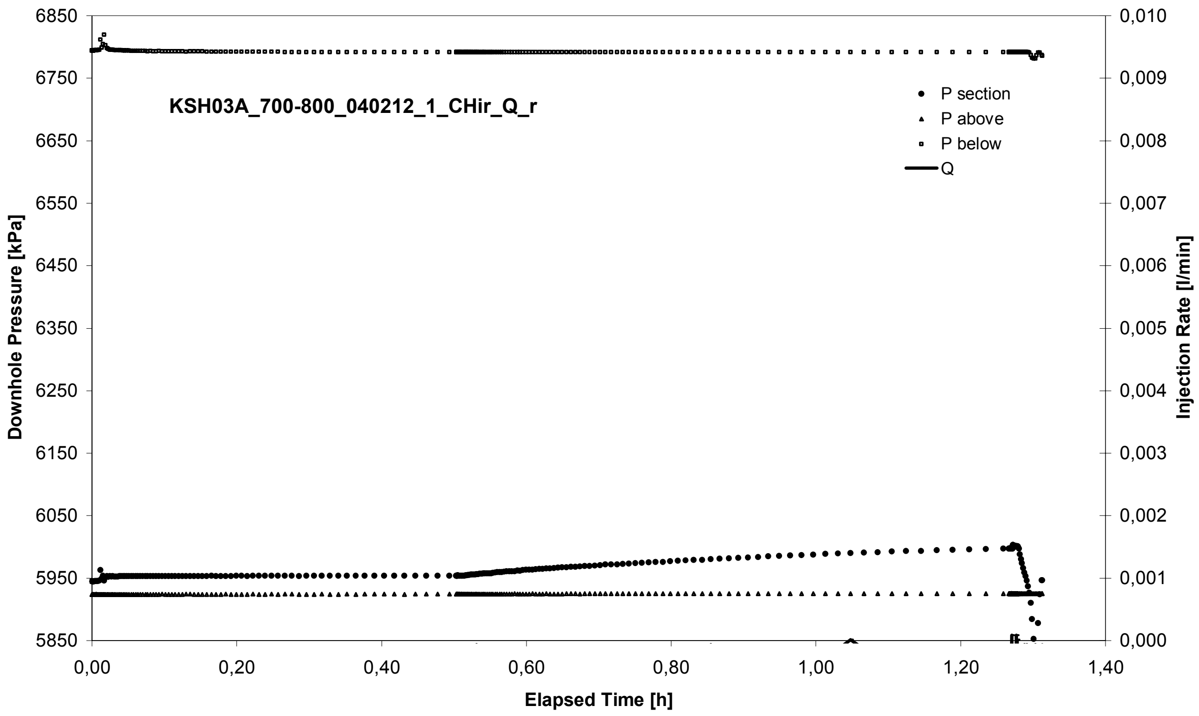
Not Analysed

CHIR phase; HORNER match

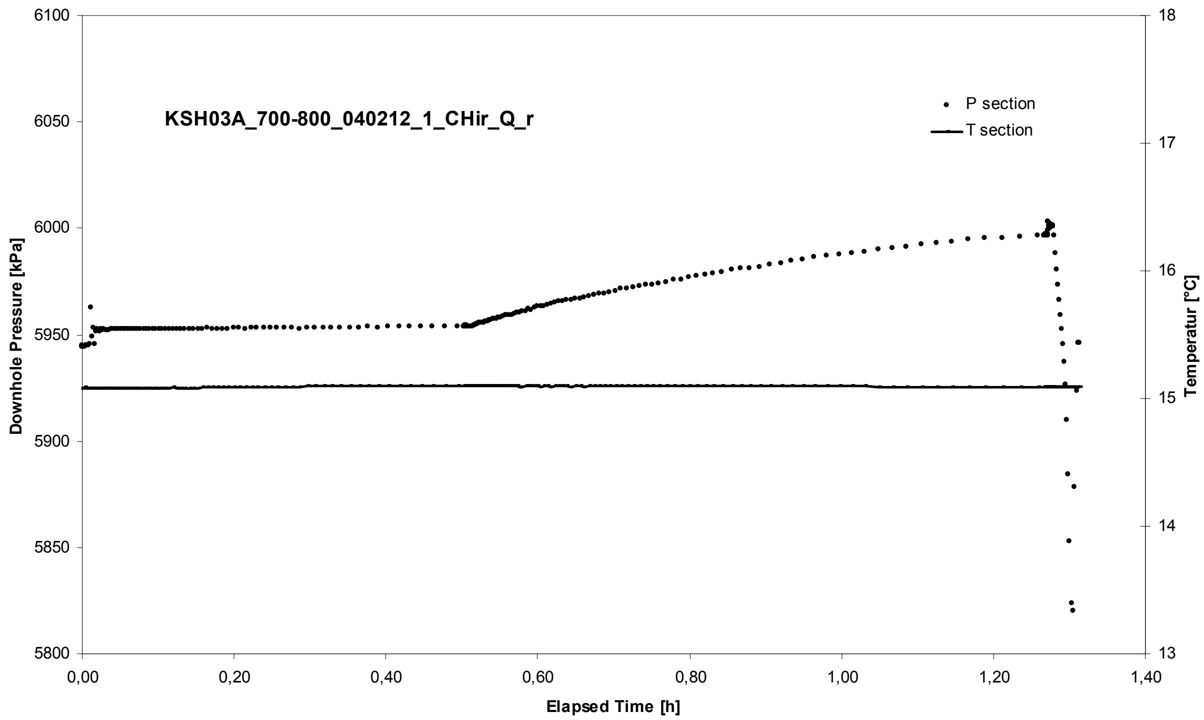
APPENDIX 2-7

Test 700 – 800 m

Analysis diagrams



Pressure and flow rate vs. time; cartesian plot



Interval pressure and temperature vs. time; cartesian plot

Not Analysed

CHI phase; log-log match

Not Analysed

CHIR phase; log-log match

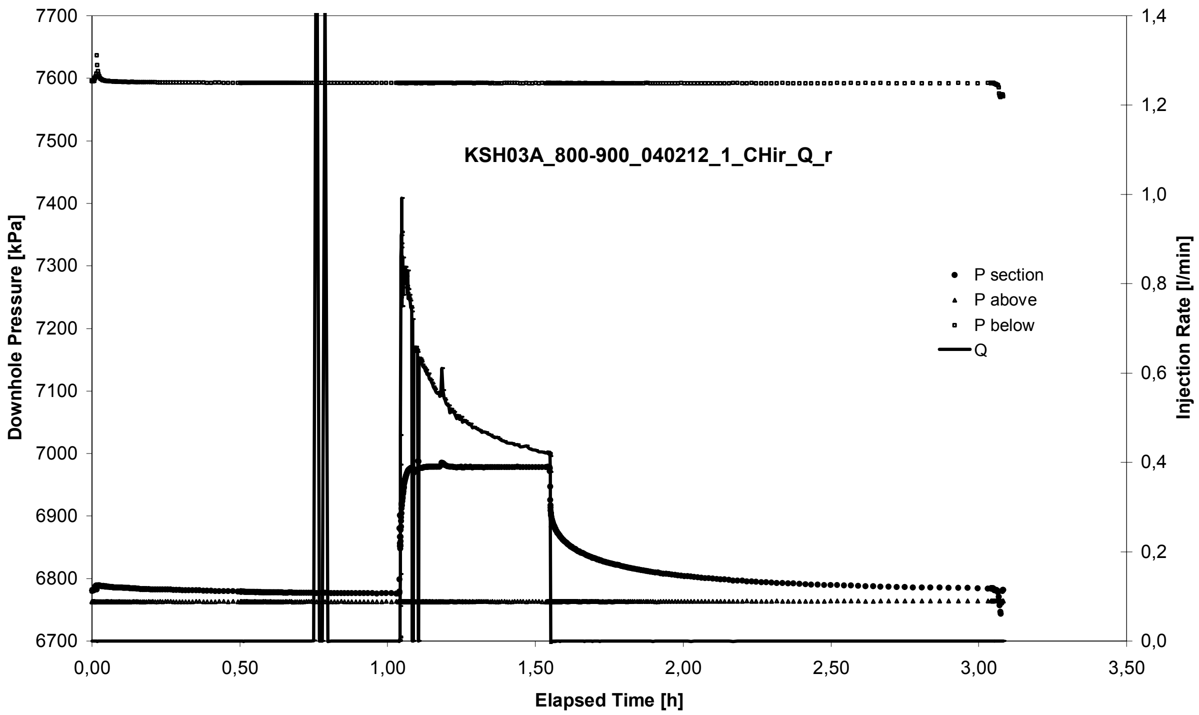
Not Analysed

CHIR phase; HORNER match

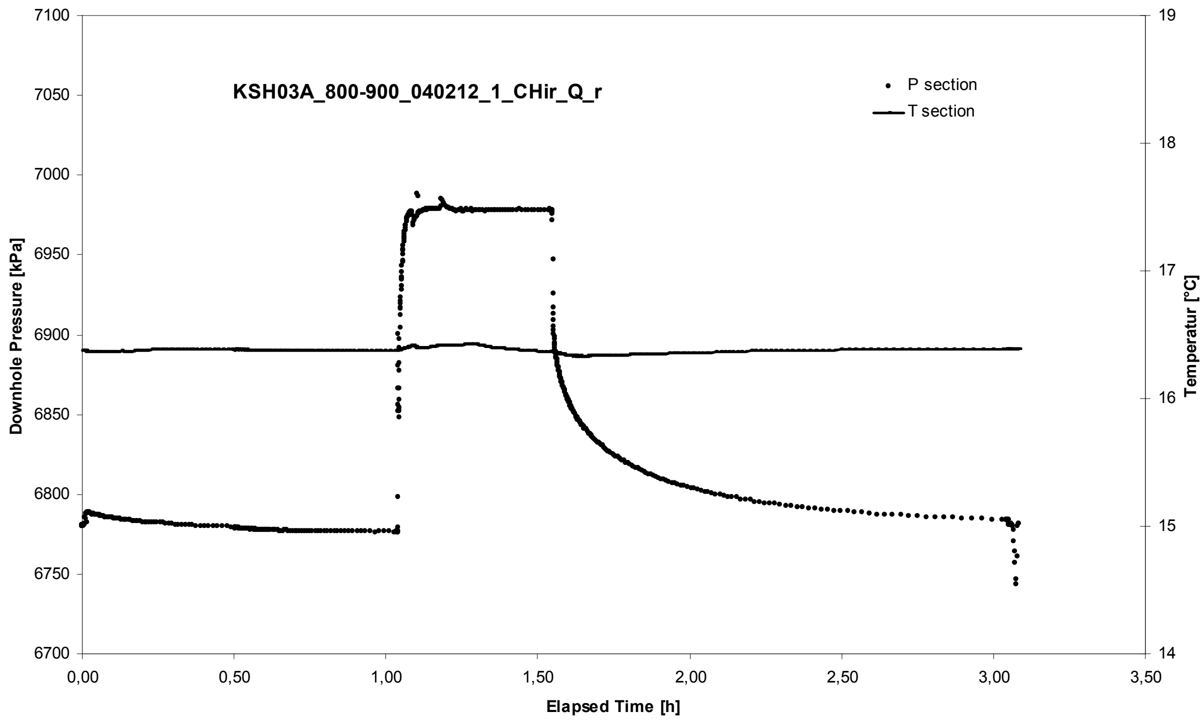
APPENDIX 2-8

Test 800 – 900 m

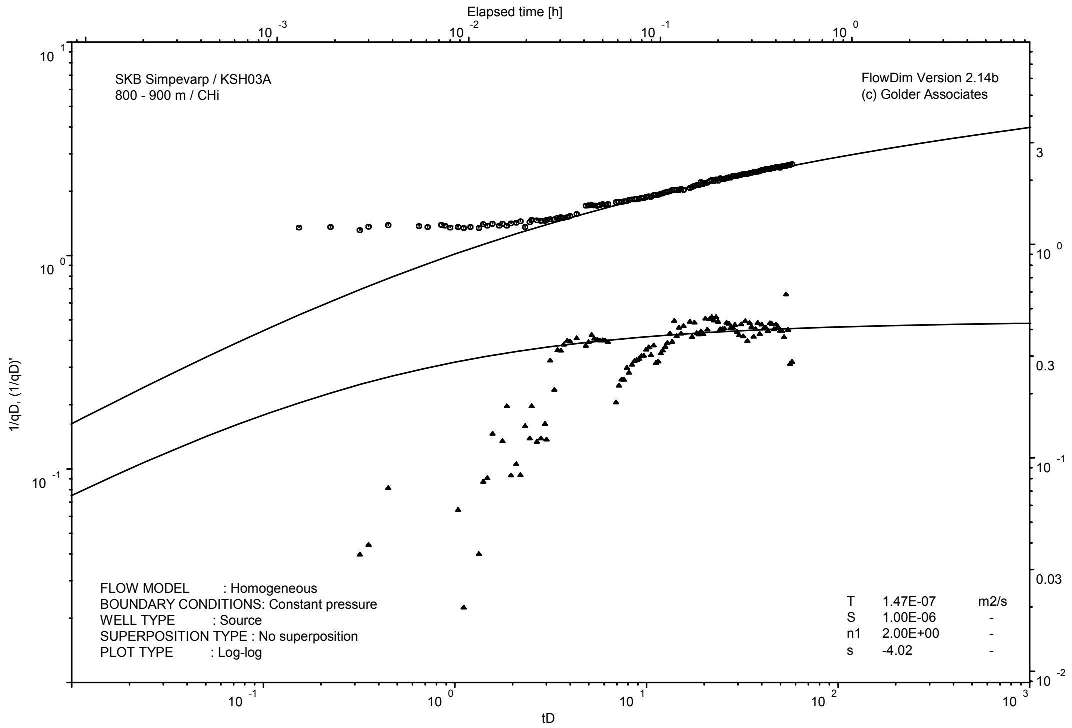
Analysis diagrams



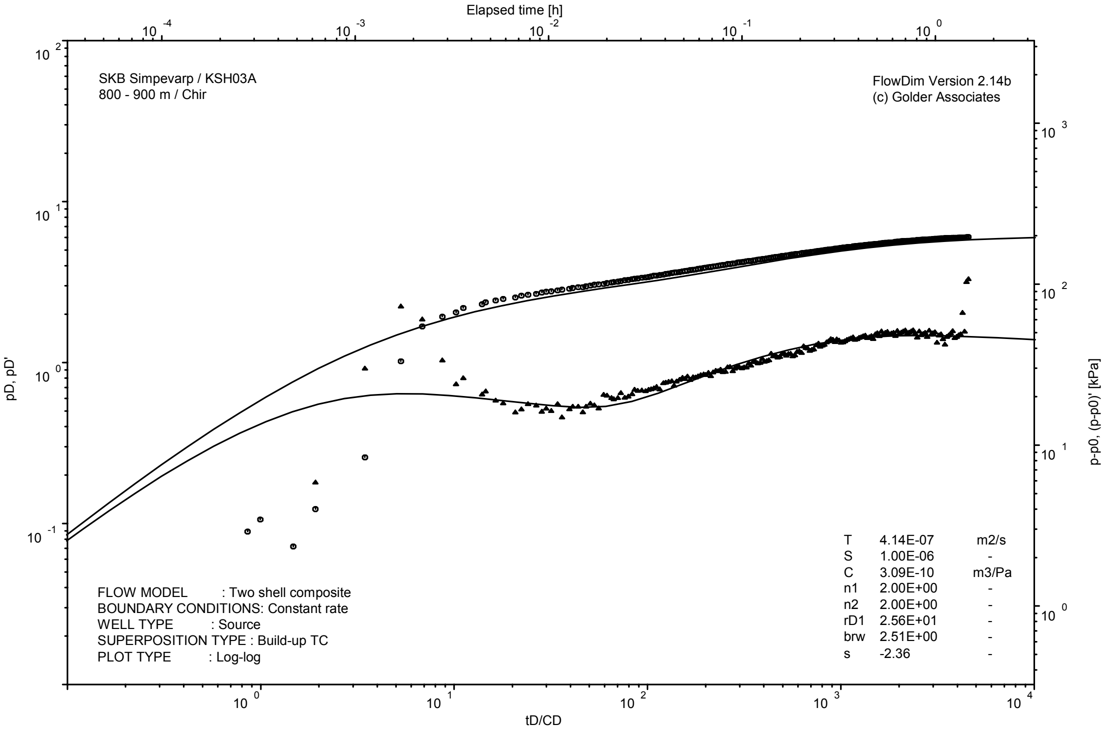
Pressure and flow rate vs. time; cartesian plot



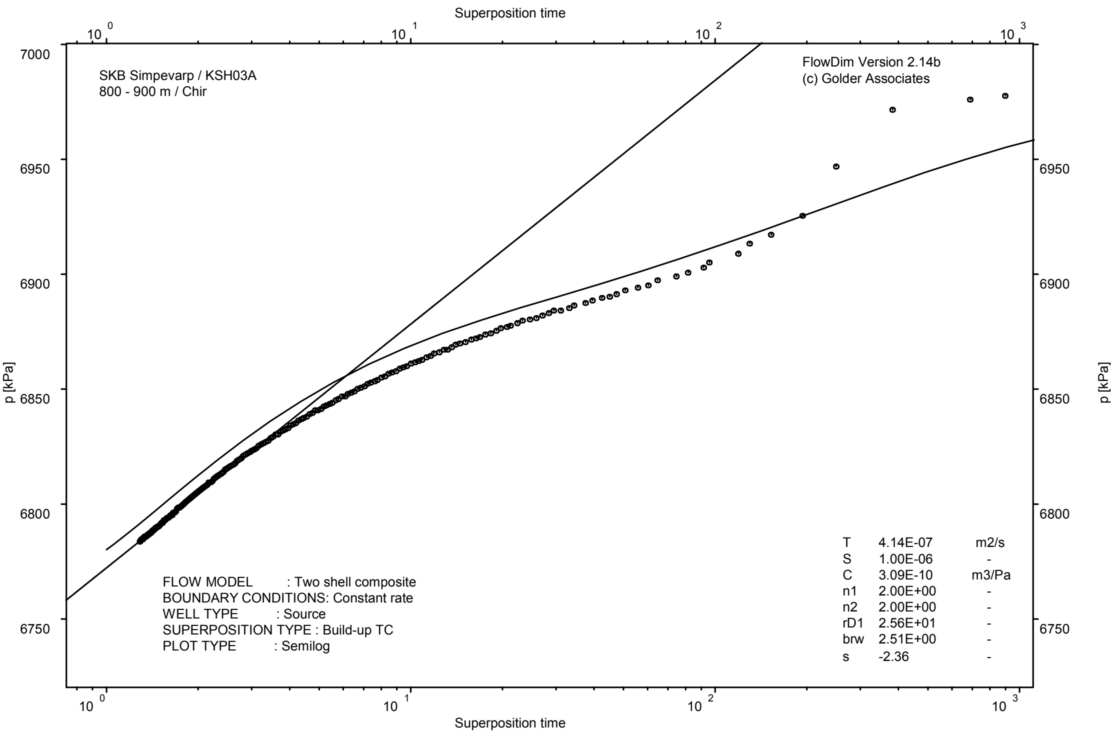
Interval pressure and temperature vs. time; cartesian plot



CHI phase; log-log match



CHIR phase; log-log match

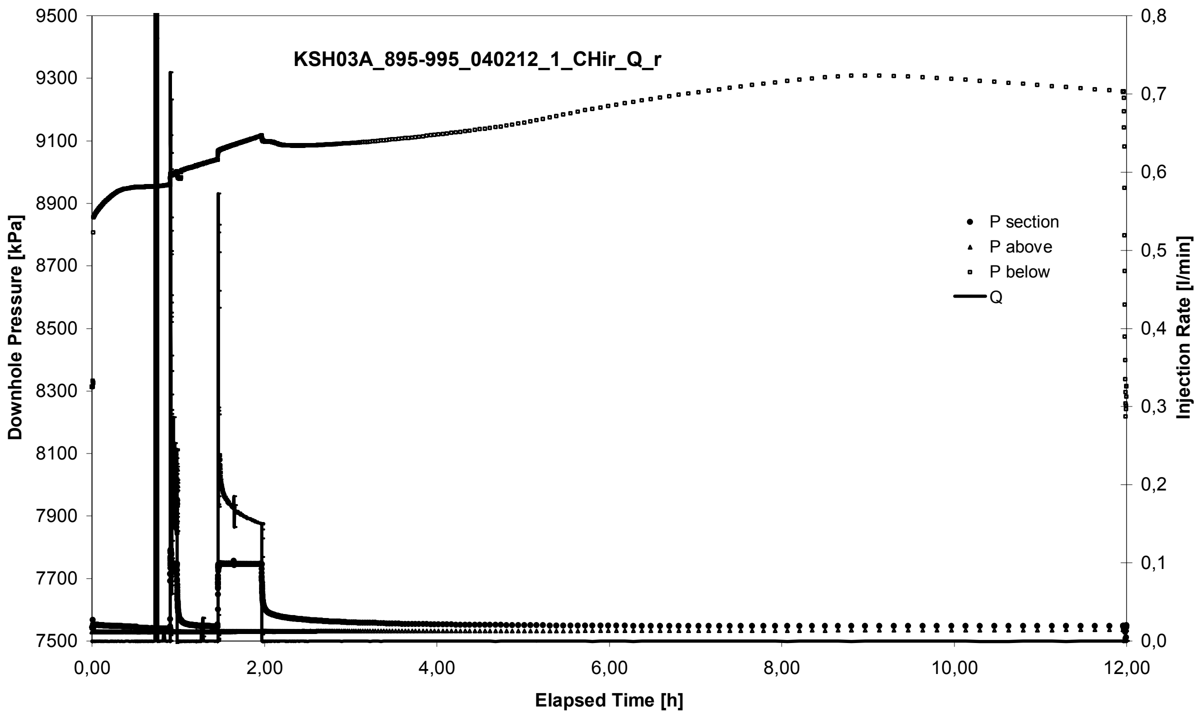


CHIR phase; HORNER match

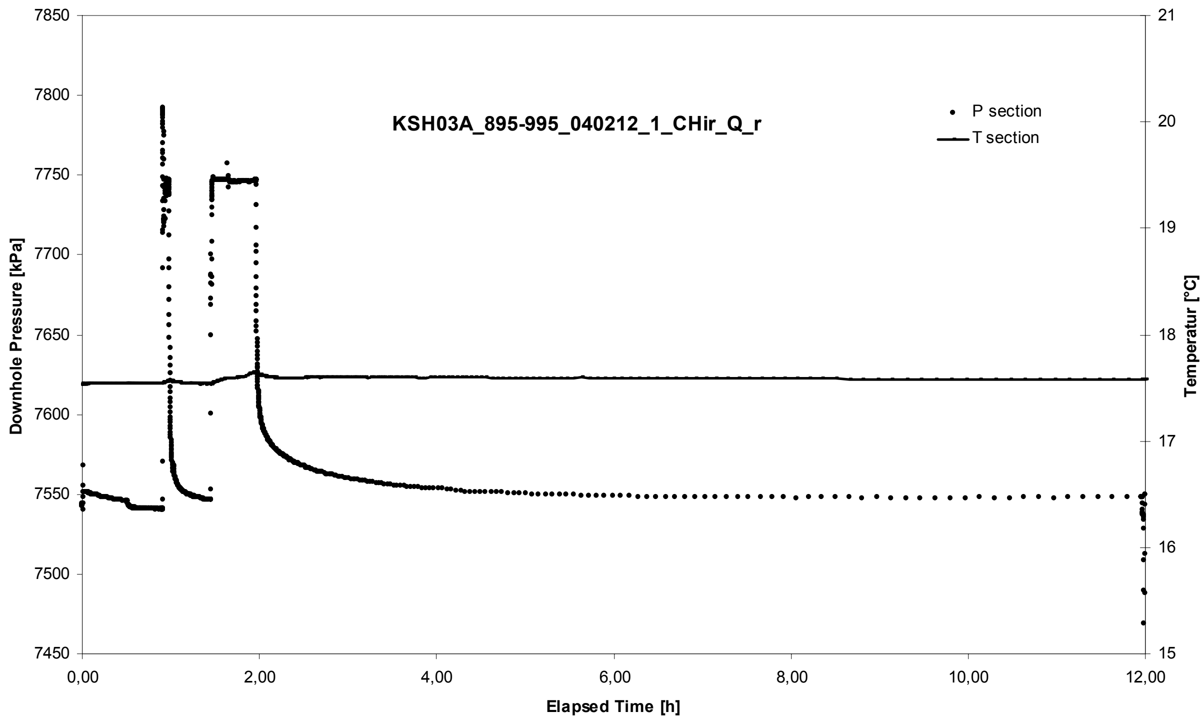
APPENDIX 2-9

Test 895 – 995 m

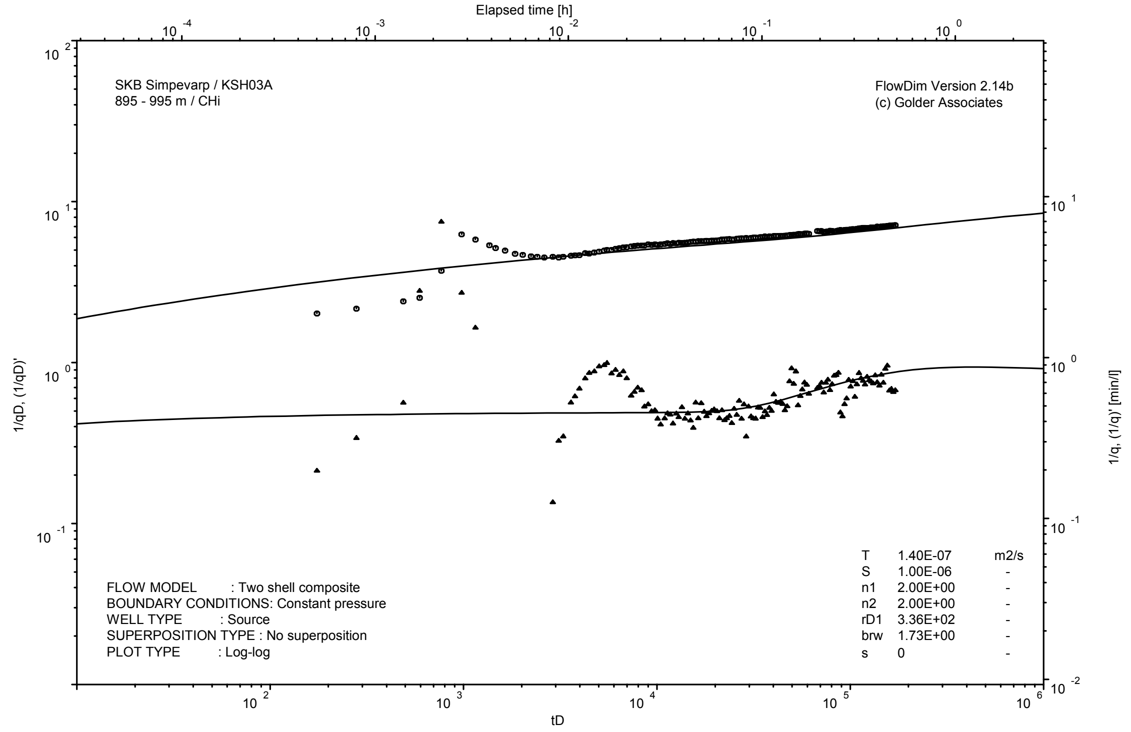
Analysis diagrams



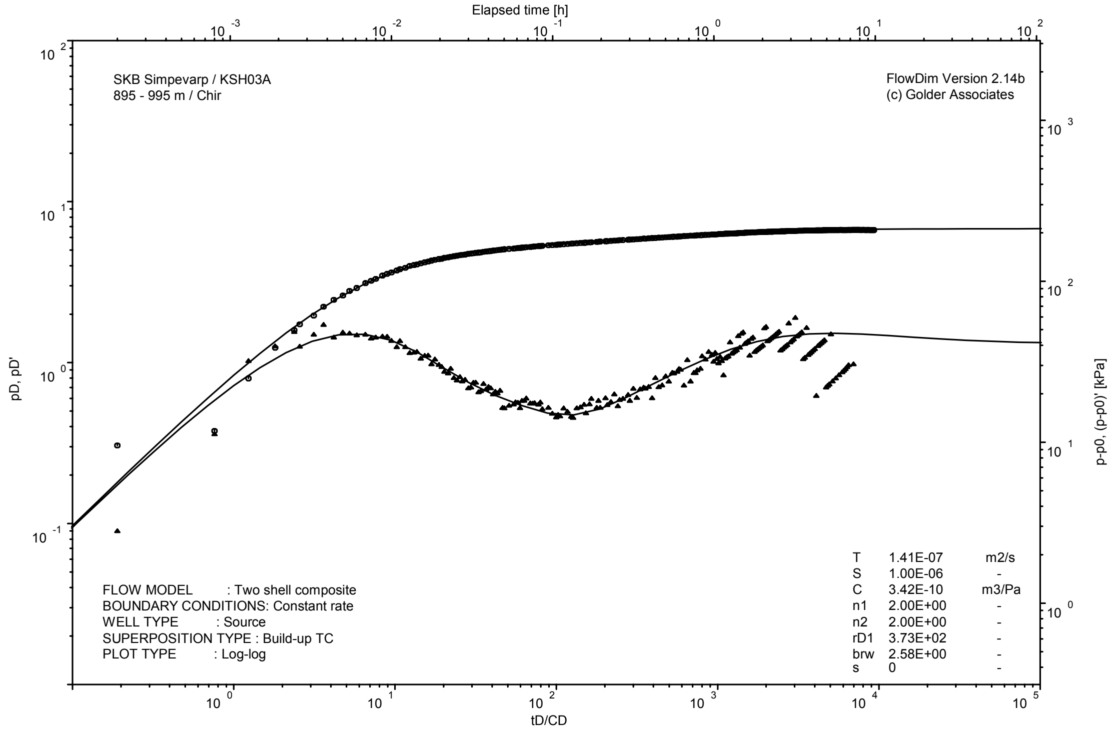
Pressure and flow rate vs. time; cartesian plot



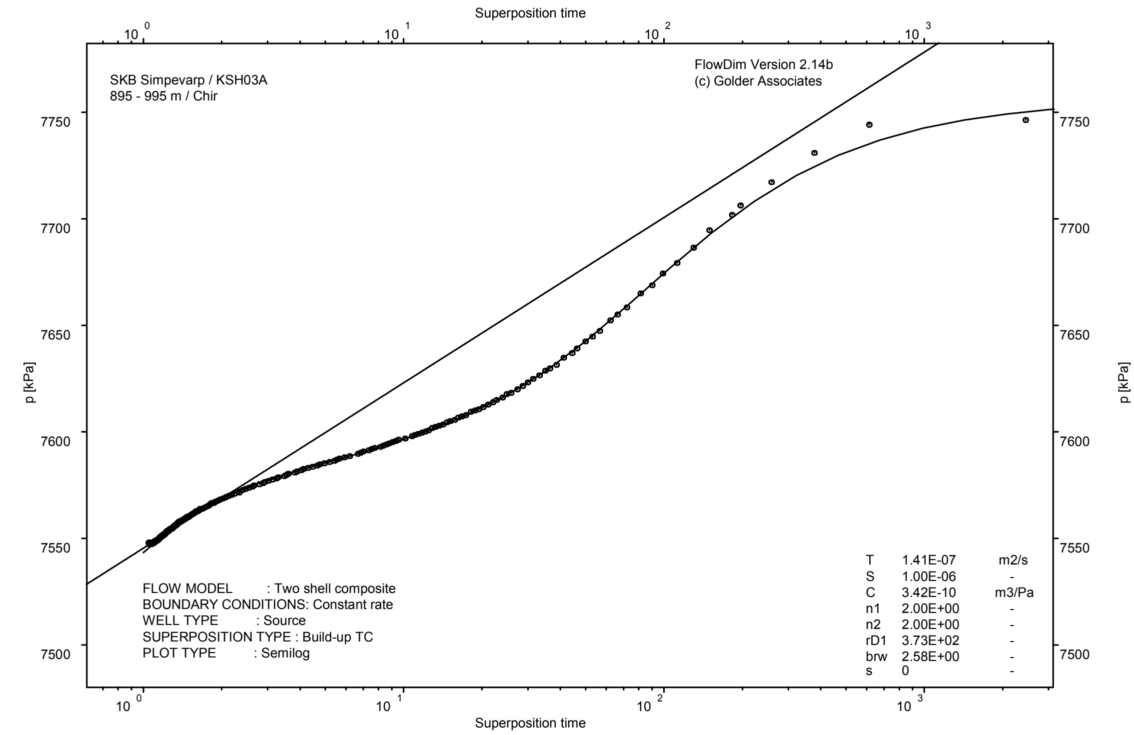
Interval pressure and temperature vs. time; cartesian plot



CHI phase; log-log match



CHIR phase; log-log match



CHIR phase; HORNER match

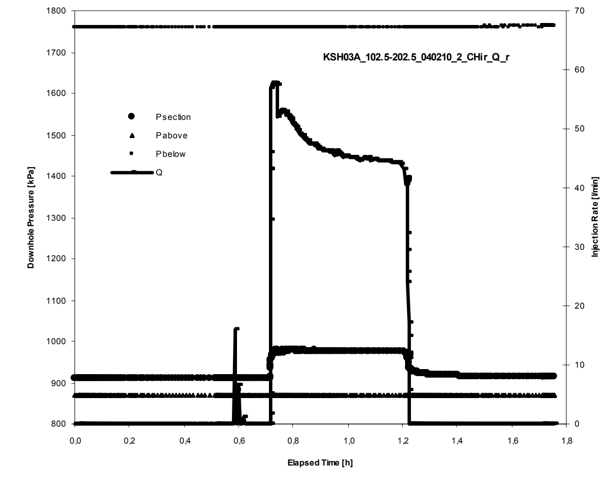
APPENDIX 3

Test Summary Sheets

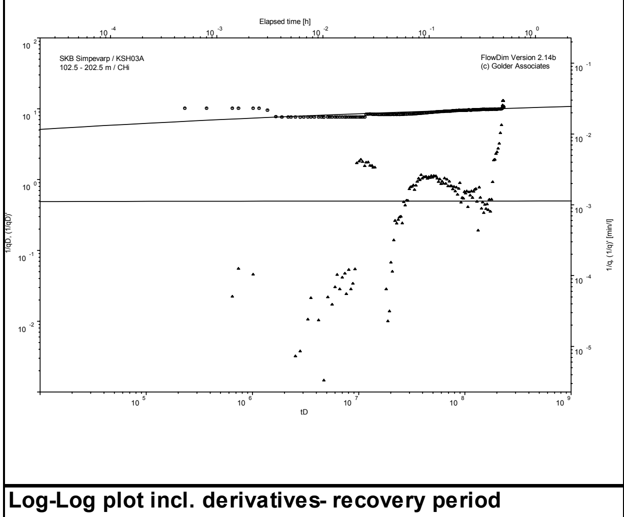
Test Summary Sheet

Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	2
Borehole ID:	KSH03A	Test start:	040210 10:58
Test section from - to (m):	102.5 - 202.5m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

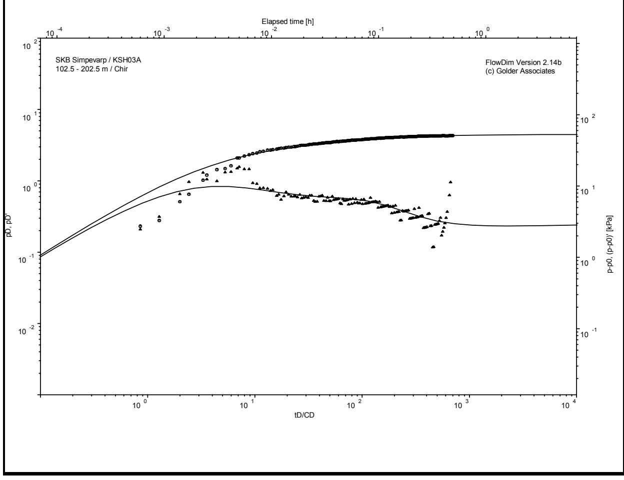
Linear plot Q and p



Log-Log plot incl. derivates- flow period



Log-Log plot incl. derivatives- recovery period



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa) =	910		
p_i (kPa) =	911,6		
p_p(kPa) =	972,1	p_F (kPa) =	914,4
Q_p (m^3/s)=	7,35E-04		
tp (s) =	1800	t_F (s) =	1800
S el S^* (-)=	1,00E-06	S el S^* (-)=	1,00E-06
EC_w (mS/m)=			
$Temp_w$(gr C)=	8,8		
Derivative fact.=	0,08	Derivative fact.=	0,13
Results		**Results**	
Q/s (m^2/s)=	1,2E-04		
T_M (m^2/s)=	1,6E-04		
Flow regime:	transient	Flow regime:	transient
dt_1 (min) =	12,58	dt_1 (min) =	1,10
dt_2 (min) =	22,10	dt_2 (min) =	4,37
T (m^2/s) =	1,9E-04	T (m^2/s) =	1,03E-04
S (-) =	1,0E-06	S (-) =	1,00E-06
K_s (m/s) =	1,9E-06	K_s (m/s) =	1,03E-06
S_s (1/m) =	1,0E-08	S_s (1/m) =	1,00E-08
C (m^3/Pa) =	NA	C (m^3/Pa) =	1,67E-07
C_D (-) =	NA	C_D (-) =	1,84E+01
ξ (-) =	0	ξ (-) =	-3,61
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Selected representative parameters.

dt_1 (min) =	1,1	C (m^3/Pa) =	1,67E-07
dt_2 (min) =	4,37	C_D (-) =	1,02E-03
T_T (m^2/s) =	2,1E-04	ξ (-) =	-3,61
S (-) =	1,0E-06		
K_s (m/s) =	2,1E-06		
S_s (1/m) =	1,0E-08		

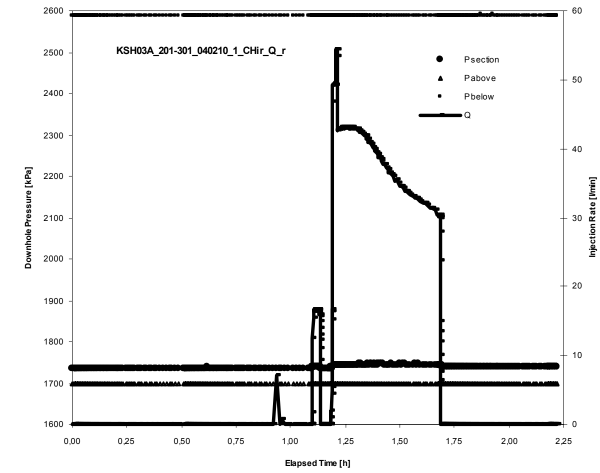
Comments:

The recommended transmissivity of 2.06E-4 m2/s was derived from the analysis of the CHir phase (outer zone), which shows a good data and derivative quality. The confidence range for the interval transmissivity is estimated to be 9.0E-5 to 2.5E-4 m2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 912.4 kPa.

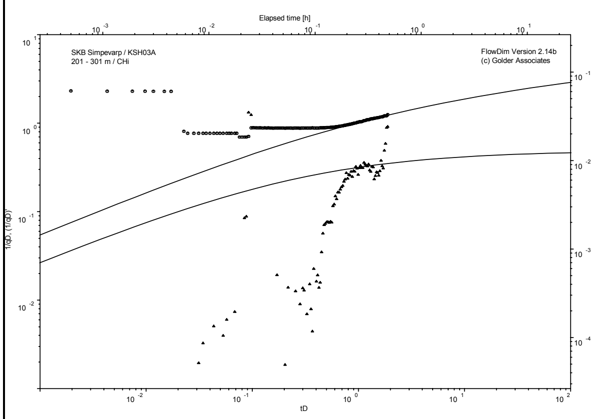
Test Summary Sheet

Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040210 14:10
Test section from - to (m):	201 - 301 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

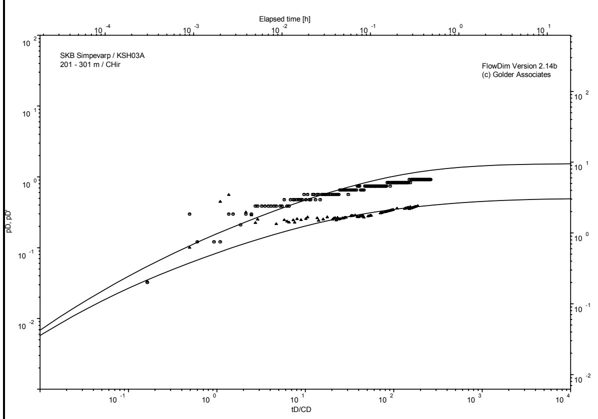
Linear plot Q and p



Log-Log plot incl. derivates- flow period



Log-Log plot incl. derivatives- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa) =	1735,8		
p_i (kPa) =	1736,4		
p_p(kPa) =	1744,1	p_F (kPa) =	1738
Q_p (m^3/s)=	5,04E-04		
tp (s) =	1800	t_F (s) =	1800
S el S^* (-)=	1,00E-06	S el S^* (-)=	1,00E-06
EC_w (mS/m)=			
$Temp_w$(gr C)=	8,9		
Derivative fact.=	0,02	Derivative fact.=	0,07
Results		**Results**	
Q/s (m^2/s)=	5,5E-04		
T_M (m^2/s)=	7,2E-04		
Flow regime:	transient	Flow regime:	transient
dt_1 (min) =	13,12	dt_1 (min) =	*
dt_2 (min) =	21,13	dt_2 (min) =	*
T (m^2/s) =	1,09E-04	T (m^2/s) =	1,58E-04
S (-) =	1,00E-06	S (-) =	1,00E-06
K_s (m/s) =	1,1E-06	K_s (m/s) =	1,58E-06
S_s (1/m) =	1,0E-08	S_s (1/m) =	1,00E-08
C (m^3/Pa) =	NA	C (m^3/Pa) =	6,69E-07
C_D (-) =	NA	C_D (-) =	73,735912
ξ (-) =	-6,73	ξ (-) =	-8,50
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Selected representative parameters.

dt_1 (min) =	*	C (m^3/Pa) =	6,69E-07
dt_2 (min) =	*	C_D (-) =	3,06E-06
T_T (m^2/s) =	1,58E-04	ξ (-) =	-8,50
S (-) =	1,00E-06		
K_s (m/s) =	1,58E-06		
S_s (1/m) =	1,00E-08		

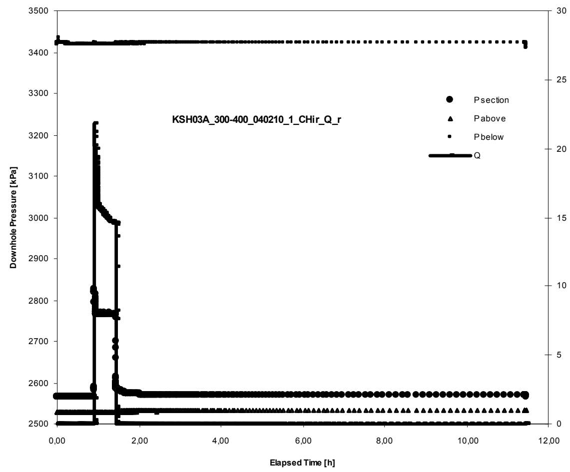
Comments:

The recommended transmissivity of 1.58E-4 m2/s was derived from the analysis of the CHir phase, which shows the best data and derivative quality. The confidence range for the interval transmissivity is estimated to be 1.0E-4 to 4.0E-4 m2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 1737.0 kPa.

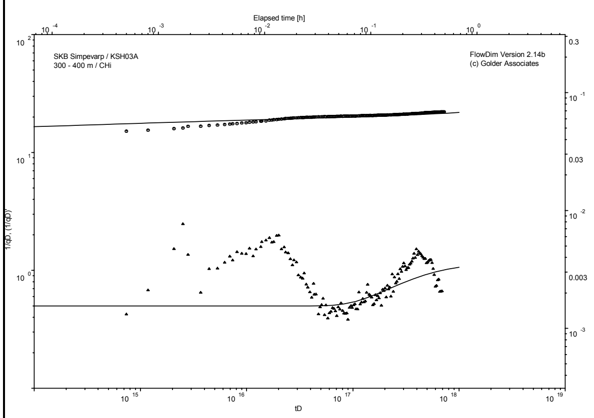
Test Summary Sheet

Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040210 18:00
Test section from - to (m):	300 - 400 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

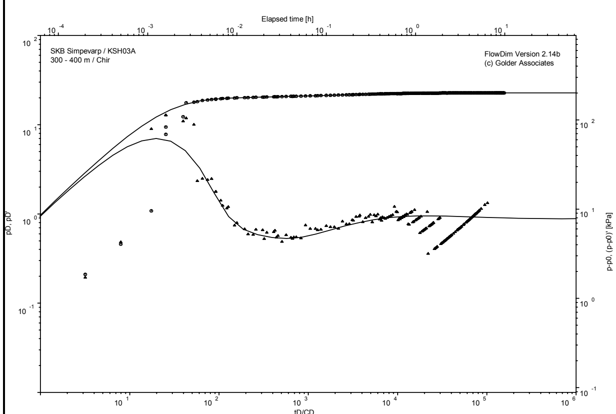
Linear plot Q and p



Log-Log plot incl. derivates- flow period



Log-Log plot incl. derivatives- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa) =	2565,5		
p_i (kPa) =	2566		
p_p(kPa) =	2764,4	p_F (kPa) =	2567,7
Q_p (m^3/s)=	2,40E-04		
tp (s) =	1800	t_F (s) =	36000
S el S* (-)=	1,00E-06	S el S* (-)=	1,00E-06
EC_w (mS/m)=			
$Temp_w$(gr C)=	10,0		
Derivative fact.=	0,1	Derivative fact.=	0,13
Results		**Results**	
Q/s (m^2/s)=	1,2E-05		
T_M (m^2/s)=	1,5E-05		
Flow regime:	transient	Flow regime:	transient
dt_1 (min) =	2,00	dt_1 (min) =	0,80
dt_2 (min) =	4,35	dt_2 (min) =	3,13
T (m^2/s) =	4,2E-05	T (m^2/s) =	4,49E-05
S (-) =	1,0E-06	S (-) =	1,00E-06
K_s (m/s) =	4,2E-07	K_s (m/s) =	4,49E-07
S_s (1/m) =	1,0E-08	S_s (1/m) =	1,00E-08
C (m^3/Pa) =	NA	C (m^3/Pa) =	6,51E-09
C_D (-) =	NA	C_D (-) =	0,71751986
ξ (-) =	11,68	ξ (-) =	12,84
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Selected representative parameters.

dt_1 (min) =	0,8	C (m^3/Pa) =	6,51E-09
dt_2 (min) =	3,13	C_D (-) =	1,02E+11
T_T (m^2/s) =	2,6E-05	ξ (-) =	12,84
S (-) =	1,0E-06		
K_s (m/s) =	2,6E-07		
S_s (1/m) =	1,0E-08		

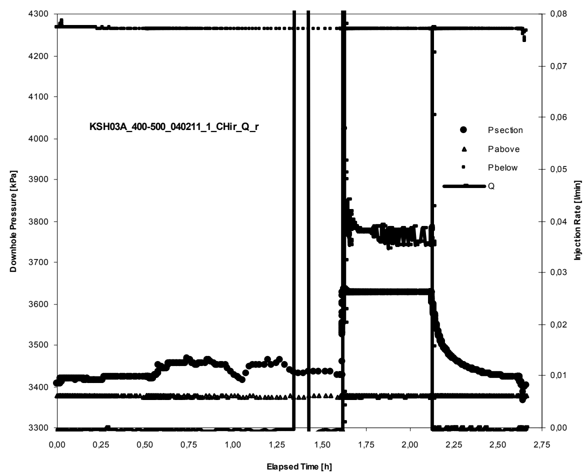
Comments:

The recommended transmissivity of 2.6E-5 m2/s was derived from the analysis of the CHir phase (outer zone), which shows a good data and derivative quality. The confidence range for the interval transmissivity is estimated to be 2.0E-5 to 5.0E-5 m2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 2567.4 kPa.

Test Summary Sheet

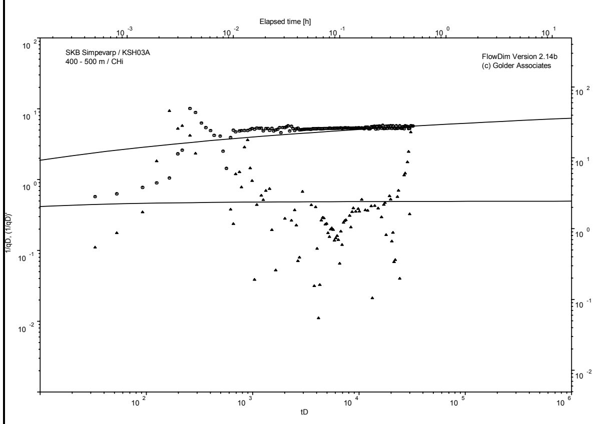
Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040211 09:50
Test section from - to (m):	400 - 500 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

Linear plot Q and p

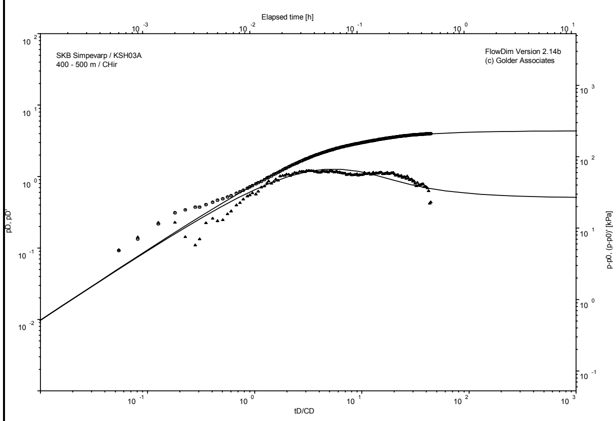


Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa) =	3407,8		
p_i (kPa) =	3426,5		
p_p(kPa) =	3626,5	p_F (kPa) =	3420,5
Q_p (m^3/s)=	6,00E-07		
tp (s) =	1800	t_F (s) =	1800
S el S^* (-)=	1,00E-06	S el S^* (-)=	1,00E-06
EC_w (mS/m)=			
$Temp_w$(gr C)=	11,2		
Derivative fact.=	0,2	Derivative fact.=	0,04
Results		**Results**	
Q/s (m^2/s)=	2,9E-08		
T_M (m^2/s)=	3,8E-08		
Flow regime:	transient	Flow regime:	transient
dt_1 (min) =	8,06	dt_1 (min) =	*
dt_2 (min) =	18,10	dt_2 (min) =	*
T (m^2/s) =	2,6E-08	T (m^2/s) =	1,93E-08
S (-) =	1,0E-06	S (-) =	1,00E-06
K_s (m/s) =	2,6E-10	K_s (m/s) =	1,93E-10
S_s (1/m) =	1,0E-08	S_s (1/m) =	1,00E-08
C (m^3/Pa) =	NA	C (m^3/Pa) =	4,95E-10
C_D (-) =	NA	C_D (-) =	0,05455796
ξ (-) =	0	ξ (-) =	-0,97
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Log-Log plot incl. derivates- flow period



Log-Log plot incl. derivatives- recovery period



Selected representative parameters.

dt_1 (min) =	*	C (m^3/Pa) =	4,95E-10
dt_2 (min) =	*	C_D (-) =	7,87E-03
T_T (m^2/s) =	1,9E-08	ξ (-) =	-0,97
S (-) =	1,0E-06		
K_s (m/s) =	1,9E-10		
S_s (1/m) =	1,0E-08		

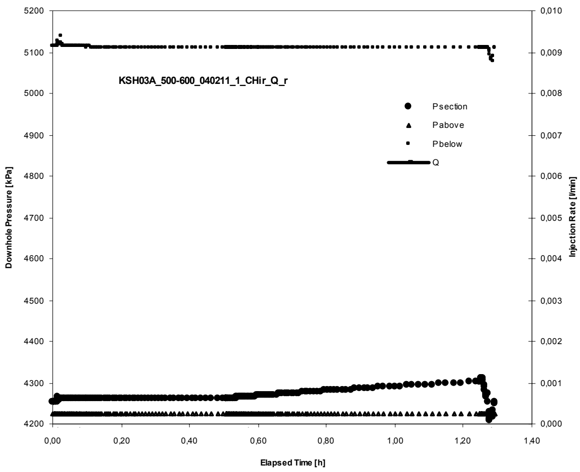
Comments:

The recommended transmissivity of 1.9E-8 m2/s was derived from the analysis of the CHir phase, which shows the best data and derivative quality. The confidence range for the interval transmissivity is estimated to be 8.0E-9 to 3.0E-8 m2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 3393.1 kPa.

Test Summary Sheet

Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040211 14:19
Test section from - to (m):	500 - 600 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

Linear plot Q and p



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa) =	4252,9		
p_i (kPa) =	-		
p_p(kPa) =	-	p_F (kPa) =	-
Q_p (m^3/s)=	-		
tp (s) =	-	t_F (s) =	-
S el S* (-)=	-	S el S* (-)=	-
EC_w (mS/m)=			
$Temp_w$(gr C)=	12,5		
Derivative fact.=	-	Derivative fact.=	-
Results		**Results**	
Q/s (m^2/s)=	-		
T_M (m^2/s)=	-		
Flow regime:	-	Flow regime:	-
dt_1 (min) =	-	dt_1 (min) =	-
dt_2 (min) =	-	dt_2 (min) =	-
T (m^2/s) =	NA	T (m^2/s) =	NA
S (-) =	NA	S (-) =	NA
K_s (m/s) =	NA	K_s (m/s) =	NA
S_s (1/m) =	NA	S_s (1/m) =	NA
C (m^3/Pa) =	NA	C (m^3/Pa) =	NA
C_D (-) =	NA	C_D (-) =	NA
ξ (-) =	NA	ξ (-) =	NA
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Log-Log plot incl. derivates- flow period

Not Analysed

Log-Log plot incl. derivatives- recovery period

Not Analysed

Selected representative parameters.

dt_1 (min) =	-	C (m^3/Pa) =	NA
dt_2 (min) =	-	C_D (-) =	NA
T_T (m^2/s) =	< 1E-11	ξ (-) =	NA
S (-) =	NA		
K_s (m/s) =	NA		
S_s (1/m) =	NA		

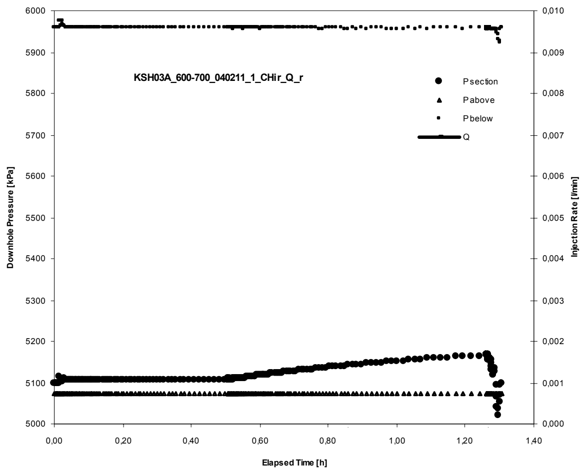
Comments:

The recommended transmissivity of < 1 E-11 m2/s was derived from experience of previous tests with flow rates of less than 1 ml/min.

Test Summary Sheet

Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040211 17:11
Test section from - to (m):	600 - 700 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

Linear plot Q and p



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa) =	5099,6		
p_i (kPa) =	-		
p_p(kPa) =	-	p_F (kPa) =	-
Q_p (m^3/s)=	-		
tp (s) =	-	t_F (s) =	-
S el S^* (-)=	-	S el S^* (-)=	-
EC_w (mS/m)=			
$Temp_w$(gr C)=	13,8		
Derivative fact.=	-	Derivative fact.=	-
Results		**Results**	
Q/s (m^2/s)=	-		
T_M (m^2/s)=	-		
Flow regime:	-	Flow regime:	transient
dt_1 (min) =	-	dt_1 (min) =	-
dt_2 (min) =	-	dt_2 (min) =	-
T (m^2/s) =	NA	T (m^2/s) =	NA
S (-) =	NA	S (-) =	NA
K_s (m/s) =	NA	K_s (m/s) =	NA
S_s (1/m) =	NA	S_s (1/m) =	NA
C (m^3/Pa) =	NA	C (m^3/Pa) =	NA
C_D (-) =	NA	C_D (-) =	NA
ξ (-) =	NA	ξ (-) =	NA
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Log-Log plot incl. derivates- flow period

Not Analysed

Log-Log plot incl. derivatives- recovery period

Not Analysed

Selected representative parameters.			
dt_1 (min) =	-	C (m^3/Pa) =	NA
dt_2 (min) =	-	C_D (-) =	NA
T_T (m^2/s) =	< 1E-11	ξ (-) =	NA
S (-) =	NA		
K_s (m/s) =	NA		
S_s (1/m) =	NA		

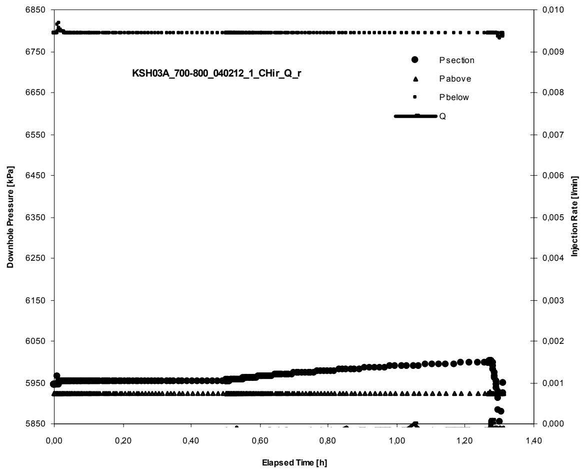
Comments:

The recommended transmissivity of < 1 E-11 m2/s was derived from experience of previous tests with flow rates of less than 1 ml/min.

Test Summary Sheet

Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040212 10:22
Test section from - to (m):	700 - 800 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

Linear plot Q and p



Flow period		**Recovery period**	
Indata		**Indata**	
p_0 (kPa) =	5945		
p_i (kPa) =	-		
p_p(kPa) =	-	p_F (kPa) =	-
Q_p (m^3/s)=	-		
tp (s) =	-	t_F (s) =	-
S el S^* (-)=	-	S el S^* (-)=	-
EC_w (mS/m)=			
$Temp_w$(gr C)=	15,1		
Derivative fact.=	-	Derivative fact.=	-
Results		**Results**	
Q/s (m^2/s)=	-		
T_M (m^2/s)=	-		
Flow regime:	transient	Flow regime:	transient
dt_1 (min) =	-	dt_1 (min) =	-
dt_2 (min) =	-	dt_2 (min) =	-
T (m^2/s) =	NA	T (m^2/s) =	NA
S (-) =	NA	S (-) =	NA
K_s (m/s) =	NA	K_s (m/s) =	NA
S_s (1/m) =	NA	S_s (1/m) =	NA
C (m^3/Pa) =	NA	C (m^3/Pa) =	NA
C_D (-) =	NA	C_D (-) =	NA
ξ (-) =	NA	ξ (-) =	NA
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Log-Log plot incl. derivates- flow period

Not Analysed

Log-Log plot incl. derivatives- recovery period

Not Analysed

Selected representative parameters.

dt_1 (min) =	-	C (m^3/Pa) =	NA
dt_2 (min) =	-	C_D (-) =	NA
T_T (m^2/s) =	< 1E-11	ξ (-) =	NA
S (-) =	NA		
K_s (m/s) =	NA		
S_s (1/m) =	NA		

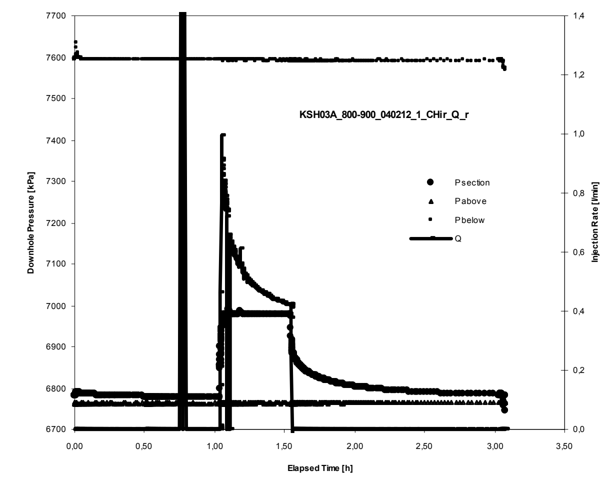
Comments:

The recommended transmissivity of < 1 E-11 m2/s was derived from experience of previous tests with flow rates of less than 1 ml/min.

Test Summary Sheet

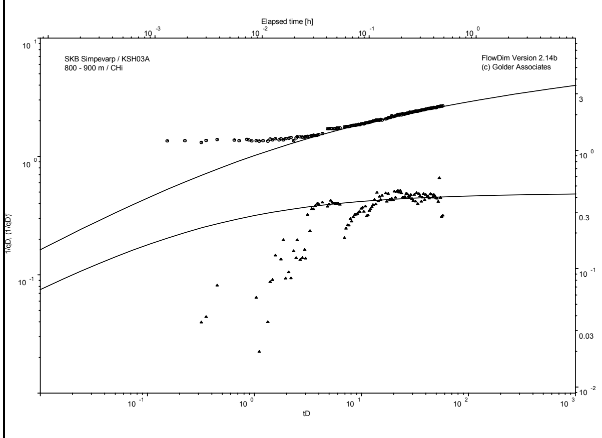
Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040212 13:52
Test section from - to (m):	800 - 900 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

Linear plot Q and p

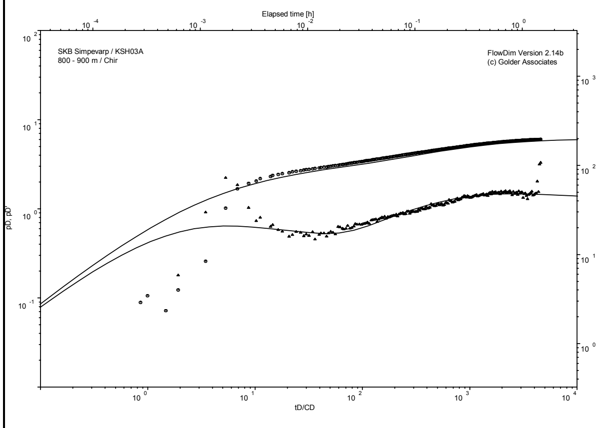


Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa) =	6788,6		
p_i (kPa) =	6776,5		
p_p(kPa) =	6978,1	p_F (kPa) =	6784,2
Q_p (m^3/s)=	6,99E-06		
tp (s) =	1800	t_F (s) =	5400
S el S^* (-)=	1,00E-06	S el S^* (-)=	1,00E-06
EC_w (mS/m)=			
$Temp_w$(gr C)=	15,1		
Derivative fact.=	0,13	Derivative fact.=	0,09
Results		**Results**	
Q/s (m^2/s)=	3,4E-07		
T_M (m^2/s)=	4,5E-07		
Flow regime:	transient	Flow regime:	transient
dt_1 (min) =	6,73	dt_1 (min) =	0,40
dt_2 (min) =	27,85	dt_2 (min) =	1,09
T (m^2/s) =	1,5E-07	T (m^2/s) =	4,14E-07
S (-) =	1,0E-06	S (-) =	1,00E-06
K_s (m/s) =	1,5E-09	K_s (m/s) =	4,14E-09
S_s (1/m) =	1,0E-08	S_s (1/m) =	1,00E-08
C (m^3/Pa) =	NA	C (m^3/Pa) =	3,09E-10
C_D (-) =	NA	C_D (-) =	3,41E-02
ξ (-) =	-4,02	ξ (-) =	-2,36
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Log-Log plot incl. derivates- flow period



Log-Log plot incl. derivatives- recovery period



Selected representative parameters.

dt_1 (min) =	0,4	C (m^3/Pa) =	3,09E-10
dt_2 (min) =	1,09	C_D (-) =	3,04E-04
T_T (m^2/s) =	1,7E-07	ξ (-) =	-2,36
S (-) =	1,0E-06		
K_s (m/s) =	1,7E-09		
S_s (1/m) =	1,0E-08		

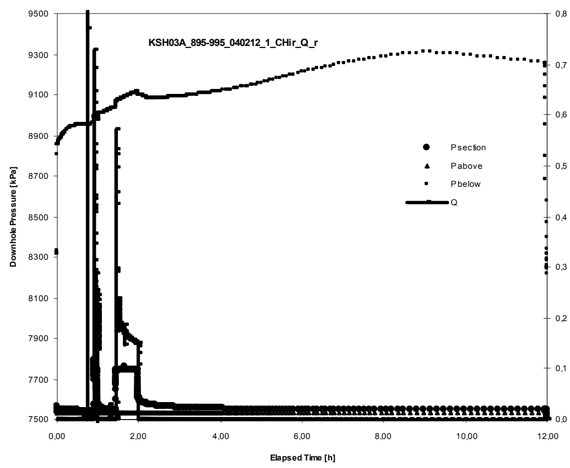
Comments:

The recommended transmissivity of 1.7E-7 m2/s was derived from the analysis of the CHir phase (outer zone), which shows the best data and derivative quality. The confidence range for the interval transmissivity is estimated to be 1.0E-7 to 5.0E-7 m2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 6772.3 kPa.

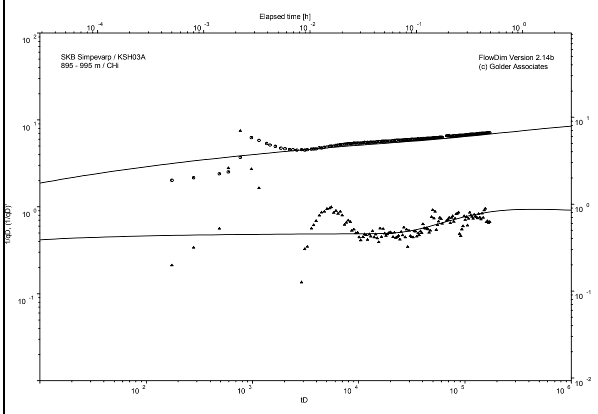
Test Summary Sheet

Project:	Hydraulic Injection Tests	Test type:[1]	Chir
Area:	Simpevarp	Test no:	1
Borehole ID:	KSH03A	Test start:	040212 18:14
Test section from - to (m):	895 - 995 m	Responsible for test execution:	Reinder van der Wall
Section diameter, $2 \cdot r_w$ (m):	0,076	Responsible for test evaluation:	C. Enachescu

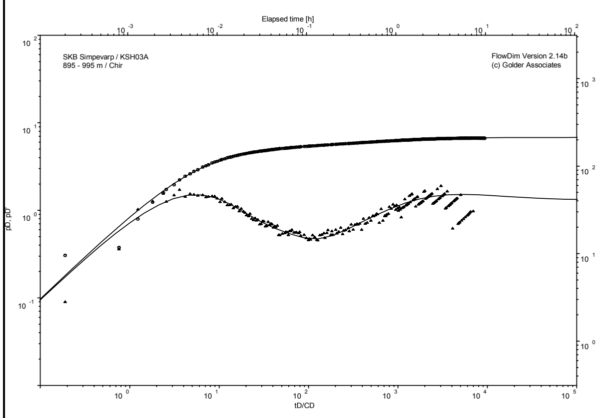
Linear plot Q and p



Log-Log plot incl. derivates- flow period



Log-Log plot incl. derivatives- recovery period



Flow period		Recovery period	
Indata		**Indata**	
p_0 (kPa) =	7543		
p_i (kPa) =	7546,8		
p_p(kPa) =	7746,8	p_F (kPa) =	7538,6
Q_p (m^3/s)=	2,48E-06		
tp (s) =	1800	t_F (s) =	36000
S el S^* (-)=	1,00E-06	S el S^* (-)=	1,00E-06
EC_w (mS/m)=			
$Temp_w$(gr C)=	17,5		
Derivative fact.=	0,12	Derivative fact.=	0,05
Results		**Results**	
Q/s (m^2/s)=	1,2E-07		
T_M (m^2/s)=	1,6E-07		
Flow regime:	transient	Flow regime:	transient
dt_1 (min) =	1,73	dt_1 (min) =	5,18
dt_2 (min) =	6,38	dt_2 (min) =	11,25
T (m^2/s) =	1,4E-07	T (m^2/s) =	1,41E-07
S (-) =	1,0E-06	S (-) =	1,00E-06
K_s (m/s) =	1,4E-09	K_s (m/s) =	1,41E-09
S_s (1/m) =	1,0E-08	S_s (1/m) =	1,00E-08
C (m^3/Pa) =	NA	C (m^3/Pa) =	3,42E-10
C_D (-) =	NA	C_D (-) =	3,77E-02
ξ (-) =	0	ξ (-) =	0
T_{GRF}(m^2/s) =		T_{GRF}(m^2/s) =	
S_{GRF}(-) =		S_{GRF}(-) =	
D_{GRF} (-) =		D_{GRF} (-) =	

Selected representative parameters.

dt_1 (min) =	5,18	C (m^3/Pa) =	3,42E-10
dt_2 (min) =	11,25	C_D (-) =	3,77E-02
T_T (m^2/s) =	5,5E-08	ξ (-) =	0
S (-) =	1,0E-06		
K_s (m/s) =	5,5E-10		
S_s (1/m) =	1,0E-08		

Comments:

The recommended transmissivity of 5.5E-8 m2/s was derived from the analysis of the CHir phase (outer zone), which shows a good data and derivative quality. The confidence range for the interval transmissivity is estimated to be 5.0E-8 to 2.0E-7 m2/s. The flow dimension displayed during the test is 2. The static pressure measured at transducer depth, was derived from the CHir phase using straight line extrapolation in the Horner plot to a value of 7545.4 kPa.

APPENDIX 4

Nomenclature

The following symbols are extracted from the more comprehensive list of symbols provided by SKB. Only the symbols that were used or deemed to be used in the future in the context of test analysis are presented.

Character	Explanation	Dimension	Unit
b	Aquifer thickness (Thickness of 2D formation)	[L]	m
L_w	Test section length.	[L]	m
r_w	Borehole, well or soil pipe radius in test section.	[L]	m
r_D	Dimensionless radius, $r_D=r/r_w$	-	-
Q_p	Flow in test section immediately before stop of flow. Stabilised pump flow in flow logging.	$[L^3/T]$	m^3/s
Q_m	Arithmetical mean flow during perturbation phase.	$[L^3/T]$	m^3/s
V	Volume	$[L^3]$	m^3
V_w	Water volume in test section.	$[L^3]$	m^3
V_p	Total water volume injected/pumped during perturbation phase.	$[L^3]$	m^3
t	Time	[T]	hour,min,s
t_0	Duration of rest phase before perturbation phase.	[T]	s
t_p	Duration of perturbation phase. (from flow start as far as p_p).	[T]	s
t_F	Duration of recovery phase (from p_p to p_F).	[T]	s
t_1, t_2 etc	Times for various phases during a hydro test.	[T]	hour,min,s
dt	Running time from start of flow phase and recovery phase respectively.	[T]	s
dt_e	$dt_e = (dt \cdot tp) / (dt + tp)$ Agarwal equivalent time with dt as running time for recovery phase.	[T]	s
t_D	$t_D = T \cdot t / (S \cdot r_w^2)$. Dimensionless time	-	-
p	Static pressure; including non-dynamic pressure which depends on water velocity. Dynamic pressure is normally ignored in estimating the potential in groundwater flow relations.	$[M/(LT)^2]$	kPa
p_a	Atmospheric pressure	$[M/(LT)^2]$	kPa
p_t	Absolute pressure; $p_t=p_a+p_g$	$[M/(LT)^2]$	kPa
p_g	Gauge pressure; Difference between absolute pressure and atmospheric pressure.	$[M/(LT)^2]$	kPa
p_0	Initial pressure before test begins, prior to packer expansion.	$[M/(LT)^2]$	kPa
p_i	Pressure in measuring section before start of flow.	$[M/(LT)^2]$	kPa
p_f	Pressure during perturbation phase.	$[M/(LT)^2]$	kPa
p_s	Pressure during recovery.	$[M/(LT)^2]$	kPa
p_p	Pressure in measuring section before flow stop.	$[M/(LT)^2]$	kPa
p_F	Pressure in measuring section at end of recovery.	$[M/(LT)^2]$	kPa
p_D	$p_D=2\pi \cdot T \cdot p/(Q \cdot \rho_w g)$, Dimensionless pressure	-	-
dp	Pressure difference, drawdown of pressure surface between two points of time.	$[M/(LT)^2]$	kPa
dp_f	$dp_f = p_i - p_f$ or $= p_f - p_i$, drawdown/pressure increase of pressure surface between two points of time during perturbation phase. dp_f usually expressed positive.	$[M/(LT)^2]$	kPa
dp_s	$dp_s = p_s - p_p$ or $= p_p - p_s$, pressure increase/drawdown of pressure surface between two points of time during recovery phase. dp_s usually expressed positive.	$[M/(LT)^2]$	kPa
dp_p	$dp_p = p_i - p_p$ or $= p_p - p_i$, **maximal** pressure increase/drawdown of pressure surface between two points of time during perturbation phase. dp_p expressed positive.	$[M/(LT)^2]$	kPa
dp_F	$dp_F = p_p - p_F$ or $= p_F - p_p$, **maximal** pressure increase/drawdown of pressure surface between two points of time during recovery phase. dp_F expressed positive.	$[M/(LT)^2]$	kPa

H	Total head; (potential relative a reference level) (indication of h for phase as for p). $H=h_e+h_p+h_v$	[L]	m
h	Groundwater pressure level (hydraulic head (piezometric head; possible to use for level observations in boreholes, static head)); (indication of h for phase as for p). $h=h_e+h_p$	[L]	m
h_e	Height of measuring point (Elevation head); Level above reference level for measuring point.	[L]	m
s_p	Drawdown in measuring section before flow stop.	[L]	m
h_0	Initial above reference level before test begins, prior to packer expansion.	[L]	m
h_i	Level above reference level in measuring section before start of flow.	[L]	m
h_f	Level above reference level during perturbation phase.	[L]	m
h_s	Level above reference level during recovery phase.	[L]	m
h_p	Level above reference level in measuring section before flow stop.	[L]	m
h_F	Level above reference level in measuring section at end of recovery.	[L]	m
dh	Level difference, drawdown of water level between two points of time.	[L]	m
dh_f	$dh_f = h_i - h_f$ or $= h_f - h_i$, drawdown/pressure increase of pressure surface between two points of time during perturbation phase. dh_f usually expressed positive.	[L]	m
dh_s	$dh_s = h_s - h_p$ or $= h_p - h_s$, pressure increase/drawdown of pressure surface between two points of time during recovery phase. dh_s usually expressed positive.	[L]	m
dh_p	$dh_p = h_i - h_p$ or $= h_p - h_i$, maximal pressure increase/drawdown of pressure surface between two points of time during perturbation phase. dh_p expressed positive.	[L]	m
dh_F	$dh_F = h_p - h_F$ or $= h_F - h_p$, maximal pressure increase/drawdown of pressure surface between two points of time during perturbation phase. dh_F expressed positive.	[L]	m
Te_w	Temperature in the test section (taken from temperature logging). Temperature		^oC
Te_{w0}	Temperature in the test section during undisturbed conditions (taken from temperature logging). Temperature		^oC
g	Constant of gravitation (9.81 $m*s^{-2}$) (Acceleration due to gravity)	$[L/T^2]$	m/s^2
π	Constant (approx 3.1416).	[-]	
r	Residual. $r= p_c-p_m$, $r= h_c-h_m$, etc. Difference between measured data (p_m, h_m, etc) and estimated data (p_c, h_c, etc)		
Q/s	Specific capacity $s=dp_p$ or $s=s_p=h_0-h_p$ (open borehole)	$[L^2/T]$	m^2/s
D	Interpreted flow dimension according to Barker, 1988.	[-]	-
dt_1	Time of starting for semi-log or log-log evaluated characteristic counted from start of flow phase and recovery phase respectively.	[T]	s
dt_2	End of time for semi-log or log-log evaluated characteristic counted from start of flow phase and recovery phase respectively.	[T]	s
T	Transmissivity	$[L^2/T]$	m^2/s
T_M	Transmissivity according to Moye (1967)	$[L^2/T]$	m^2/s
T_S	Transmissivity evaluated from slug test	$[L^2/T]$	m^2/s
T_{Sf}, T_{Lf}	Transient evaluation based on semi-log or log-log diagram for perturbation phase in injection or pumping.	$[L^2/T]$	m^2/s
T_{Ss}, T_{Ls}	Transient evaluation based on semi-log or log-log diagram for recovery phase in injection or pumping.	$[L^2/T]$	m^2/s

T_T	Transient evaluation (log-log or lin-log). Judged best evaluation of T_{Sf}, T_{Lf}, T_{Ss}, T_{Ls}	$[L^2/T]$	m^2/s
T_{NLR}	Evaluation based on non-linear regression.	$[L^2/T]$	m^2/s
S	Storage coefficient, (Storativity)	[-]	-
S*	Assumed storage coefficient	[-]	-
S_f	Fracture storage coefficient	[-]	-
S_m	Matrix storage coefficient	[-]	-
S_{NLR}	Storage coefficient, evaluation based on non-linear regression	[-]	-
S_s	Specific storage coefficient; confined storage.	[1/L]	1/m
S_s*	Assumed specific storage coefficient; confined storage.	[1/L]	1/m
ξ	Skin factor	[-]	-
ξ*	Assumed skin factor	[-]	-
C	Wellbore storage coefficient	$[(LT^2)\cdot M^2]$	m^3/Pa
C_D	$C_D = C\cdot\rho_w g /(2\pi\cdot S\cdot r_w^2)$, Dimensionless wellbore storage coefficient	[-]	-
ω	$\omega = S_f /(S_f + S_m)$, storage ratio (Storativity ratio); the ratio of storage coefficient between that of the fracture and total storage.	[-]	-
λ	$\lambda = \alpha\cdot (K_m / K_f) \cdot r_w^2$ interporosity flow coefficient.	[-]	-
T_{GRF}	Transmissivity interpreted using the GRF method	$[L^2/T]$	m^2/s
S_{GRF}	Storage coefficient interpreted using the GRF method	[1/L]	1/m
D_{GRF}	Flow dimension interpreted using the GRF method	[-]	-
c_w	Water compressibility; corresponding to β in hydrogeological literature.	$[(LT^2)/M]$	1/Pa
c_r	Pore-volume compressibility, (rock compressibility); Corresponding to α/n in hydrogeological literature.	$[(LT^2)/M]$	1/Pa
c_t	$c_t = c_r + c_w$, total compressibility; compressibility per volumetric unit of rock obtained through multiplying by the total porosity, n. (Presence of gas or other fluids can be included in c_t if the degree of saturation (volume of respective fluid divided by n) of the pore system of respective fluid is also included)	$[(LT^2)/M]$	1/Pa
n	Total porosity	-	-
ρ	Density	$[M/L^3]$	$kg/(m^3)$
ρ_w	Fluid density in measurement section during pumping/injection	$[M/L^3]$	$kg/(m^3)$
μ	Dynamic viscosity	[M/LT]	Pa s
μ_w	Dynamic viscosity (Fluid density in measurement section during pumping/injection)	[M/LT]	Pa s

APPENDIX 5

SICADA data tables

General Information

Borehole	Borehole secup (m)	Borehole seclow (m)	Test type (1-6)	Formation type (-)	Date for test, start YYYYMMDD	Start flow/ injection hhmmss	Qp (m**3/s)	tp (s)	t_F (s)	h_i (m)	h_p (m)	h_F (m)	p_i (kPa)	p_p (kPa)	p_F (kPa)	Te_w (° C)	EC_w (mS/m)	TDS_w (mg/L)	TDS_{wm} (mg/L)	Reference	Comments (-)
KSH03A	102,5	202,5	1	1	20040210	114300	7,35E-04	1800	1800				911,6	972,1	914,4	8,8					
KSH03A	201	301	1	1	20040210	152100	5,04E-04	1800	1800				1736,4	1744,1	1738,0	8,9					
KSH03A	300	400	1	1	20040210	185600	2,40E-04	1800	36000				2566,0	2764,4	2567,7	10,0					
KSH03A	400	500	1	1	20040211	112800	6,00E-07	1800	1800				3426,5	3626,5	3420,5	11,2					
KSH03A	500	600	1	1	20040211	-	-	-	-				-	-	-	12,5					
KSH03A	600	700	1	1	20040211	-	-	-	-				-	-	-	13,8					
KSH03A	700	800	1	1	20040212	-	-	-	-				-	-	-	15,1					
KSH03A	800	900	1	1	20040212	145500	6,99E-06	1800	5400				6776,5	6978,1	6784,2	16,4					
KSH03A	895	995	1	1	20040212	194300	2,48E-06	1800	36000				7546,8	7746,8	7538,6	17,5					

Basic Evaluation

Borehole	Borehole secup (m)	Borehole seclow (m)	Date for test, start YYYYMMDD	Q/s (m^2/ s)	T_Q (m^2/s)	T_M (m^2/s)	b (m)	B (m)	TB (1D) (m^3/s)	TB-measl-L (1D) (m^3/s)	TB-measl-U (1D) (m^3/s)	SB (1D) (m)	SB* (1D) (m)	L (1D) (m)	T_T (2D) (m^2/s)	T-measl-L (2D) (m^2/s)	T-measl-U (2D) (m^2/ s)	S (2D) (-)	S* (2D) (-)	K´/b´ (2D) (1/s)	K_S (3D) (m/s)	K_S-measl-L (3D) (m/s)	K_S-measl-U (3D) (m/s)	S_S (3D) (1/m)	S_S* (3D) (1/m)	C (m**3/Pa)	C_D (-)	ξ (1,2 or 3D) (-)	w (-)	l (-)	dt_1 (min)	dt_2 (min)	Comments (-)
KSH03A	102,5	202,5	20040210	1,20E-04		1,56E-04	100								2,06E-04	9,00E-05	2,50E-04		1,00E-06							1,67E-07		-3,61			1,1	4,4	
KSH03A	201	301	20040210	5,50E-04		7,16E-04	100								1,58E-04	1,00E-04	4,00E-04		1,00E-06							6,69E-07		-8,50			-	-	
KSH03A	300	400	20040210	1,18E-05		1,53E-05	100								2,58E-05	2,00E-05	5,00E-05		1,00E-06							6,51E-09		12,84			0,8	3,1	
KSH03A	400	500	20040211	2,94E-08		3,83E-08	100								1,93E-08	8,00E-09	3,00E-08		1,00E-06							4,95E-10		-0,97			-	-	
KSH03A	500	600	20040211	#NV		#NV	100								1,00E-11	1,00E-13	1,00E-11		1,00E-06							#NV		#NV			-	-	
KSH03A	600	700	20040211	#NV		#NV	100								1,00E-11	1,00E-13	1,00E-11		1,00E-06							#NV		#NV			-	-	
KSH03A	700	800	20040212	#NV		#NV	100								1,00E-11	1,00E-13	1,00E-11		1,00E-06							#NV		#NV			-	-	
KSH03A	800	900	20040212	3,45E-07		4,49E-07	100								1,65E-07	1,00E-07	5,00E-07		1,00E-06							3,09E-10		-2,36			0,4	1,1	
KSH03A	895	995	20040212	1,22E-07		1,58E-07	100								5,47E-08	5,00E-08	2,00E-07		1,00E-06							3,42E-10		0,00			5,2	11,3	