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Äspö Hard Rock Laboratory

TRUE Block Scale experiment

Preliminary results of selective pressure build-up tests in borehole KI0023B

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Solexperts AG

June 1998
Revised October 1998

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Sammanfattning

Som en del av karakteriseringen i True Block Scale utfördes selektiva flödes- och tryckuppbyggnadstester i borrhål KI0023B. Med utrustningen SKB UHT karakteriserades totalt 18 testintervaller.

Analyserna visar:

- ett heterogent berg med ett konduktivt spricksystem som dominerar grundvattenflödet
- en transmissivitet mellan $\leq 10^{-10}$ till 10^{-5} m^2/s

Abstract

Selective flow and pressure build-up tests were conducted as part of the characterisation of Borehole KI0023B of the True Block Scale Experiment. In all, 18 test intervals were characterised using the SKB UHT Equipment.

The analyses indicate:

- a heterogeneous rock mass in which conductive fractures dominate the groundwater flow patterns
- a transmissivity range from $\leq 10^{-10}$ to 10^{-5} m^2/s

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1 Introduction

During 1996 characterisation work for the TRUE Block Scale Project commenced at Äspö with drilling of borehole KA2563A from the spiral tunnel. Characterisation data from this borehole and data from boreholes KA2511A, KA3510A, and K10025F have been used to update the structural model of the south-western part of the Äspö HRL (Hermanson, 1997). Based on this updated model and the identified centre of gravity for further investigations, an additional borehole, K10023B, has been completed, which is located in the "I-tunnel" (Figure 1-1).

Borehole K10023B has been characterised with acoustic flow logging (UCM), borehole radar (RAMAC), borehole TV (RAAX-BIPS), detailed double packer flow logging, and selective flow and build-up tests.

1.1 Scope

The scope of this report is to document the methods and preliminary results of the "Selective Flow and Pressure Build-up Tests" performed in Borehole KI0025B from January 19 - 30, 1998.

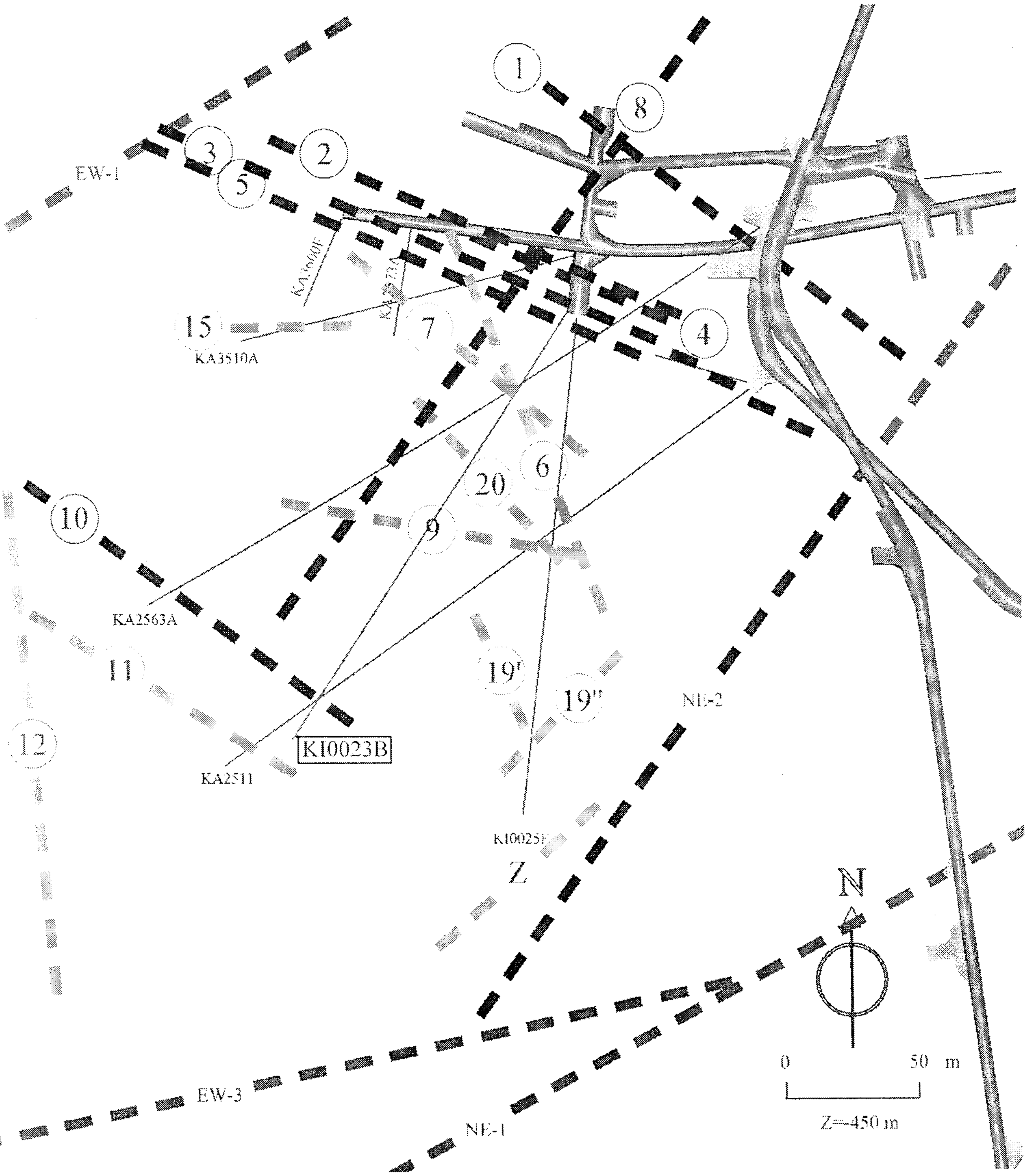

Figure 1-1. *Updated deterministic model of the TRUE BS volume (Hermanson 1997). Horizontal section through interpreted structures at Z=-450 masl. Borehole KI0023B is vertically projected onto section.*

2 Methods

2.1 Test Interval Selection

Test interval selection was a co-operative effort between Solexperts (J. Adams), SKB (A. Winberg), and ANDRA (M. De Combarieu). Selections were based primarily on correlation of the drilling data, detailed double-packer flow logging, and the BIPS imaging data. Twenty-three potential test intervals were selected. Each interval was assigned a priority value of 1, 2 or 3, based on its geometric and potential hydraulic significance (Table 2-1). Priority 1 intervals were to be tested in any case; Priority 2 intervals were to be cancelled only in the case of extreme time restrictions; and Priority 3 Intervals were to be tested only if time allowed.

Time restraints due to equipment problems at the beginning of the campaign resulted in cancellation of all of the Priority 3 Intervals (Intervals 15 - 18). Interval No. 12 was also cancelled during the test campaign after a review of the existing data, which indicated that the interval did not warrant detailed testing.

2.2 Equipment

The underground hydraulic test system (UHT-1) developed by SKB was used for performing the tests. The UHT-1 is constructed for underground hydraulic testing in 56 mm and 76 mm diameter boreholes. Maximum borehole length is 300 m and the maximum working depth is 500 metres below sea level. In general, the testing system consists of three main components:

- **Down-hole System**, including Packer system (double or single) for isolating the target test interval, down-hole shut-in valve, central tubing, and control lines for packer inflation and pressure measurement.
- **Hoisting Rig** for installing and removing the packer system.
- **Surface System**, including data acquisition, flow and pressure control and measurement equipment.

The UHT is documented in detail in Appendix A.

In general, the equipment functioned well. However, some test were disturbed because the system depressurised the interval to a pressure far below the target pressure when initiating the test. This had a particularly great impact on tests in low-permeable intervals because the time required to recover from the depressurisation is dependent on the inflow rate from the interval.

Table 2-1: Proposed Intervals for Selective Flow and Pressure Build-up Tests in Borehole K10023B

Interval No.	Interval (Borehole m)	Interval Length (m)	Priority	Comments
1	41.45 - 42.45	1	1	Structure #6/#7? Open fractures at 41.6, 42.1, and 42.3
2	42.4 - 43.4	1	1	Structure #6/#7? Open fracture at 43.04
3	43.4 - 44.4	1	1	Structure #6/#7? Open fractures at 43.65 and 44.11
4	50.0 - 51.0	1	1	Open fracture at 50.47
5	68.4 - 69.4	1	1	Structure #20? Open fracture at 68.94 Lower Packer is placed on the fracture at 69.83 m
6	69.4 - 70.4	1	1	Structure #20? Open compound fracture at 69.83
7	70.4 - 71.4	1	1	Structure #20? Open fracture at 71.0 - 71.2 Upper Packer is placed on the fracture at 69.83 m
8	75.1 - 76.1	1	1	Multiple open fractures 75.4 - 75.64, Single open fracture at 75.95
9	78.6 - 79.6	1	1	Multiple open fractures centred at 79.18
10	85.0 - 86.0	1	1	Faint multiple open fracture centred at 85.54 (Flow logging anomaly)
11	87.1 - 88.1	1	2	Multiple open fractures centred at 87.61
12	104.4 - 105.4	1	1	Multiple open fractures 104.77 - 105.11
13	109.5 - 110.5	1	1	Multiple open fractures 109.71 - 110.29
14	111.45 - 112.45	1	1	Structure #19? Open fractures at 111.55, 111.96 and 112.43
15	115.8 - 116.8	1	3	Open fracture at 116.10 - 116.53 (low angle to borehole)
16	125.7 - 126.7	1	3	Multiple open fractures 126.03 - 126.43
17	162.55 - 163.55	1	3	Open fracture at 163.03
18	163.9 - 164.9	1	3	Open fractures at 164.25 and 164.47
19	168.1 - 169.1	1	2	Open fractures at (168.1) 168.34, 168.29, (169.05)
20	170.2 - 171.2	1	2	Structure #10? Multiple open fractures 170.37 - 170.8 Open fracture at 171.04
21	111.2 - 111.7	0.5	2	Structure #19? Open fracture at 111.55
22	111.7 - 112.2	0.5	2	Structure #19? Open fracture at 111.96
23	112.2 - 112.7	0.5	2	Structure #19? Open fracture at 112.43

2.3 Test Performance

The planned test sequence for each interval consisted of a compliance period (packer inflation), a constant-pressure withdrawal test (HW), followed by a pressure recovery period (HWS). The constant pressure tests were to be conducted by decreasing the ambient pressure in the test section by 100 kPa (10 m water column) to minimise the effects of turbulent flow when testing high-permeability features. This approach, however, proved to be disadvantageous when testing low-permeability features, because flow rates were below the range of the flow meters. The test approach was altered during the test campaign to allow the pressure differential to be designed according to the anticipated permeability of the interval.

The permeability of each interval was qualitatively evaluated during packer inflation by observing any packer-squeeze effects that may have occurred. Packer squeeze occurs when the packers are expanded with the shut-in valve closed. The degree to which packer squeeze occurs, and is subsequently dissipated, is analogous to a pulse test and provides a qualitative indication of the transmissivity of the interval. Three general types of packer-squeeze effects were observed during testing:

1. **Slight Squeeze:** A pressure squeeze that dissipated almost immediately, indicating a relatively high permeability. The ensuing constant-pressure test was conducted using a dP $\approx$ 100 kPa.

2. **Moderate Squeeze:** A pressure squeeze that dissipated within the 30-minute compliance period. Because skin effects could be expected to be minimal for lower permeability intervals, the dP was increased to approximately 1000 kPa in order to increase the flow rate.

3. **Big Squeeze:** A pressure squeeze that did not dissipate within the allotted compliance period. No active tests were conducted in such intervals because flow rates could be expected to below the range of the flow meter.

Three of the 18 intervals tested (4, 9 and 13) exhibited "big squeeze" effects. No active tests were performed in these intervals.

2.4 Analysis

The preliminary test interpretation is conducted using standard analytical models to produce hydraulic coefficients for the test intervals.

Objectives of the preliminary interpretation are the following:

- Flow-model identification (if possible)
- Evaluation of hydraulic parameters (T, and K_e) and wellbore effects (wellbore storage, skin)
- Estimates of the pressure distribution within the borehole.

Flow-model identification is conducted using diagnostic plots. Once the various parts of the well response have been identified (i.e. inner boundary, basic flow model, and outer boundary), the appropriate analytical method is applied.

2.4.1 Constant-pressure Tests

Transient analysis of constant-pressure tests is conducted using the straight-line method described by JACOB & LOHMAN, 1952. Straight-line analysis is performed by plotting 1/q versus the log of time. If an infinite-acting radial-flow period is identified on the diagnostic plot, a straight-line is fit to the data and transmissivity is calculated using the following formula:

$$T = \frac{2.3}{4\pi\,\Delta hm}$$

where:

Δh = constant change in pressure expressed as head [m]

m = slope of straight line [(s/m^3)/log cycle]

For constant rate test, a straight line is fit to the indicated data set on a semi-log graph of Δp vs. log time. Transmissivity is estimated using the following equation (COOPER & JACOB, 1946):

$$T = \frac{2.3q}{4\pi\,m}$$

where:

q = flow rate [m^3/s]

m = slope of a straight line [m/log cycle]

A steady-state approximation of transmissivity is calculated for each flow period using the following formula presented by Zeigler, (1976). The formula can be applied to both constant pressure and constant rate data.

$$T = \left[\frac{Q_p}{2\pi\Delta h}\right]\ln\left[\frac{r_i}{r_w}\right]$$

where:

T = transmissivity [m^2/s]

Q_p = flow at the end of the flow phase [m^3/s]

Δh = pressure drop in the test section expressed in meters of water [m]

L = interval length [m]

r_i = radius of influence (estimated) [m]

r_w = borehole radius [m]

An initial value of 1 m is assumed for the radius of influence, r_i. T and r_I are then calculated iteratively using the above equation for T and the following equation for r_i:

$$r_i = \sqrt{\frac{2.25Tt}{S}}$$

where:

t	=	time at which steady-state conditions are reached	[s]
S	=	storativity	[-]

If steady-state conditions have not been achieved by the end of the pumping period, then t is taken as the total pumping time. In addition, a storativity value is required to solve the above equation. Because a reliable estimate of storativity cannot be made from single-well tests, a value must be assumed. S-values ranging from $1x10^{-8}$ to $2x10^{-5}$ have been reported for the flow system at Äspö (Uchida et al, 1994, and Winberg, 1996). Uchida et al (1994), report an empirical relationship where:

$$S = .001\sqrt{T}$$

The above approach yields S-values ranging from $1.1x10^{-8}$ to $8.8x10^{-7}$ for tests conducted in the TRUE-1 Experiment.

A constant S-value of $1x10^{-7}$ is assumed for the steady-state and skin-factor analyses reported in this document.

2.4.2 Pressure Build-up Tests

The pressure build-up period following a constant-pressure test can be analysed in a comparable manner to a constant rate test. If steady-state conditions were established prior to shut-in, the analysis is identical to that of the flow test. If no steady-state conditions were reached (i.e. infinite-acting radial flow at the end of the period), then the effects of the preceding flow period must be accounted for.

For cases in which steady-state conditions are not reached, diagnostic plots are prepared according to AGARWAL (1980), who presented a relationship that plots the recovery pressure change versus an equivalent time instead of elapsed time. The equivalent time function essentially converts the pressure recovery event to an equivalent constant rate test response that can be analysed using the straight-line analysis method presented above. Equivalent time is calculated using the following formula:

$$\Delta t_e = \frac{t_p \Delta t}{t_p + \Delta t}$$

where:

Δt_e	=	equivalent time	[s]
tp	=	duration of preceding flow period	[s]
Δt	=	elapsed recovery time	[s]

3 Results

Analysis and interpretation of the test sequences yields information regarding the flow models that control the test responses, the transmissivity of the intervals, and the pressure distribution along the borehole. The analyses of the individual intervals are presented in Appendix B. Results of the analyses are summarised in Table 3-1 and described in the following sections.

3.1 Flow Models

The formation responses observed in KI0023B can be grouped into two general flow models:

1. Infinite-acting radial flow, in some cases with increasing flow dimension at late-time
2. Apparent composite system with inner-T < outer-T (infinite-acting flow periods were not clearly identifiable). This may indicate a low-permeability fracture that intersects the interval and interconnects to a higher-permeability interval at some distance from the borehole.

The flow model grouping appears to correlate with transmissivity estimates for the intervals. In general, intervals with transmissivity > $1x10^{-9}$ fall into Group No. 1, whereas intervals with inner zone T<$1x10^{-9}$ fall into Group 3. Clear flow model identification was generally not possible for intervals with transmissivity <$1x10^{-7}$. Borehole pressure history effects lend some degree of ambiguity to the identification of flow models, especially in low-permeable intervals. Borehole pressure history effects are discussed in more detail in Section 3.3.

3.2 Transmissivity

Transmissivity estimates are made from transient and steady-state analyses of the various test events for the 15 intervals in which active tests were performed. The preliminary analyses indicate a transmissivity range from $\leq 10^{-10}$ to 10^{-5} m^2/s (Table 3-1 and Figure 3-1). Two to four T-values are presented for each interval, depending on the interpreted flow model and the nature of the data. Correlation between the results is very good in Intervals 1, 7, 10 and 20.

The results for those intervals that exhibit a composite response (Intervals 3, 6, 8 , 11, 19, and 22) have the following distinctions:

- The inner zone T-value is 0.5 to 1 order of magnitude less than the steady-state T-value.
- The inner zone T-value is 1 to 2 orders of magnitude less than the outer-zone T-value.

The remaining intervals (2, 5, 14, 21, 23), have a scatter in T-values 0.5 to 1 order of magnitude. With the exception of Interval 21, the T-value from the pressure build-up period

(HWS) is greater than that from the steady-state and/or transient analysis of the preceding HW period. This systematic discrepancy may be caused by:

- borehole history effects (see the discussion in Section 3.3)
- the flow model does not adequately describe the test response.

3.3 Pressure Distribution

Pressures measured during the test campaign range from 4039 kPa in Interval 1 to 4278 kPa in Interval 20 (Table 3-1 and Figure 3-2). The reported pressures are the end-values measured during the pressure build-up phase.

The pressures measured in the guard zone (i.e. the entire borehole except for the packed-off test interval), was generally 4040 kPa, indicating that the high-permeability zone tested in Interval 1 at 41.45 – 42.45 m (Structure No. 6) dominated the pressure in the borehole. The pressure gradient along the borehole, and the dominance of Structure 6, result in a significant cross-flow during the period in which the well was "shut-in" (i.e. prior to, and during the testing campaign).

The borehole history may significantly affect the pressure responses observed during active testing, especially considering the fact that many of the tests were conducted with a dP of only 100 kPa. For intervals deep in the borehole, it is possible that the pressure disturbance created during the relatively short (<1 hour) constant-head tests is less than the pressure disturbance during the relatively long (days to weeks) borehole history period.

Table 3-1: Summary of Results of Selective Flow and Pressure Build-up Tests in Borehole KI0023B.

Interval No.	Position [m]	Interval Length (m)	Tests	Flow Model	T [m^2/s]	P [kPa]	Comments
1	**41.45 - 42.45**	1	INF			4139	No squeeze
			HW	?	1.6×10^{-5}		Steady state approx.
			HWS	W-S-2	1.8×10^{-5}	4139	
2	**42.4 - 43.4**	1	INF				Moderate Squeeze
			HW		6.6×10^{-10}		Steady state approx.
			HWS	W-S-2+	3.3×10^{-9}	4140	
3	**43.4 - 44.4**	1	INF				No squeeze
			HW	?	3.3×10^{-8}		Steady state approx.
			HWS	W-S-C?	6.4×10^{-9} 4.0×10^{-7}	4144	Early-time match Latx10-time match
4	**50.0 - 51.0**	1	INF				Big squeeze - no tests
5	**68.4 - 69.4**	1	INF				No squeeze
			HW	2	4.8×10^{-7} 1.4×10^{-7}		Transient Steady-state
			HWS	W-S-2-	9.6×10^{-7}	4198	
6	**69.4 - 70.4**	1	INF				Slight squeeze
			HW	S-2-2+	4.7×10^{-8} 5.8×10^{-8}		Transient Steady-state
			HWS	W-S-C?	6.9×10^{-9} 7.9×10^{-7}	4214	Early-time match Latx10-time match
7	**70.4 - 71.4**	1	INF				No squeeze
			HW	S-2-2+	8.4×10^{-7} 6.9×10^{-7}		Transient Steady-state (dp = 100 kPa)
			HWS	W-S-2	8.1×10^{-7}	4200	
							Step Test
			HW2		4.9×10^{-7}		Steady state dP = 300 kPa
			HW3		4.2×10^{-7}		Steady state dP = 500 kPa
			HW4		4.1×10^{-7}		Steady state dP = 800 kPa
			HW5		3.5×10^{-7}		Steady state dP = 1200 kPa
8	**75.1 - 76.1**	1	INF				Moderate squeeze
			HW		8.8×10^{-10}		Steady state approx.
			HWS	W-S-C?	2.4×10^{-10} 6.1×10^{-9}	4163	Early-time match Late-time match
9	**78.6 - 79.6**	1	INF				Big squeeze - no tests
9a	**78.3 - 79.3**	1	INF				Moved 0.3 m to confirm that feature was not missed in Int. No. 9. Big squeeze - no tests
10	**85.0 - 86.0**	1	INF				Slight squeeze
			HW	2-2+	6.1×10^{-8} 9.8×10^{-8}		Transient Steady-state
			HWS	W-2	5.8×10^{-8}	4192	
11	**87.1 - 88.1**	1	INF				Moderate squeeze
			HW	S-2?	1.8×10^{-9} 6.4×10^{-10}		Transient Steady-state
			HWS	W-S-C?	1.8×10^{-10} 3.8×10^{-9}	4174	Early-time match Late-time match
13	**109.5 - 110.5**	1	INF				Big Squeeze - no tests

Interval No.	Position [m]	Interval Length (m)	Tests	Flow Model	T [m²/s]	P [kPa]	Comments
14	**111.45 - 112.45**	1	INF				Slight Squeeze
			HW	S-2	9.7×10^{-7} 1.2×10^{-6}		Transient Steady-state
			HWS	W-S-2-?	3.9×10^{-6}	4230	Borehole-history effects
19	**168.1 - 169.1**	1	INF				Slight squeeze
			HW	?	1.6×10^{-8}		Steady state approx.
			HWS	W-S-C?	3.0×10^{-9} 6.8×10^{-7}	4243	Early-time match Late-time match
20	**170.2 - 171.2**	1	INF				
			HW	S-2	4.2×10^{-6} 2.7×10^{-6}		Transient Steady-state
			HWS	W-S-2	4.5×10^{-6}	4278	Borehole history effects
21	**111.2 - 111.7**	0.5	INF				Slight squeeze
			HW	S-2	3.9×10^{-7} 3.6×10^{-7}		Transient Steady-state
			HWS	W-S-2	2.0×10^{-6}	4227	
22	**111.7 - 112.2**	0.5	INF				Moderate squeeze
			HW	?	2.1×10^{-9}		Steady state approx.
			HWS	W-S-C?	5.2×10^{-10} 4.1×10^{-8}	4227	Early-time match Late-time match
23	**112.2 - 112.7**	0.5	INF				Slight squeeze
			HW	S-2	2.7×10^{-7} 1.4×10^{-7}		Transient Steady-state.
			HWS	W-S-2?	2.0×10^{-6}	4227	Borehole-history effects?

Test Legend:

INF	Inflation Period
HW	Constant Pressure (Head) Withdrawal Test
HWS	Pressure Build-up after Constant Pressure (Head) Withdrawal Test

Flow Model Legend:

W	Wellbore Storage
S	Skin
2	Flow Dimension
C	Composite Model

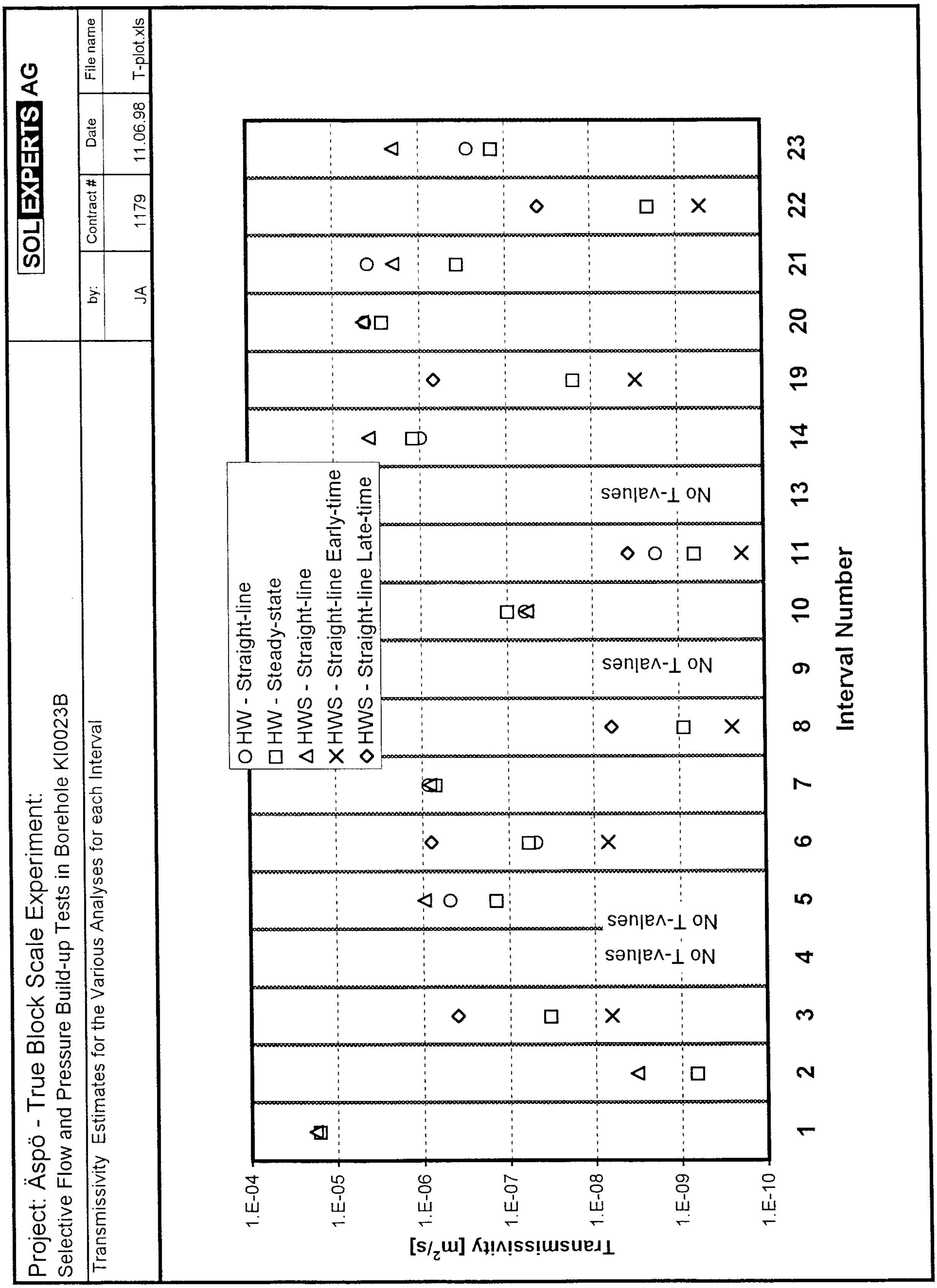

Figure 2-1. Graphical presentation of transmissivity estimates derived from analyses of the selective flow and build-up testing in Borehole KI0023B.

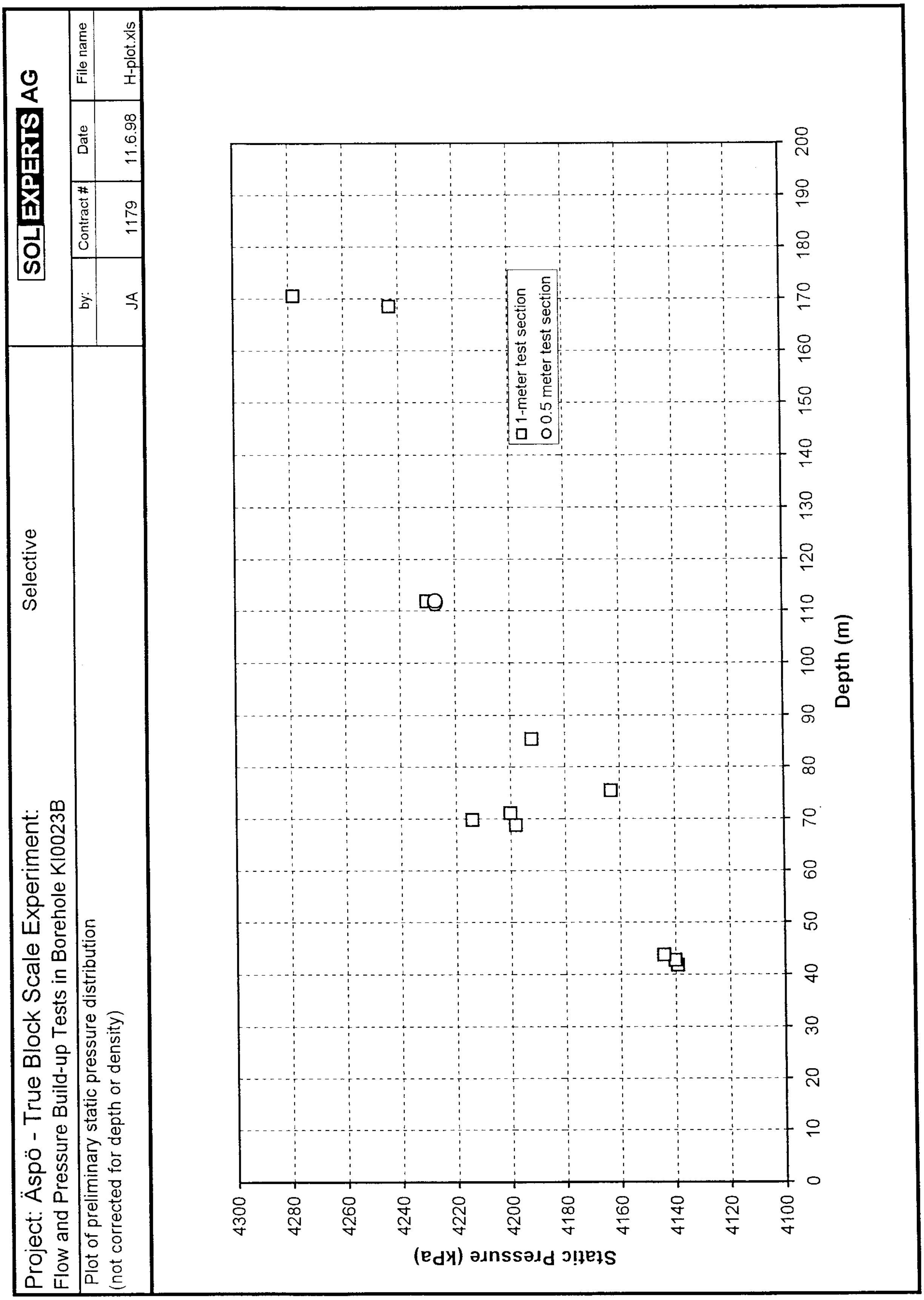

Figure 2-2. Pressure distribution along the borehole during selective flow and build-up testing in Borehole KI0023B

4 Conclusions and Recommendations

4.1 Conclusions

The selective flow and pressure build-up tests conducted in KI0023B indicate that a wide range of hydraulic properties can be found within the borehole. In order to produce the best information possible for each interval, the testing methods must take the variation in hydraulic properties, as well as the borehole history, into consideration.

In general, flow-model recognition is possible for the higher-permeable intervals. However, flow-model identification for the lower-permeable intervals proves to be more difficult. The low-permeable intervals tend to exhibit a composite response, with lower T near the borehole and higher T away from the borehole. The test responses indicate a complex, heterogeneous flow system with interaction between low- and high-permeable features.

Estimated transmissivity values for the tested intervals range from $<10^{-10}$ to 10^{-5} m^2s. The uncertainty in the values from the low-permeable intervals is significantly greater than that for the high-permeable intervals because of uncertainty regarding flow model identification and the scatter in T-values resulting from analyses of the various events.

4.2 Recommendations

Based on the preliminary results, a number of recommendations can be made regarding additional analysis of the tests from KI0023B and field procedures for future test campaigns.

4.2.1 Additional Analysis

A detailed analysis should be conducted to evaluate the impact of borehole history on the test results, and to clarify the ambiguity regarding flow models. This may tighten the scatter of T-values observed when comparing analysis results of different events conducted in a particular interval. The detailed analysis should include Intervals 6, 8, 11, 14, 20, 21, 22, and 23.

4.2.2 Procedures for Future Testing

The UHT equipment should be modified to prevent de-pressurisation of low-permeable test intervals when starting a constant pressure flow test.

The pressure differential for a constant-pressure flow test should be designed such that it is significantly greater than the potential borehole history effect. This has to be balanced with the goal of minimising skin effects due to turbulence. A minimum pressure differential of 300 kPa is recommended for conditions similar to those in KI0023B.

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Appendix A UHT Equipment Documentation

(This Section is taken from a description of the UHT Equipment that was written by GeoSigma, AB). The underground hydraulic test system (UHT-1) developed by SKB (Almen and Hansson, 1996) will be used for the tests. The UHT-1 is constructed for underground hydraulic testing in boreholes with 56 mm and 76 mm diameter. Maximum borehole length is 300 m and the maximum working depth is 500 metres below sea level.

The main components of the system (Figure A-1) are:

- Down-hole equipment with packers and pipe string
- Hoisting rig
- Mini container including a system control unit, a measurement control unit
- a data export and plotting unit.

The down-hole equipment (Figure A-2) consists of two inflatable Polyurethane packers separated by pipe(s), a mechanically operated valve, a pipe string and two pressure lines. The sealing length of each packer is 1.0 m and they are inflated using water pressurized by nitrogen. The pipe between the packers and a by-pass opening at the upper gable of the outer packer equalize the ground water pressure on both sides of the measurement section. The down-hole valve is opened by pushing the pipe string 87- 105 mm towards the bottom of the borehole and is shut by pulling the pipe string the same distance. One of the two pressure hoses (polyamide) is connected to the packers and the pressurizing system. The second pressure hose establishes hydraulic contact between the measurement chamber and a transducer (P) positioned in the Mini container.

The pressure in the section between the outer packer and the collar is shut in using a sealing device at the casing collar. The device consists of a rubber cone with openings for the pipe string and for the two pressure hoses. The device enables movement of the test tool in the borehole without de-pressurizing the entire borehole completely. A quick-coupling at the sealing-device and a pressure line to a pressure transducer in the container makes it possible to measure the borehole pressure.

The pipe string is made of aluminum with threaded pipe joints of stainless steel. The outer/inner diameter is 33/21 mm and the length of individual pipe segments is 3 metres, there are also 1 m pipes and 0.5 m pipes.

The test tool and the pipe string are lowered into the borehole using a hoisting rig, which is operated by a control panel and a power unit with a hydraulic motor (Figure A-3). The pipe holders on the feeder beam are opened hydraulically, but are closed by means of disc springs. On the control panel there are 3 manometers showing the system pressure and the pressure on each side of the piston. With the help of the piston pressure and a specially devised diagram, the lifting force can be calculated for each situation. The pipe holders are automatically opened and closed when the pipes are hoisted or lowered.

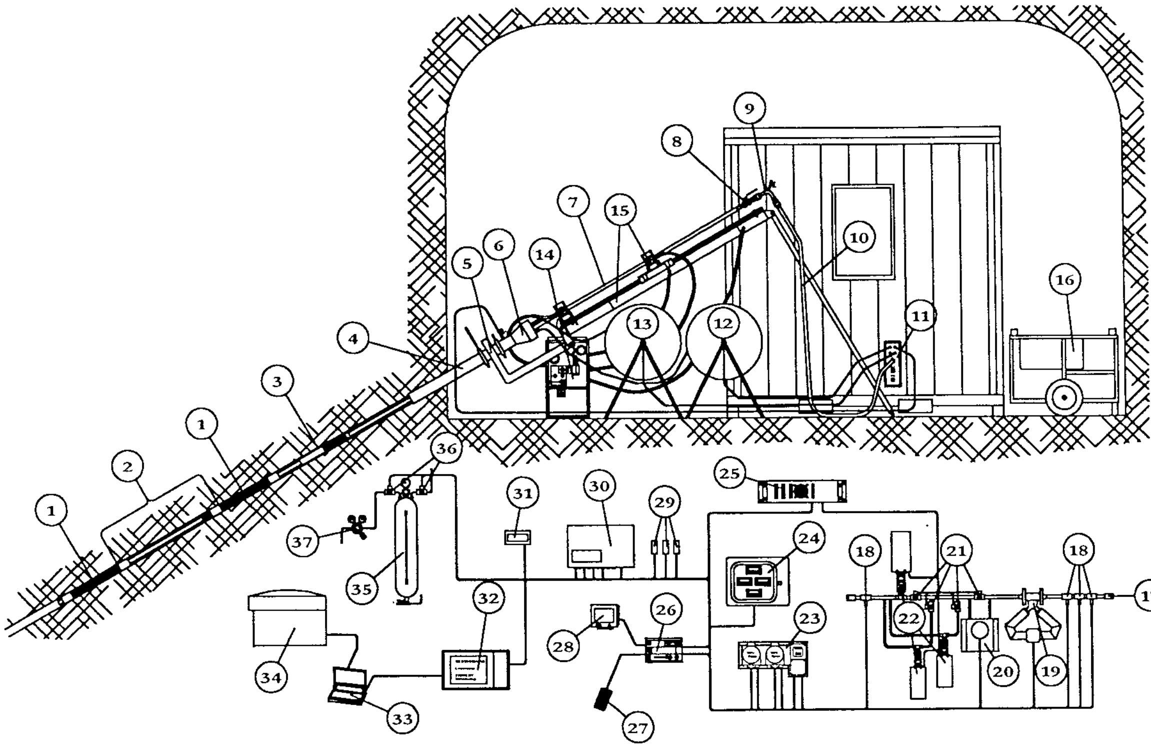

Figure 3-1. *Overview of the UHT-1 system*

1. Packer
2. Measurement section
3. Test valve
4. Casing
5. Extension beam
6. Sealing device
7. Pipe string
8. Adapter
9. Tube bend with air evacuation valve
10. Measurement hose from borehole
11. Wall leadthrough
12. Hose reel, packer
13. Hose reel section pressure
14. Control board, hoisting rig
15. Feed beam, hoisting rig
16. Power unit, hoisting rig
17. Inlet to container
18. Sensors; pressure, temperature, electrical conductivity
19. Flow meter BIG
20. Flow meter small
21. Valves
22. Regulation valves
23. Amplifier to Flow meter unit
24. Display for Flow meter unit
25. Stepping motor
26. Regulation computer
27. Regulation computer, key board
28. Regulation computer, monitor
29. Pressure transducers
30. Data scan box
31. External display
32. Measurement computer (SPC Rabbit)
33. Evaluation computer (Compaq)
34. Laser Jet printer
35. Pressure tank, packer inflation
36. Solenoid valves
37. N_2-gas regulator

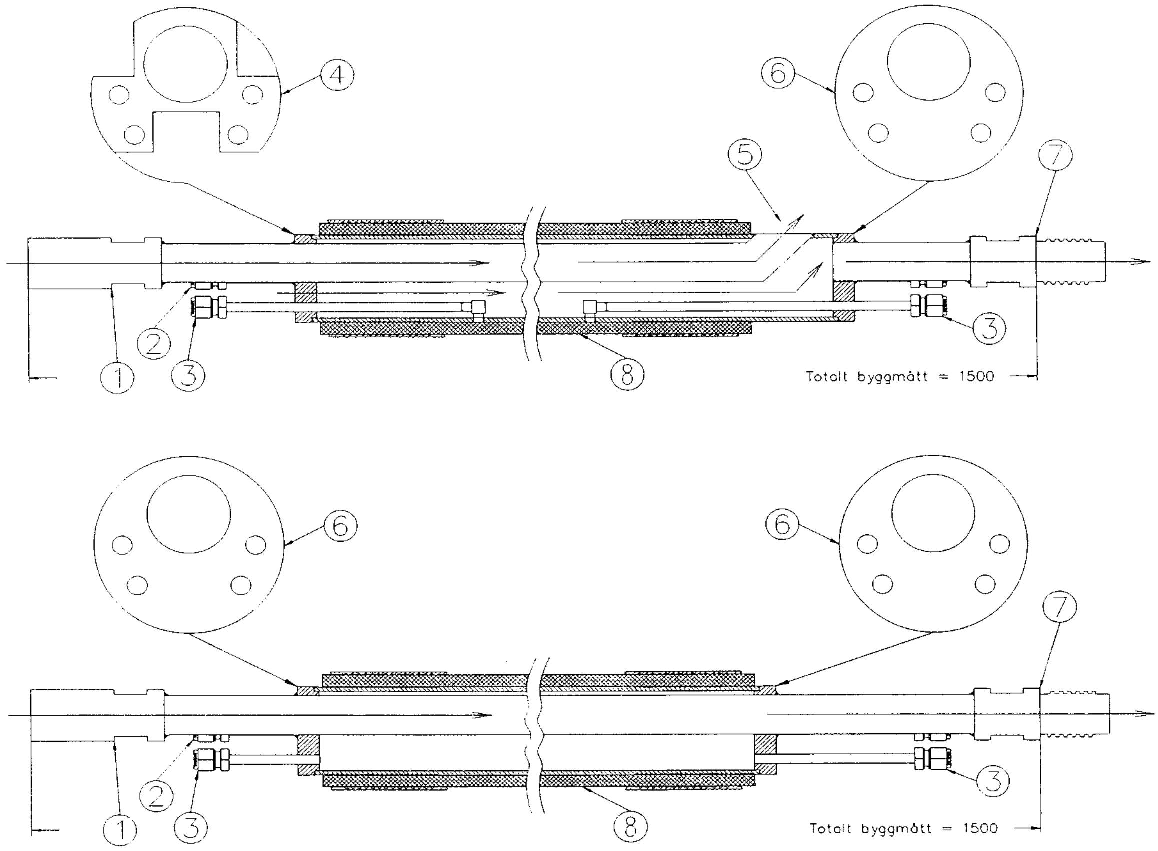

Figure A-2. Upper packer (above) and lower packer (below)

1. Female pipe joint, Ø = 33 mm, Double O-ring gasket
2. Hydraulic lead-through
3. Packer inflation cannula pipe
4. Packer gable, the openings connect borehole intervals on both side of the packer.
5. The hydraulic connection to the test section
6. Packer gable
7. Male pipe joint, Ø = 33 mm, Double O-ring gasket
8. Polyurethane

A casing extension and a beam extension are mounted on the borehole casing to fit the hoisting rig (Figure A-3).

The mini container is made of steel and has the outer dimension 2.5x1.7x2.6 m. Its walls are insulated using covered white plates and the floor is covered with an aluminum sheet. It is furnished with a table, cupboards and shelves for keeping tools, spare parts etc. The container accommodate the monitoring equipment and the computers and the printer, necessary to retrieve and plot data, respectively.

The electrical system of the container is connected to 16 A three phase AC. Inside the container there are two 230 V electrical systems. One of them is directly connected to the power net, the second, which feeds the measurement instruments is also connected to an UPS-unit (auxiliary power supply) to avoid data losses during a power failure.

The pipe system in the container is connected to a lead-through in the wall. On the outside of the lead-through, different hoses from the borehole are connected with the help of quick-couplings.

The pressure transducers, of type Druck PTX 630, measure absolute pressure, and are mounted on a board on one of the container walls. There are two sets of transducers with different pressure ranges. The standard set of pressure transducers are, cf. Section 3.3:

Interval /Packer	**No.**	**Transducer id**	**Range**	**Alternative Range**
Test section	2	P and P_b	6 MPa	(1 MPa)
Borehole	1	P_a	6 MPa	(1 MPa)
Packers	1	P_{pack}	8 MPa	(2 MPa)

The pressure transducers are connected to the borehole through cannula pipes, hydraulic hoses and polyamide hoses.

The technical specifications of the pressure transducers are:

Supply voltage: 9 - 30 VDC
Output current: 4 - 20 mA
Linearity and hysteresis: ±0.1 % of full scale
Temperature error: ±0.3 % of full scale in the range-2 °C - +30 °C

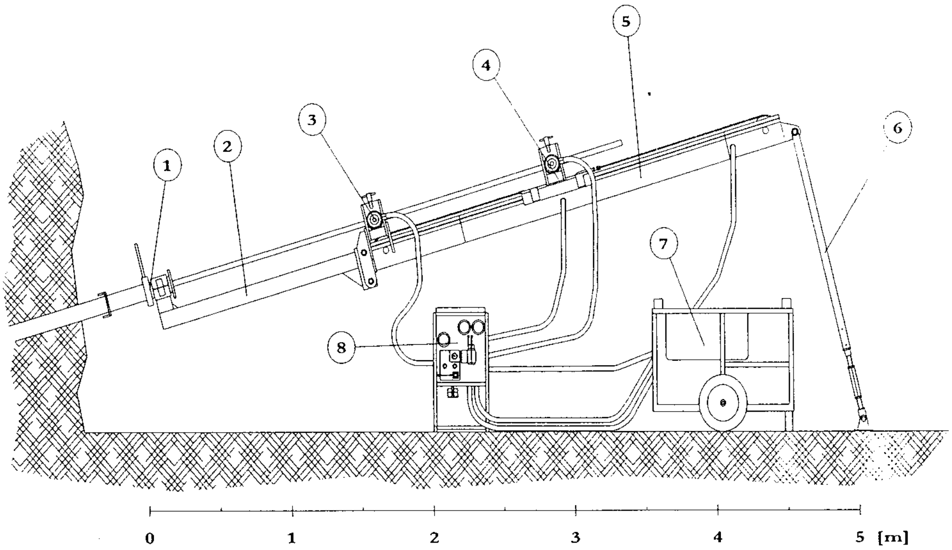

Figure A-3. *Hoisting rig*

1. Casing extension
2. Beam extension
3. Pipe holder
4. Pipe holder
5. Feeder beam
6. Legs
7. Power supply unit
8. Control panel

The flow meter unit enables monitoring and regulation of the flow during constant pressure tests and constant flow tests, respectively. The flow regulation is operated and controlled using a digital computer. The main parts of the flow meter unit are:

- Two mass flow meters (Coriolis-type),
- flow range: 0.001-100 l/min
- Valves to regulate the flow rate
- A water filter
- Two pressure transducers for measuring the pressure at the inlet and the outlet of water.
- A temperature sensor

Further more there are:

- a display unit with four displays
- a cylinder with an electric conductivity sensor
- an amplifier to the flow meter unit and the conductivity sensor.

All flow is routed through the large flow meter (Q_{big}), regardless of whether the Q_{small} is in use or not.

The technical specifications for the main components of the flow meter unit are as follows:

Flow meter Q_{small}

Type :	Micro Motion mass flow meter
Range:	0 - 1.00 Kg/minute
Accuracy:	±0.4 % of current value ± zero stability (0.0001 Kg/minute)
Pressure drop at max. flow:	c. 500 KPa
Maximum working pressure:	7 MPa

Flow meter Q_{big}

Type :	Micro Motion mass flow meter
Range:	0 - 100 Kg/ minute
Accuracy:	± 0.15 % of current value ± zero stability (0.003 Kg/minute)
Hysteresis:	< 0.1 %
Pressure drop at max. flow:	c. 500 KPa
Maximum working pressure:	5 MPa

Pressure transducers, inlet and outlet

Type :	Druck Transmitter PTX 1400
Range:	0 - 6 Mpa
Linearity and hysteresis:	± 0.1 %

Temperature sensors

Type :	GEOSIGMA BG01
Range:	0 - +32 oC
Accuracy:	±0.25 oC

Electrical Conductivity meter

Type :	Kemotron 2911
Sensor:	Kemotron 9221, 4-electrode
Range:	Adjustable, 14 intervals within the range 0 - 20 000 mS/m
Accuracy, amplifier:	±0.25 % of current value
Accuracy, cell constant:	±0.5 %
Maximum working pressure:	5 MPa
Temperature sensor:	Pt 100

When performing constant pressure tests, as is the case with the planned tests in KI0023B, the constant pressure is maintained by a standard PC (Intel 486, 100 MHz, 4MB RAM and 200 MB HDD, CRT monitor). The pressure is kept constant by regulating the water flow rate. A specially designed software opens and shuts regulation valves such that a constant pressure according to a preset value is achieved. The program is written in TURBO-C and runs on a DOS platform.

The UHT-1 measurement system is controlled by, and operated from a 120 MHz Pentium laptop computer. The software used is DM2 (Datascan Technology) , which also constitutes the platform for the Hydro Monitoring System (HMS) at the Äspö HRL. DM2 is a standard program, but has been supplemented with additional programs.

All sensors are connected to the AD-converter unit (Datascan 7320). In addition, there is a Datascan-unit for digital I/O (Datascan 7035).

The data produced by UHT 1 are evaluated in a second computer, a portable Compac 100 Mhz Pentium. The operating system is Windows 95, but the evaluation programs are run in on a DOS platform. Data files from the test are transferred to the evaluation computer during or after each test.

The UHT-1 system also includes a HP Laser Jet 5p, which is used for printing evaluation plots from the evaluation computer and display images from the measurement computer.

Appendix B Test Documentation and Analyses

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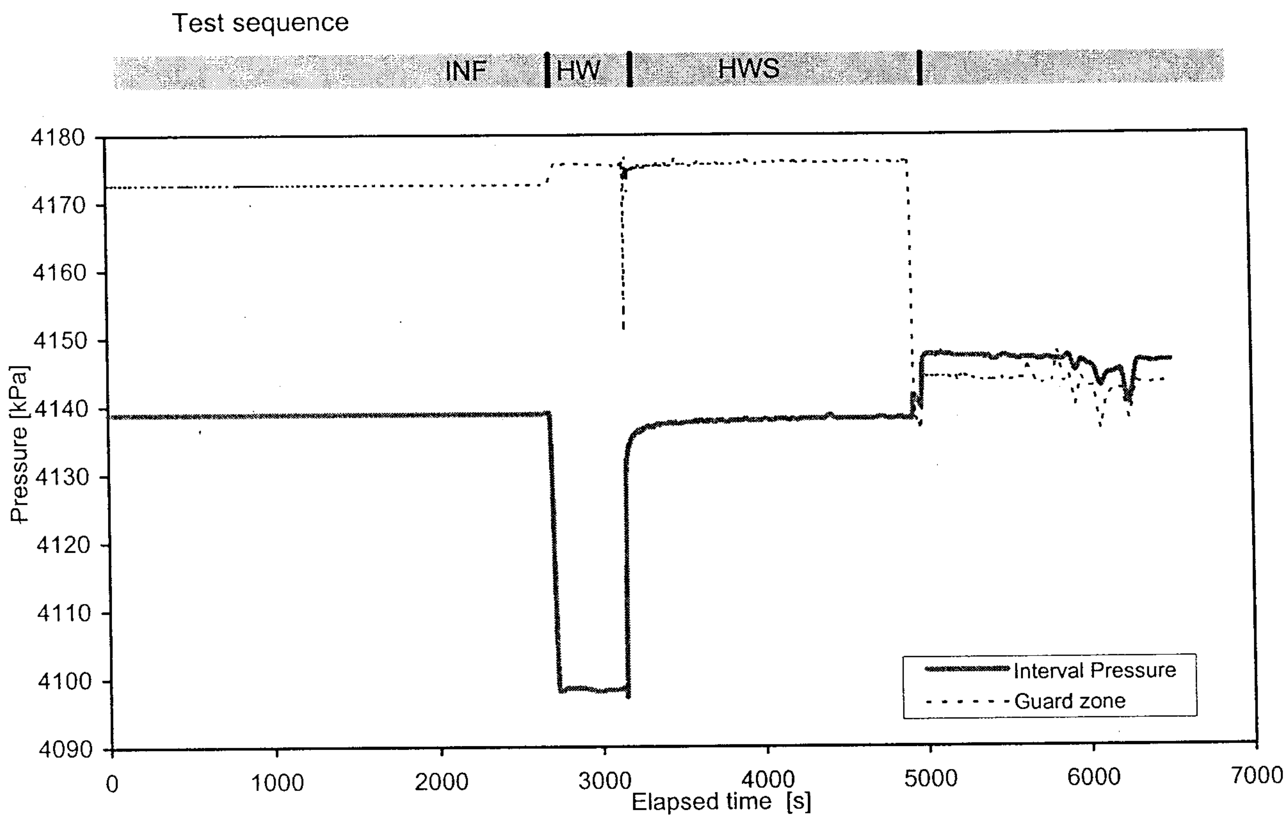
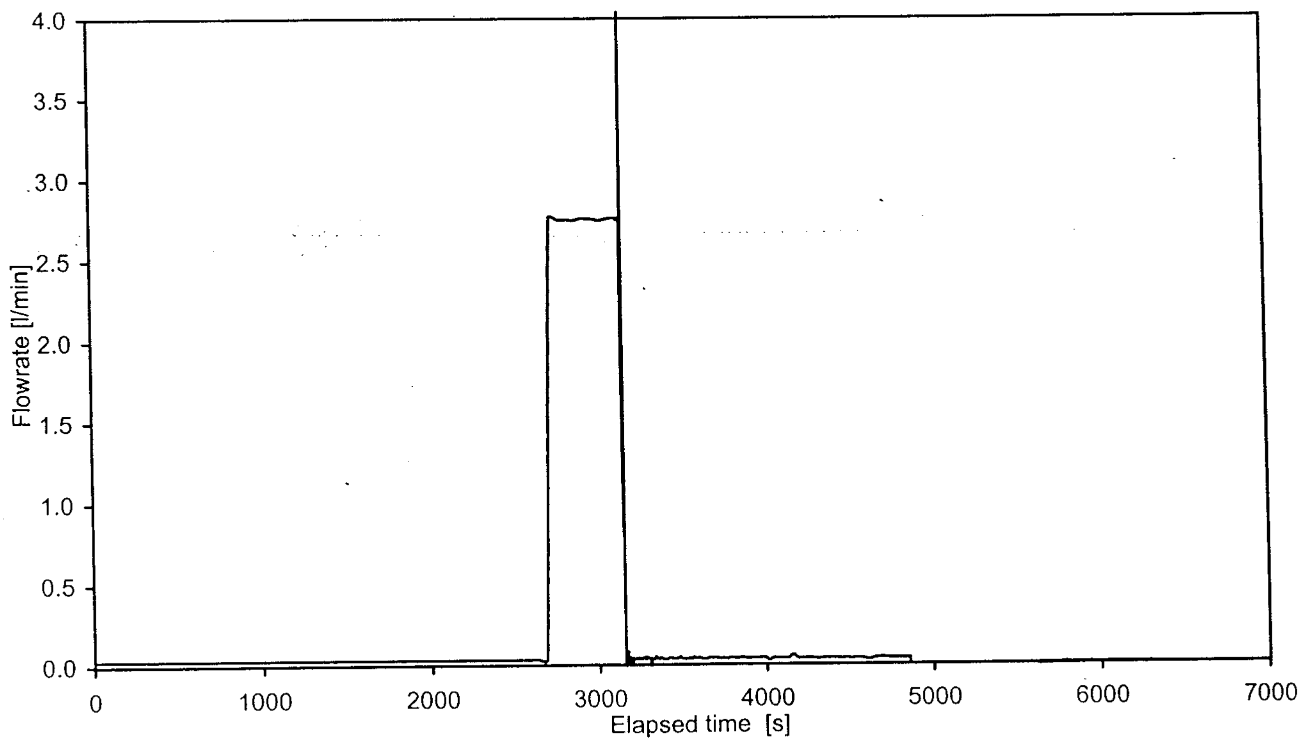
Nomenclature

INF	Inflation and Pressure Recovery Period
HW	Constant Head (Pressure) Withdrawal Period
HWS	Pressure Recovery following a Constant Head Withdrawal Period

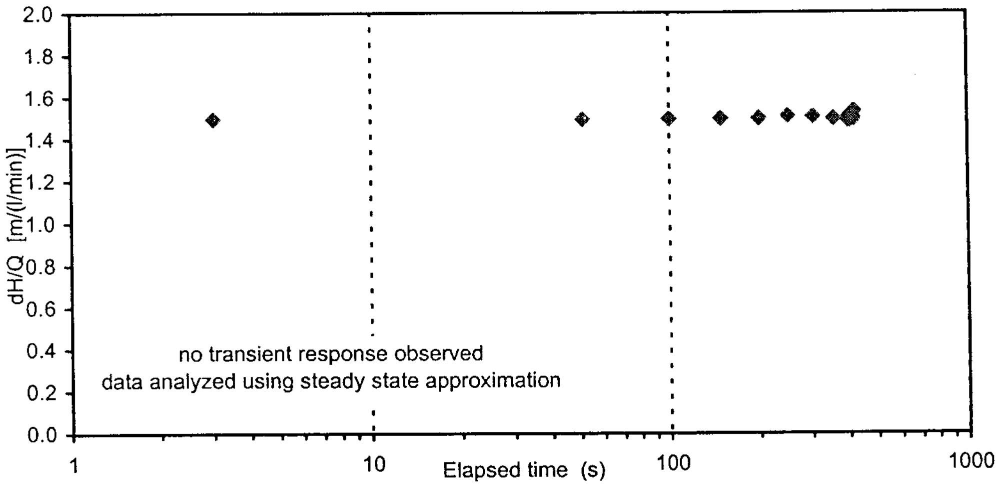
True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B1a: KI0023B Interval 1 (41.45 - 42.45 meter depth)	JA	1179	12.3.98	c1.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B1b: KI0023B Interval 1 (41.45 - 42.45 meter depth)	RG/JA	1179	8.6.98	hw1-ja.xls

HW Phase Semi-log analysis:



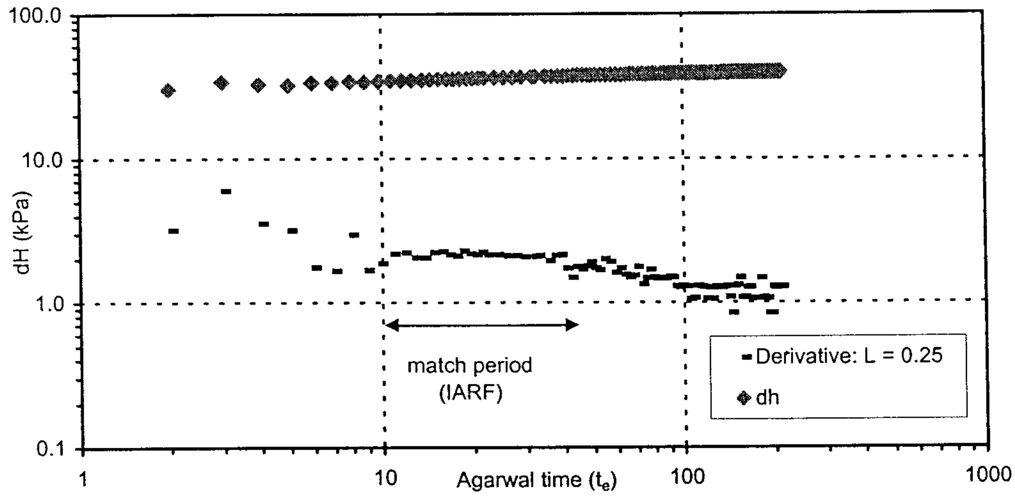
Input Values

dP = 42.00 kPa
q = 2.75 l/min
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07

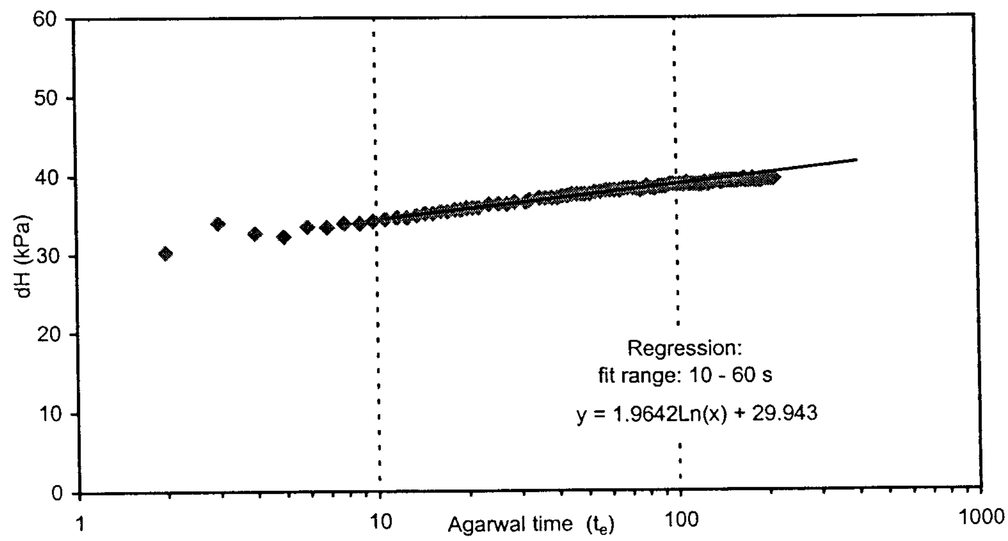
Results

T = 1.6E-05 m^2/s
K = 1.6E-05 m/s
-

HWS Phase : Log-Log Diagnostic Plot



HWS Phase semi-log analysis:



Input values

m = 4.52113 kPa/LZ
t_o = 2.E-07 Sek
L = 1.00 m
Q_{end} = 2.75 l/min
r_w = 0.038 m
t_p = 419 Sek
S_{est} = 1.0E-07 -

Results

T = 1.8E-05 m^2/s
K = 1.8E-05 m/s
sf = 1.3 -
R_i = 414.2 m
u = 2.0E-07 -

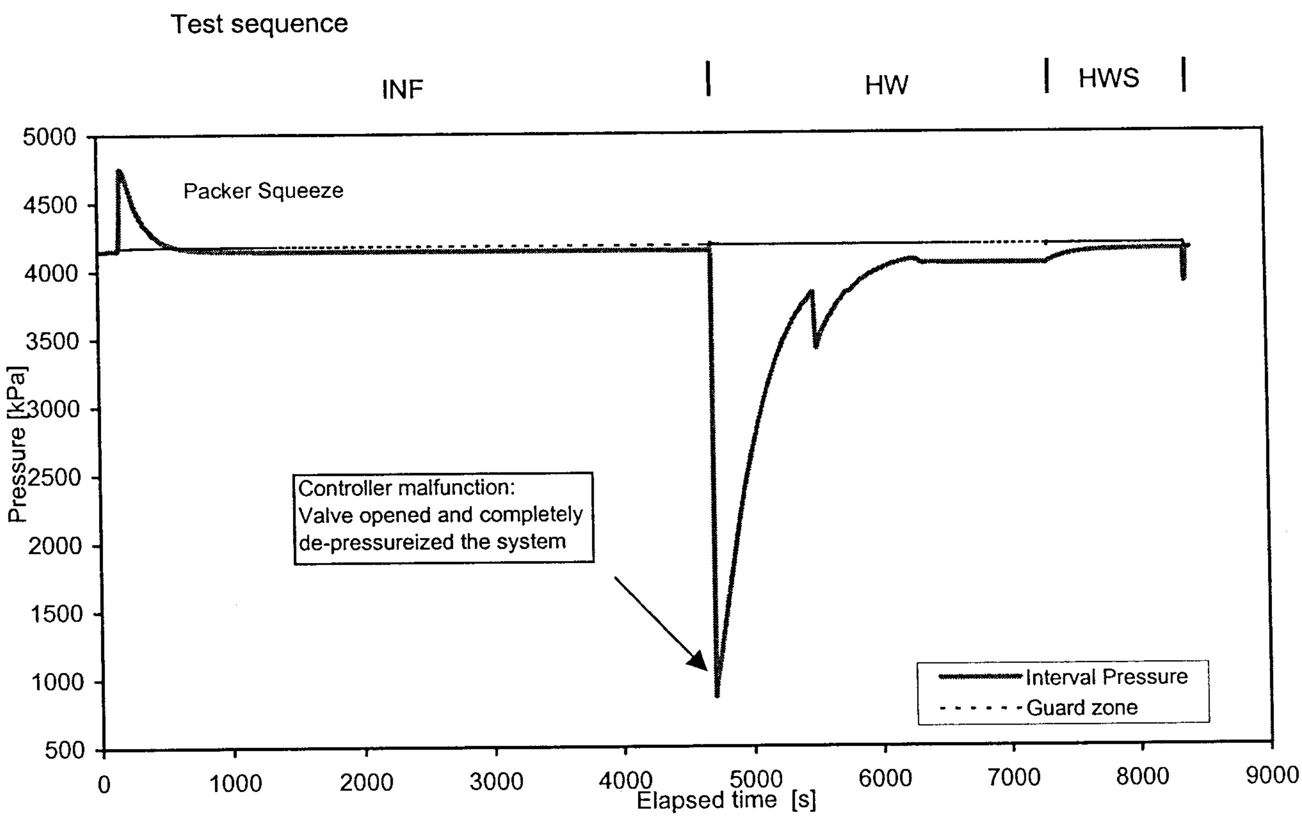
True Block Scale Experiment:

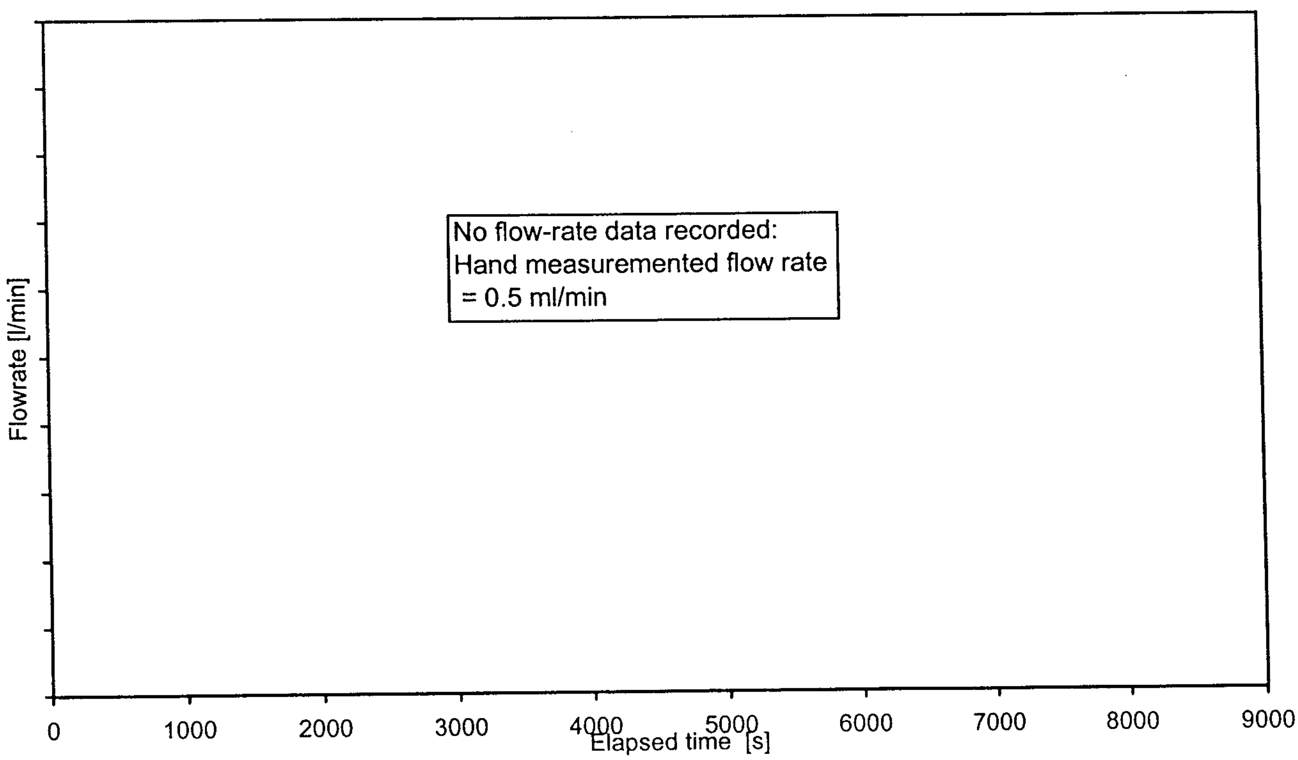
Selective Flow and Pressure Build-up Tests

Figure B2a: KI0023B Interval 2 (42.4 - 43.4 meter depth)

SOL EXPERTS AG

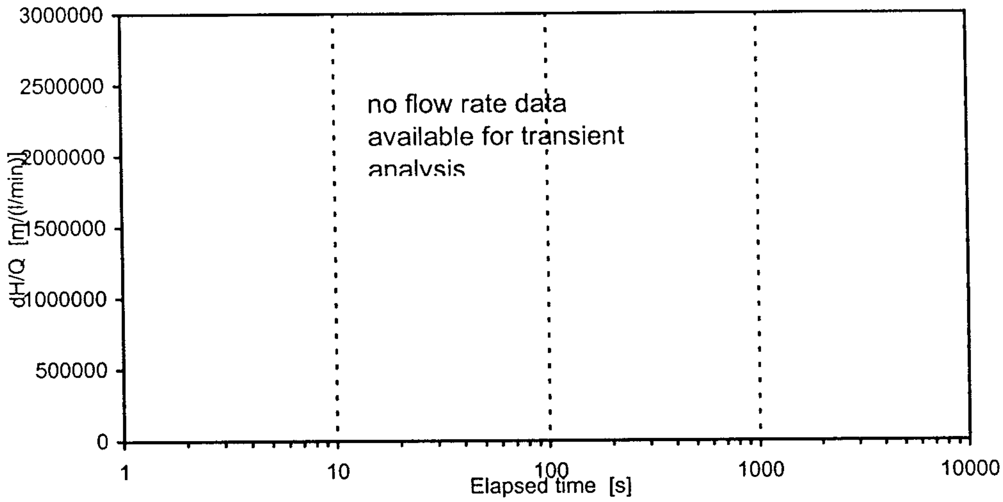
Visum:	Proj. #	Date	Filename
JA	1179	11.6.98	c2.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B2b: KI0023B Interval 2 (42.4 - 43.4 meter depth)	RG/JA	1179	08.6.98	hw2-ja.xls

HW Phase Semi-log analysis:



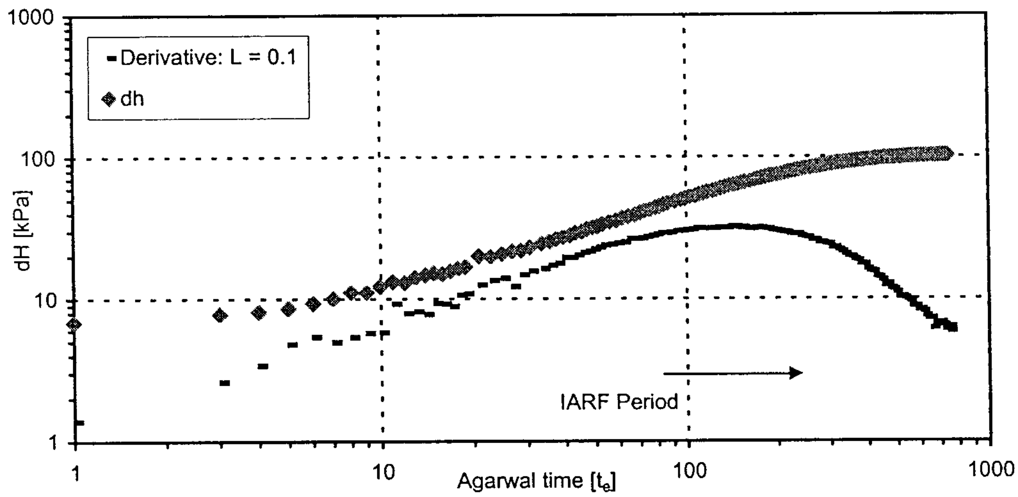
Input Values

dP = 100.00 kPa
q = 5.E-04 l/min
L = 1.00 m
r_w= 0.038 m
S_{est} = 1.0E-07 -

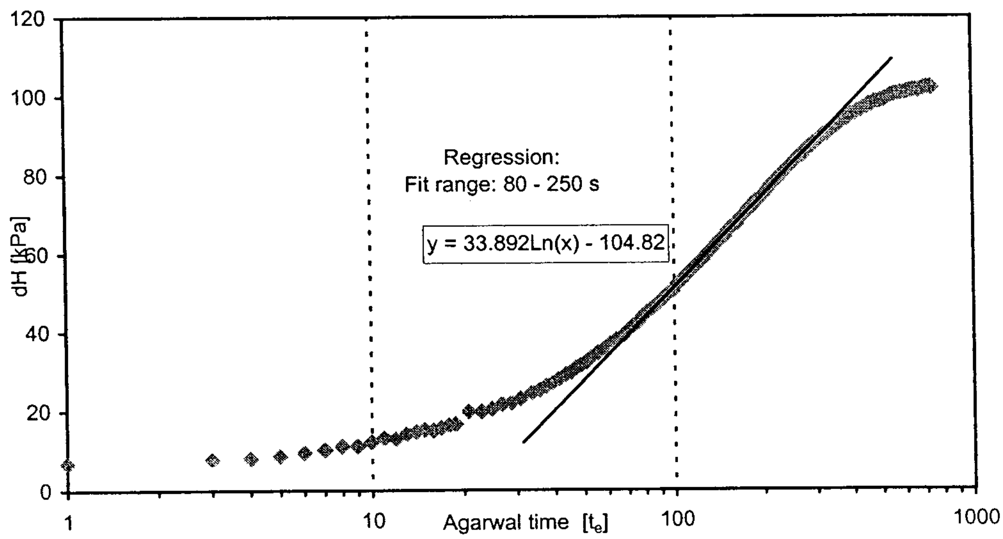
Results
steady state

T = 6.6E-10 m^2/s
K = 6.6E-10 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



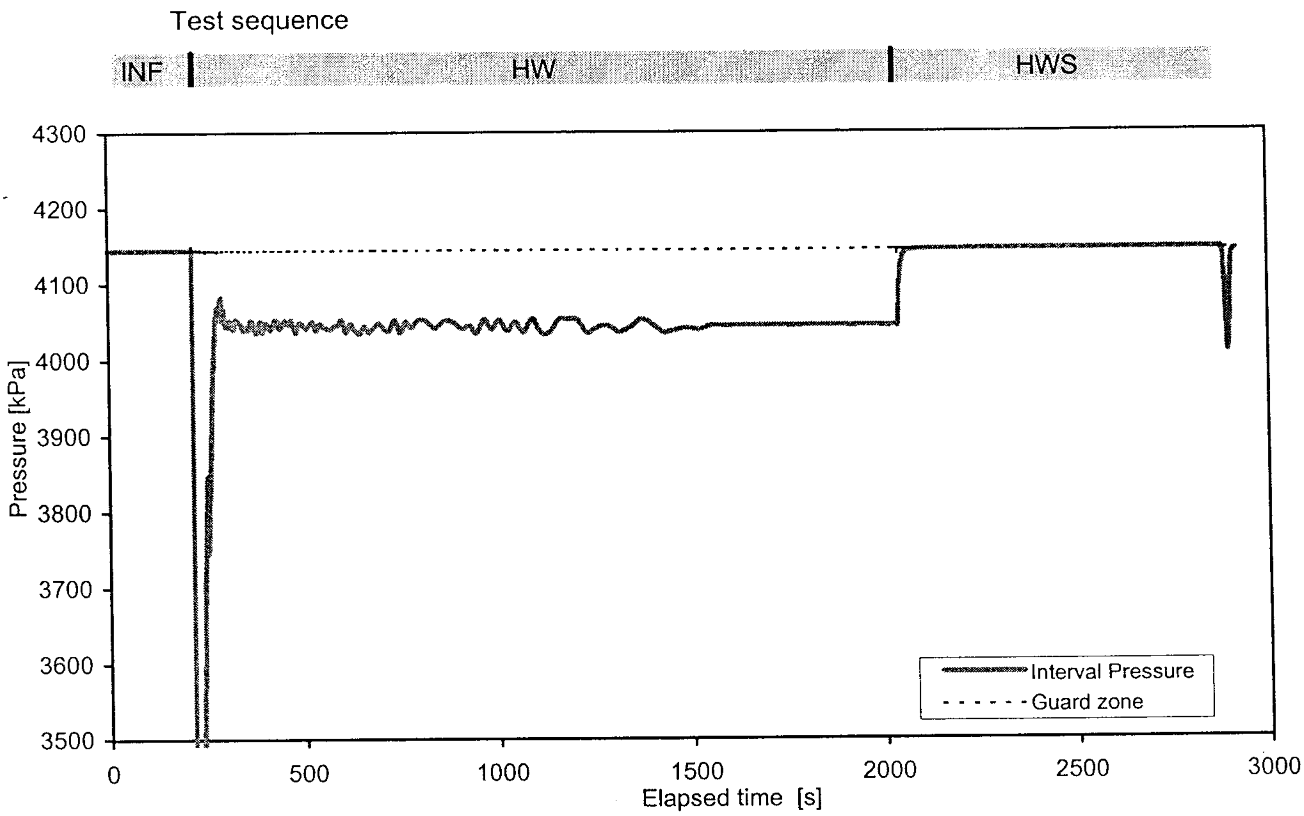
Input values

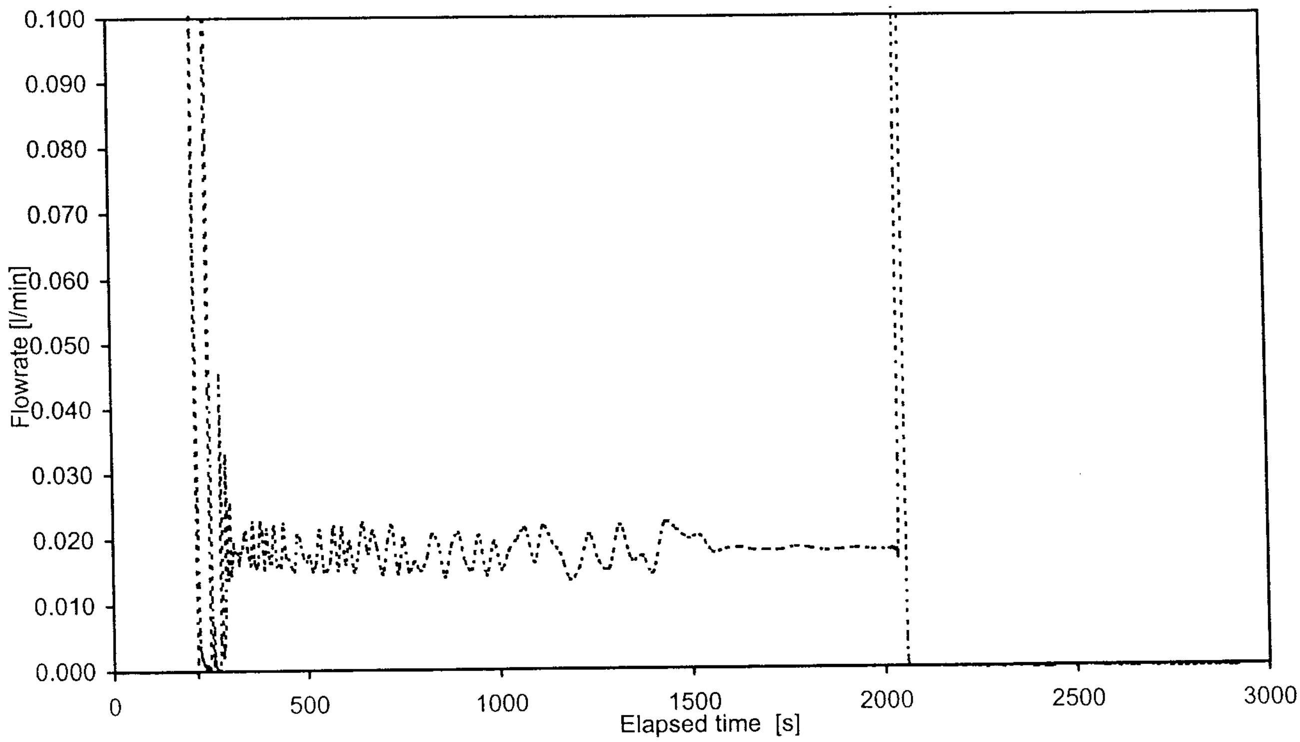
m = 4.52113 kPa/LZ
t_o = 2.E-07 Sek
L = 1.00 m
Q_{end} = 0.00 l/min
r_w= 0.038 m
t_p = 2612 Sek
S_{est} = 1.0E-07 -

Results

T = 3.3E-09 m^2/s
K = 3.3E-09 m/s
sf = 5.7 -
R_i = 13.9 m
u = 1.4E-04 -

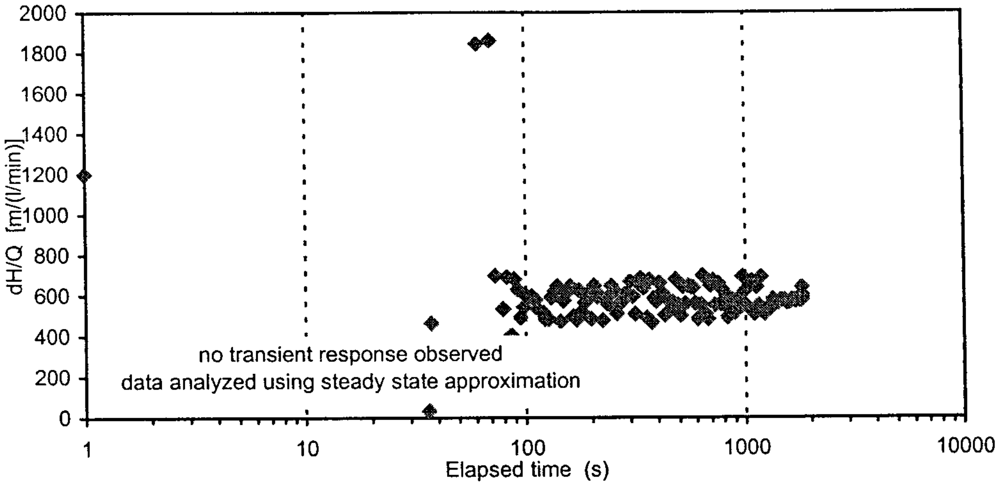
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B3a: KI0023B Interval 3 (43.4 - 44.4 meter depth)	RG	1179	12.3.98	c3.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B3b: KI0023B Interval 3 (43.4 - 44.4 meter depth)	RG/JA	1179	8.6.98	hw3-ja.xls

HW Phase Semi-log analysis:



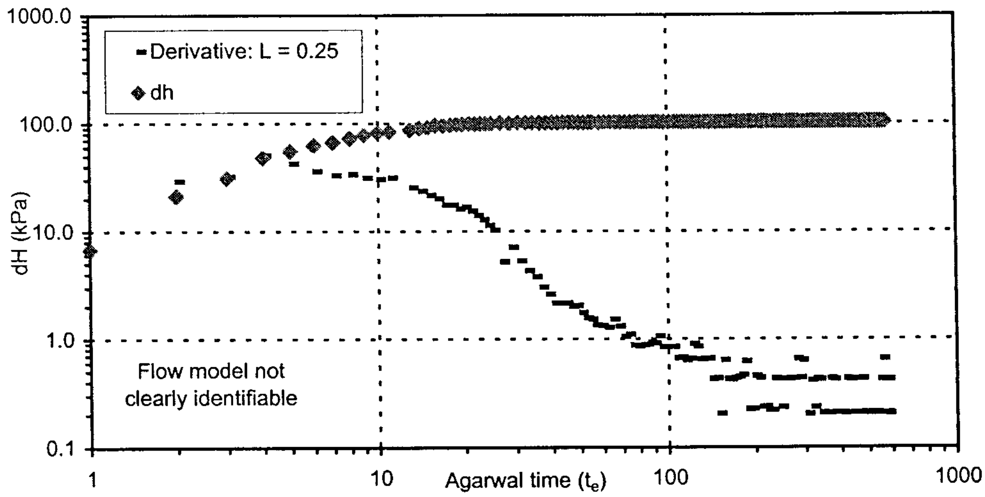
Input Values

dP = 104.00 kPa
q = 0.019 l/min
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

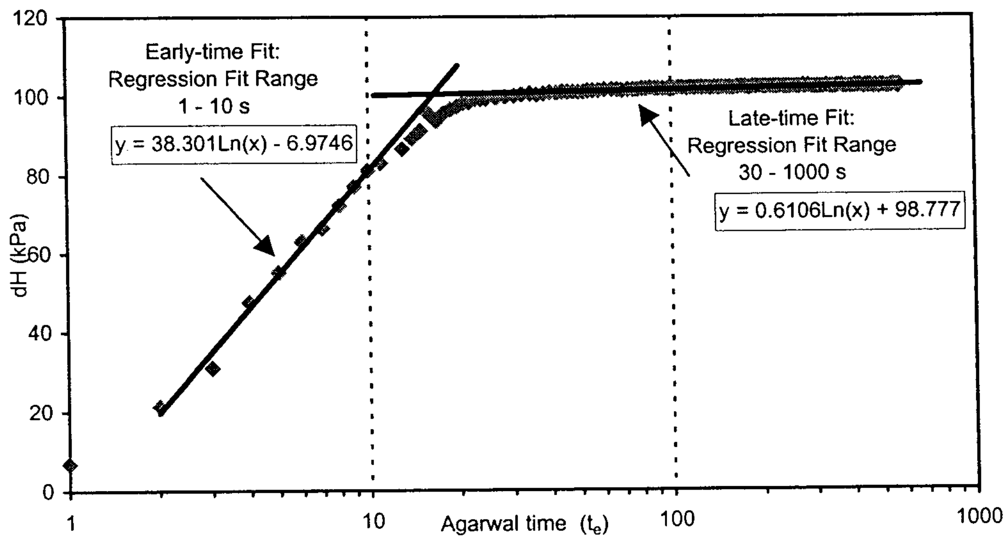
Results

T = 3.3E-08 m^2/s
K = 3.3E-08 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase semi-log analysis:



Input Values

m_{early} = 88.1666 kPa/LZ
$t_{o\text{-}early}$ = 1.E+00 sec
m_{late} = 1.40422 kPa/LZ
$t_{o\text{-}late}$ = 5.E-71 sec
L = 1.00 m
Q_{end} = 0.019 l/min
r_w = 0.038 m
t_p = 1821 sec
S_{est} = 1.0E-07 -

Early-Time Match

T = 6.4E-09 m^2/s
K = 6.4E-09 m/s
sf = -2.4 -
u 0.006 -

Late-Time Match

T = 4.0E-07 m^2/s
K = 4.0E-07 m/s
sf = 76.6 -
R_i = 128.8 m
u 3.E-06 -

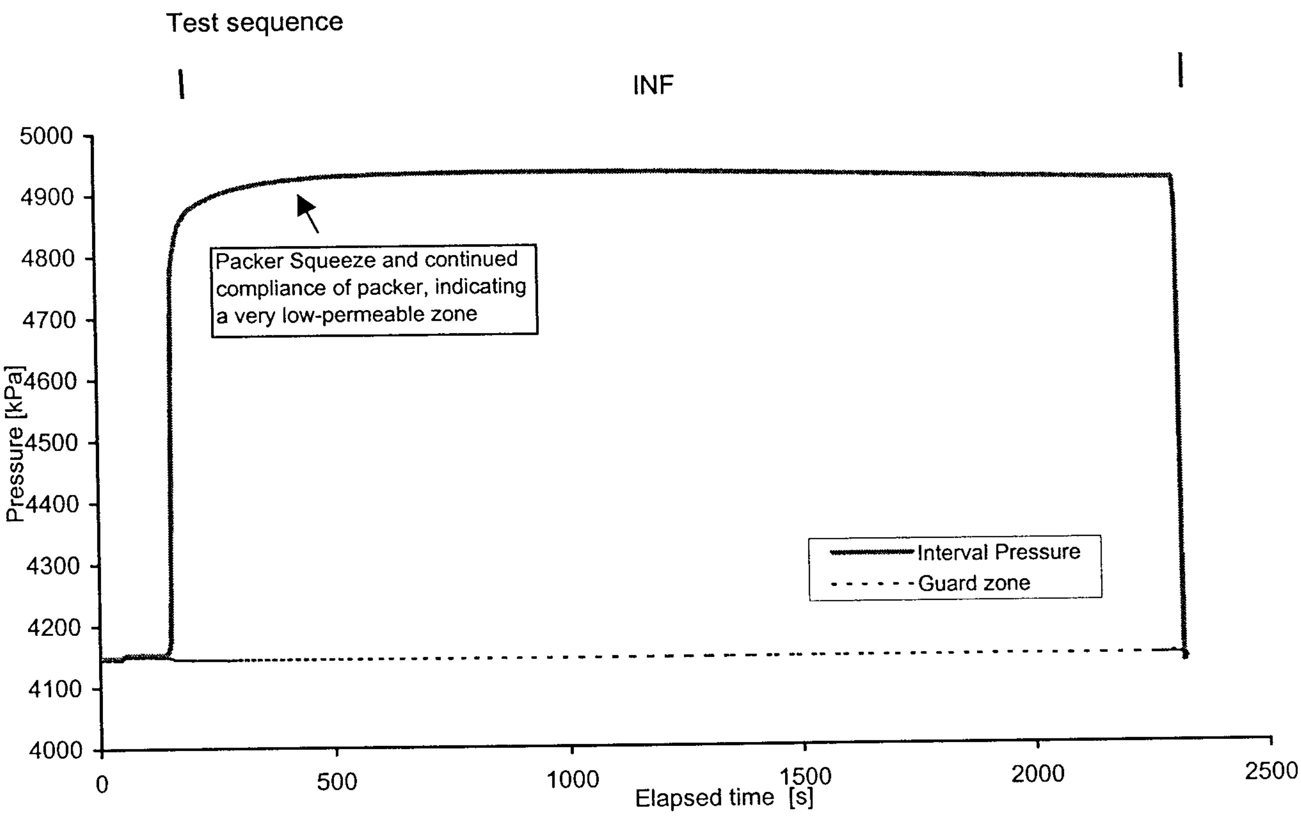
True Block Scale Experiment:

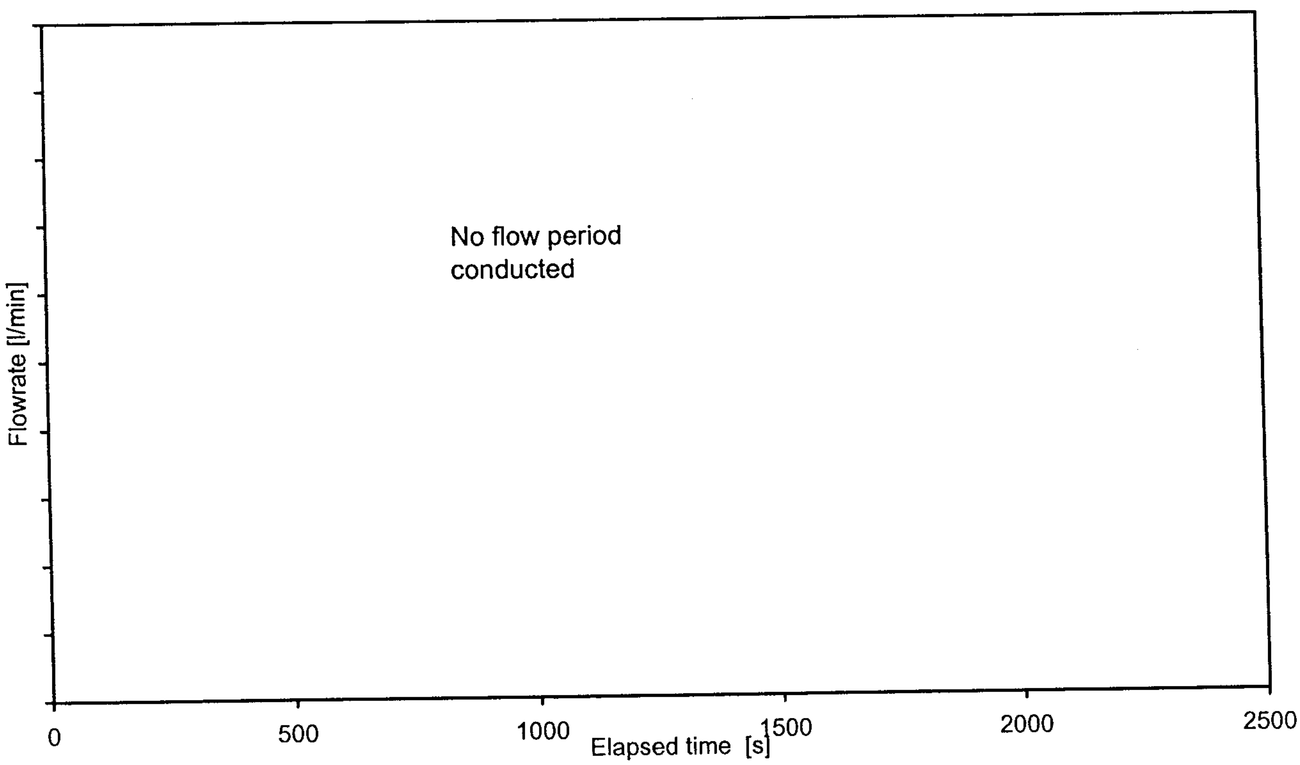
Selective Flow and Pressure Build-up Tests

Figure B4a: KI0023B Interval 4 (50.0 - 51.0 meter depth)

SOL EXPERTS AG

Visum:	Proj. #	Date	Filename
JA	1179	11.6.98	c4.xls





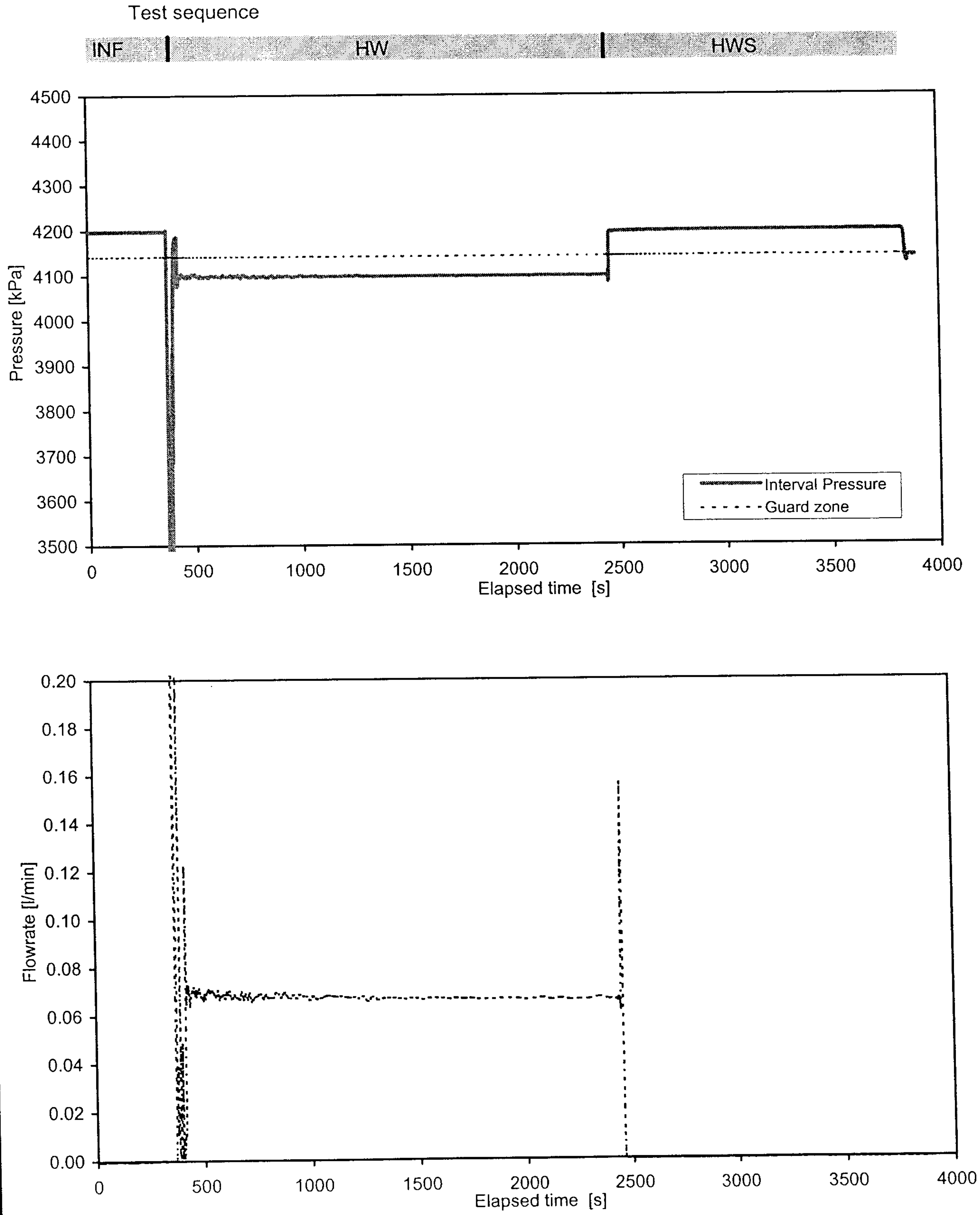
True Block Scale Experiment

Selective Flow and Pressure Build-up Tests

Figure B5a: KI0023B Interval 5 (69.4 - 70.4 meter depth)

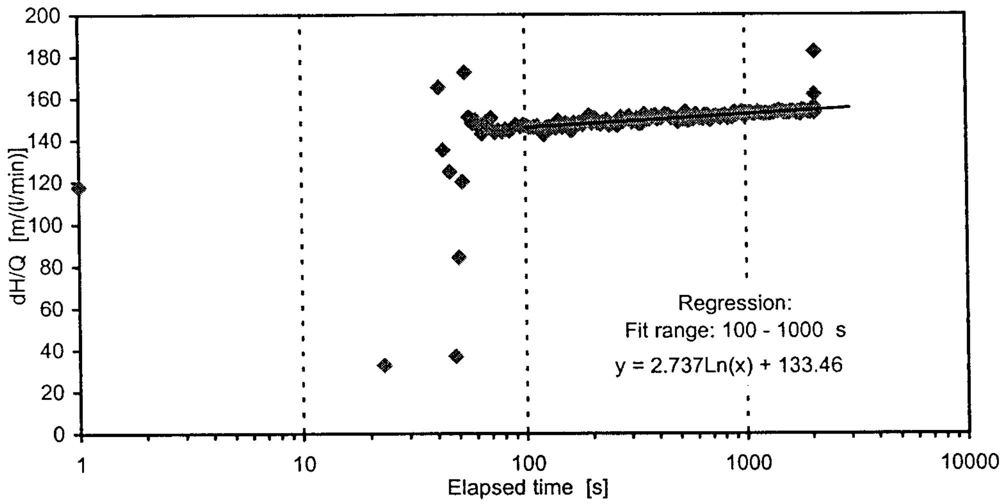
SOL EXPERTS AG

Visum:	Proj. #	Date	Filename
RG	1179	12.3.98	c5.xls



True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B5b: KI0023B Interval 5 (68.4 - 70.4 meter depth)	RG/JA	1179	8.6.98	hw5-ja.xls

HW Phase Semi-log analysis:

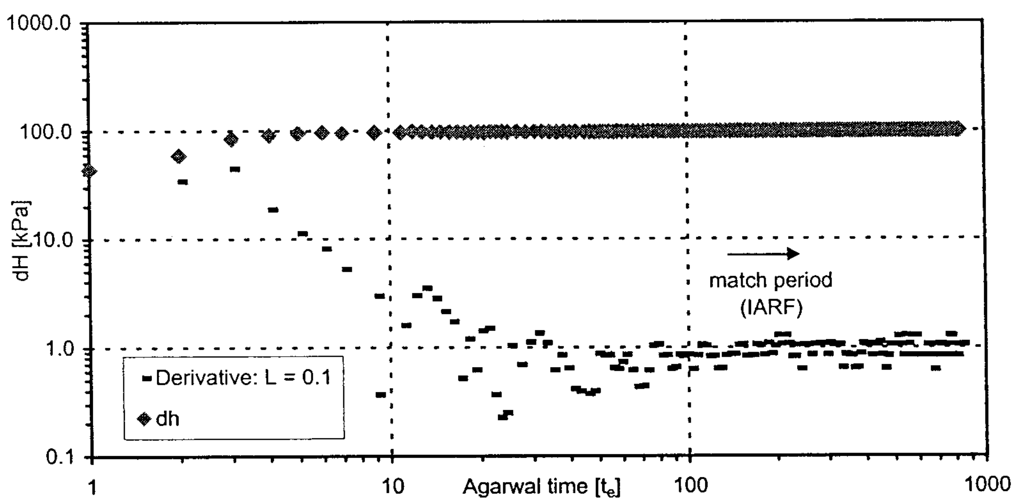


Input Values
dP = 100 kPa
q = 0.07 l/min
m = 6.30057 /LZ
t_o = 7.E-22 Sek
L = 1.00 m
r_w= 0.038 m
S_{est} = 1.0E-07 -

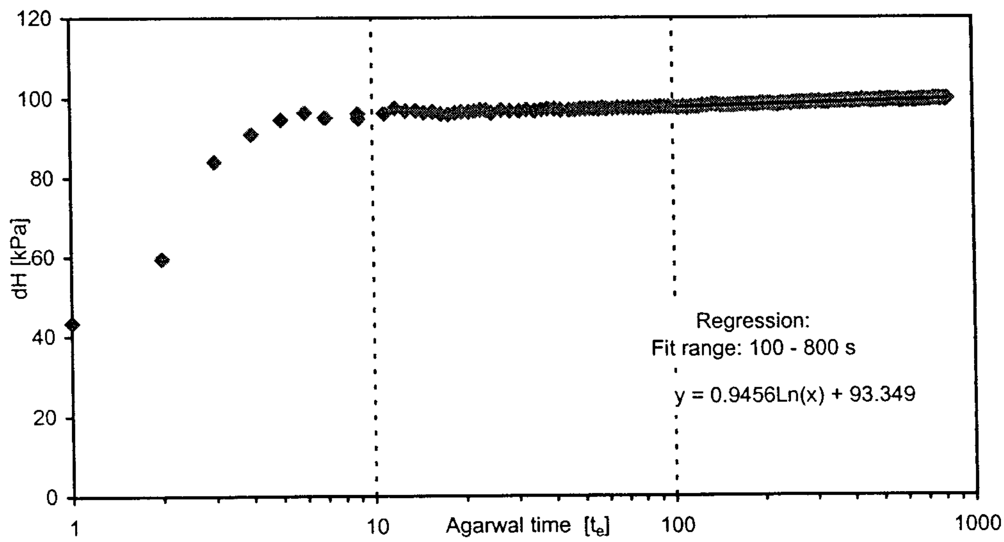
Results
transient
T = 4.8E-07 m^2/s
K = 4.8E-07 m/s
sf= 19.9

steady state
T = 1.4E-07 m^2/s
K = 1.4E-07 m/s

HWS Phase : Log-Log Diagnostic Plot



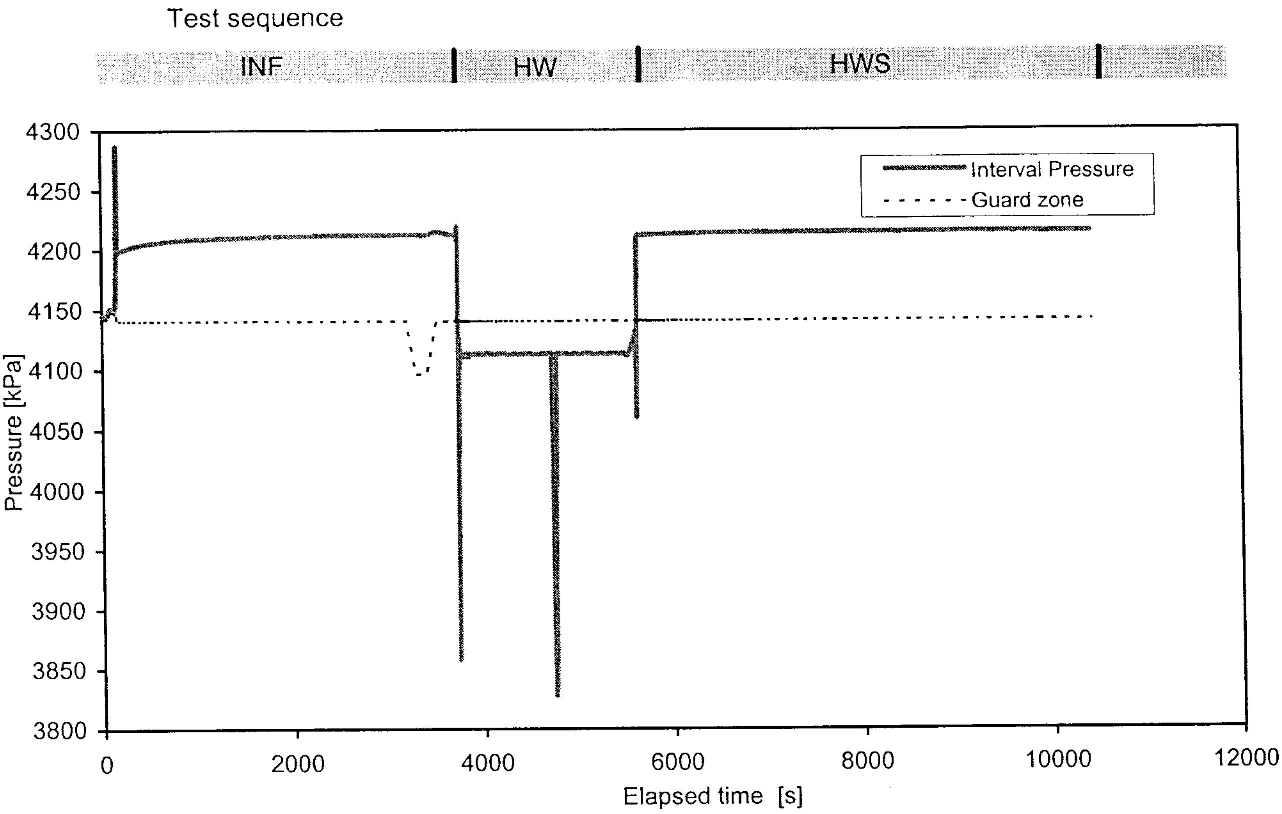
HWS Phase Semi-log analysis:

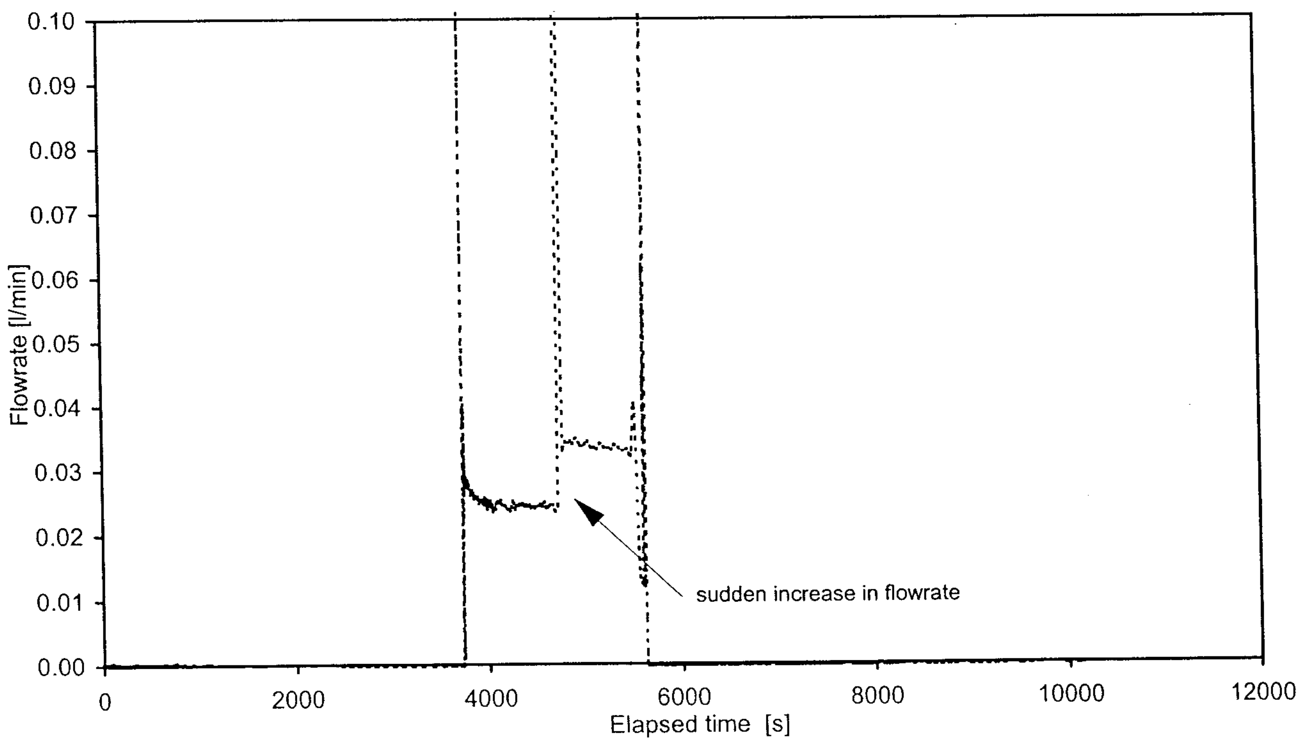


Input Values
m = 2.17677 kPa/LZ
t_o = 1.E-43 Sek
L = 1.00 m
Q_{end} = 0.07 l/min
r_w= 0.038 m
t_p = 2079 Sek
S_{est} = 1.0E-07 -

Results
T = 9.6E-07 m^2/s
K = 9.6E-07 m/s
sf = -0.9 -
R_i = 212.2 m
u = 3.8E-07 -

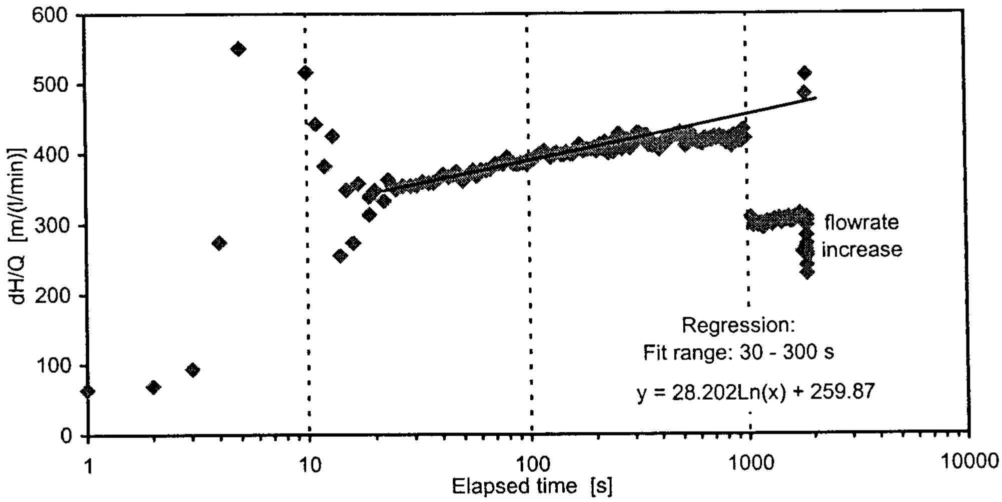
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B6a: KI0023B Interval 6 (69.4 - 70.4 meter depth)	RG	1179	13.3.98	c6.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	File name
Figure B6b: KI0023B Interval 6 (69.4 - 70.4 meter depth)	RG/JA	1179	8.6.98	hw6-JA.xls

HW Phase Semi-log analysis:



Input Values

dP = 112.00 kPa
q = 0.035 l/min
m = 64.9164 /LZ
t_o = 1.E-04 Sek
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

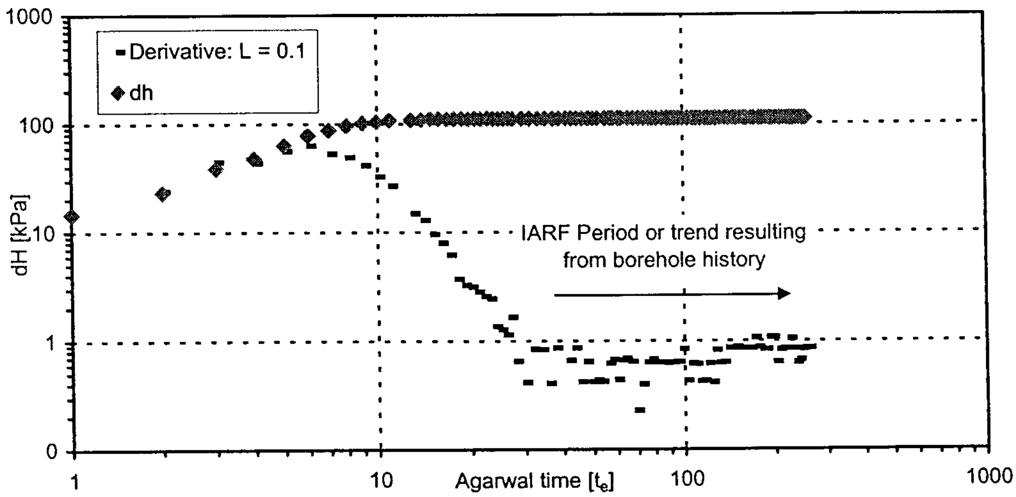
Results transient

T = 4.7E-08 m^2/s
K = 4.7E-08 m/s
sf = 1.3 -

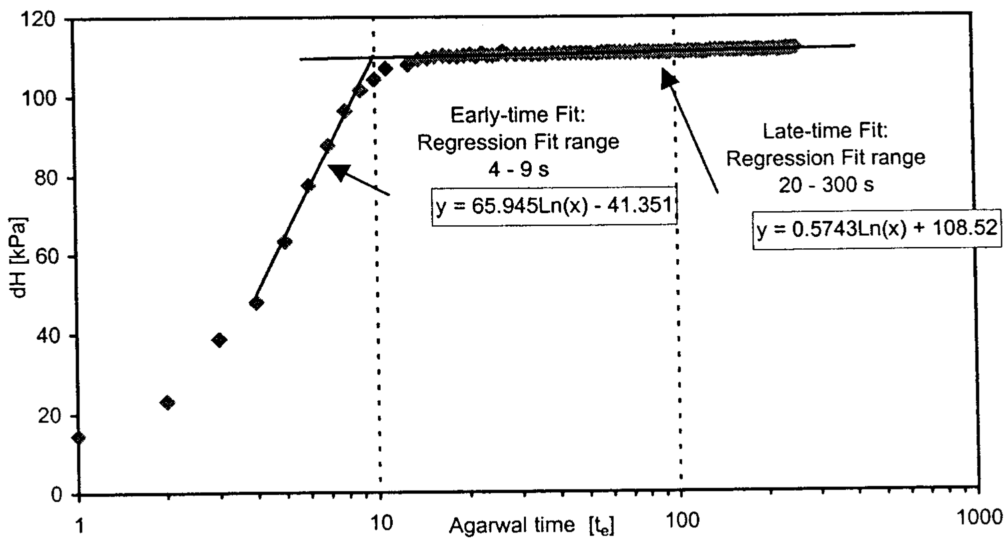
steady state

T = 5.8E-08 m^2/s
K = 5.8E-08 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



Input Values

m_{early} = 151.794 kPa/LZ
$t_{o\text{-}early}$ = 2.E+00 sec
m_{late} = 1.32135 kPa/LZ
$t_{o\text{-}late}$ = 8.E-83 sec
L = 1.00 m
Q_{end} = 0.035 l/min
r_w = 0.038 m
t_p = 1881 sec
S_{est} = 1.0E-07 -

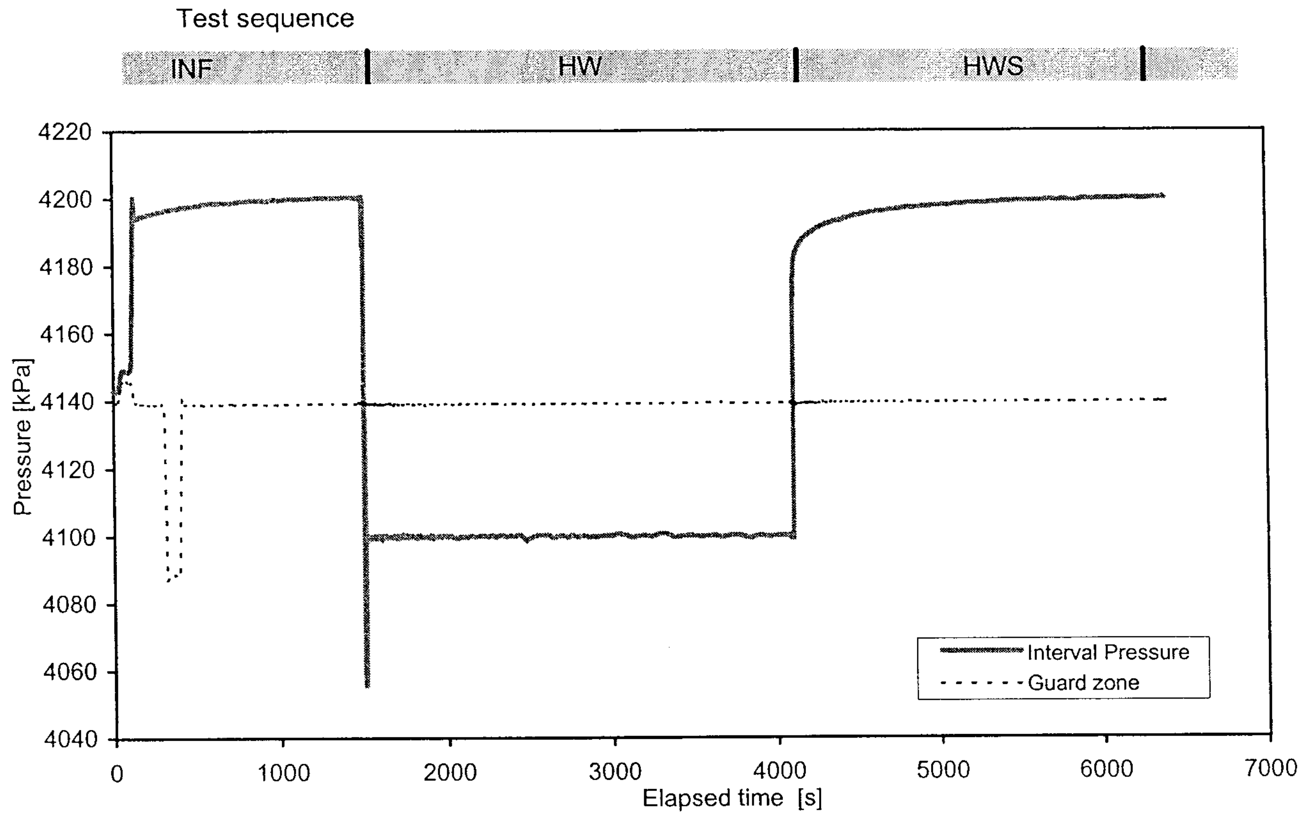
Early-Time Match

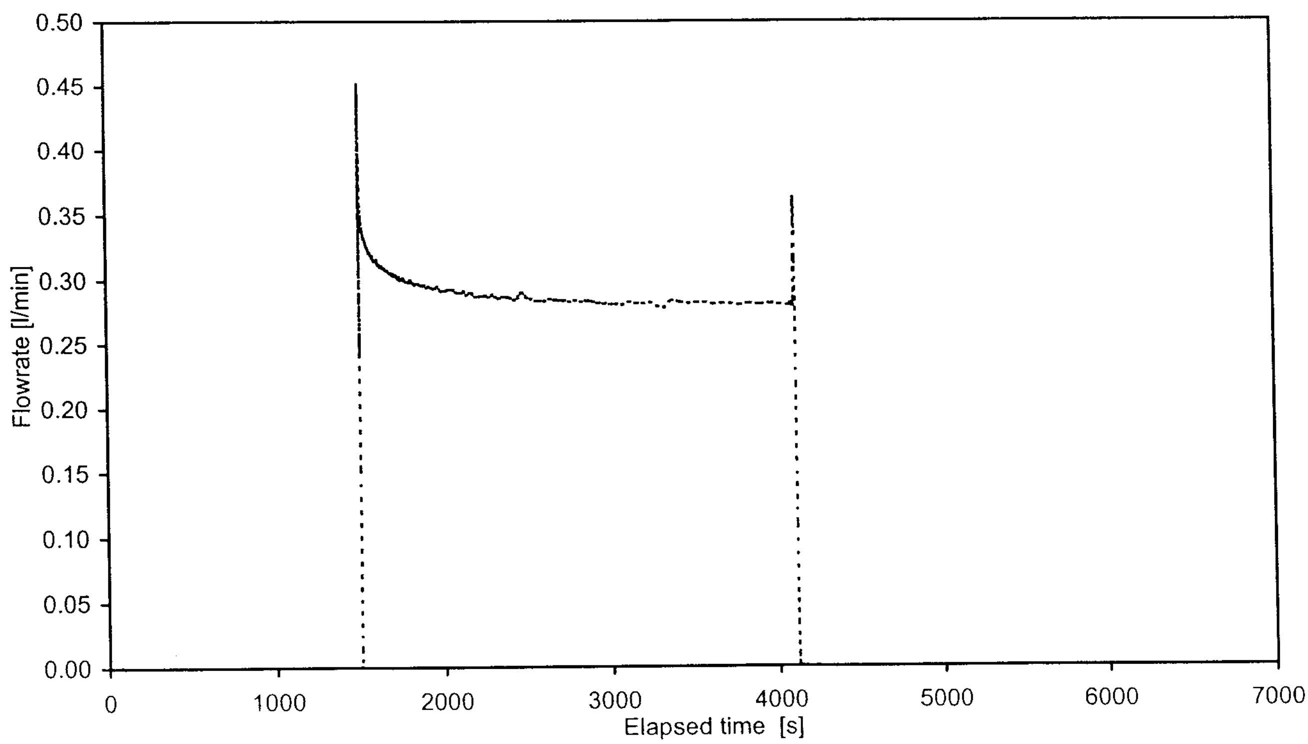
T = 6.9E-09 m^2/s
K = 6.9E-09 m/s
sf = -2.7 -
u = 1.3E-03 -

Late-Time Match

T = 7.9E-07 m^2/s
K = 7.9E-07 m/s
sf = 89.8 -
R_i = 183.1 m
u = 2.3E-06 -

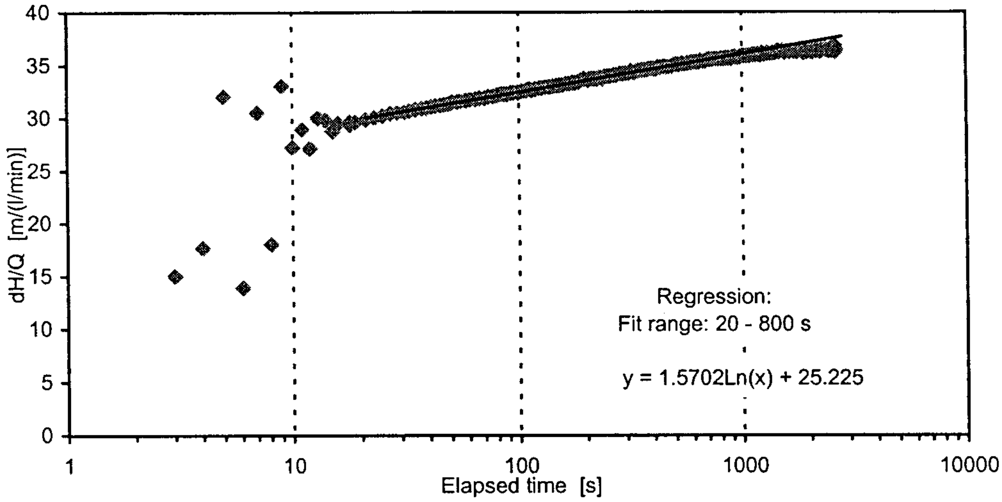
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B7a: KI0023B Interval 7 (70.4 - 71.4 meter depth)	RG	1179	12.3.98	c7.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B7b: KI0023B Interval 7 (70.4 - 71.4 meter depth)	RG/JA	1179	8.6.98	hw7-JA.xls

HW Phase Semi-log analysis:



Input Values

dP = 99.71 kPa
q = 0.28 l/min
m = 3.61414 /LZ
t_o = 1.E-07 Sek
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

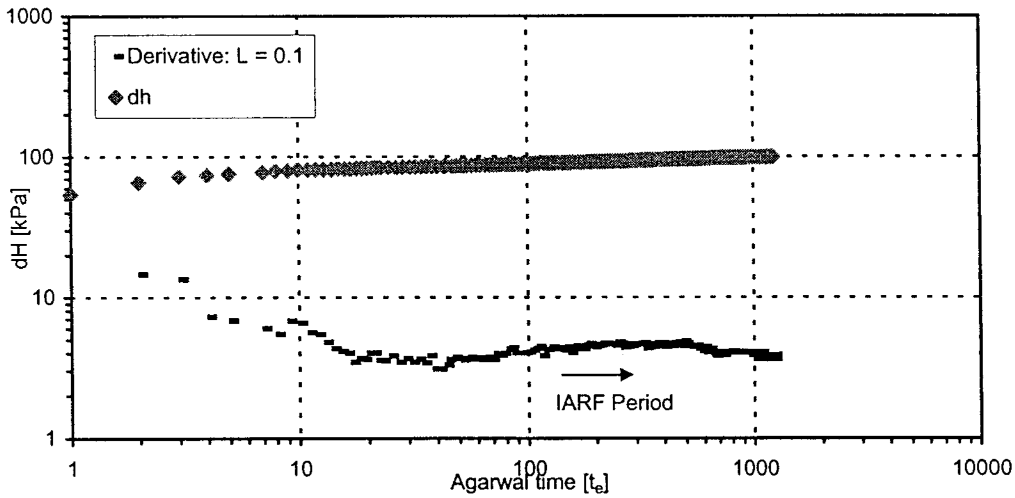
Results transient

T = 8.4E-07 m^2/s
K = 8.4E-07 m/s
sf = 3.3

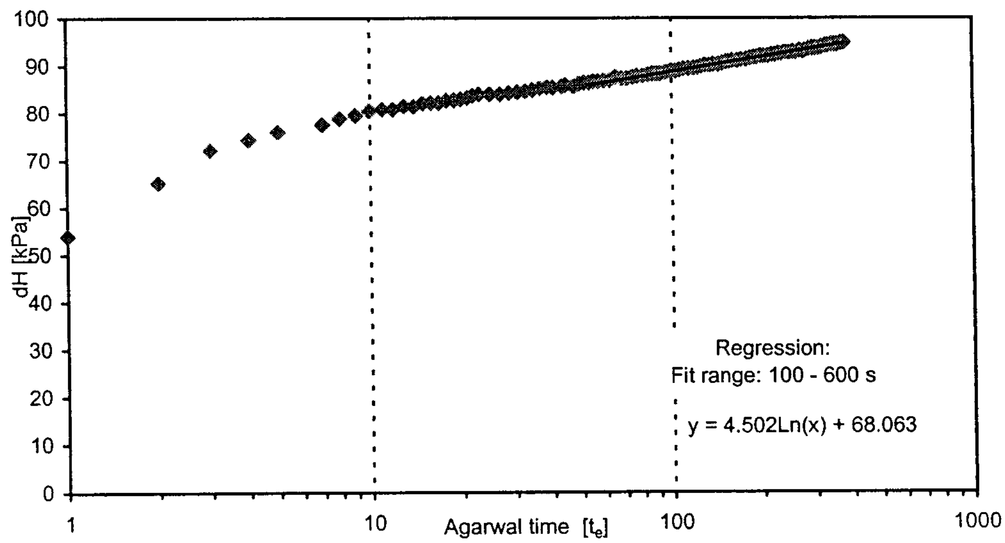
steady state

T = 6.9E-07 m^2/s
K = 6.9E-07 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



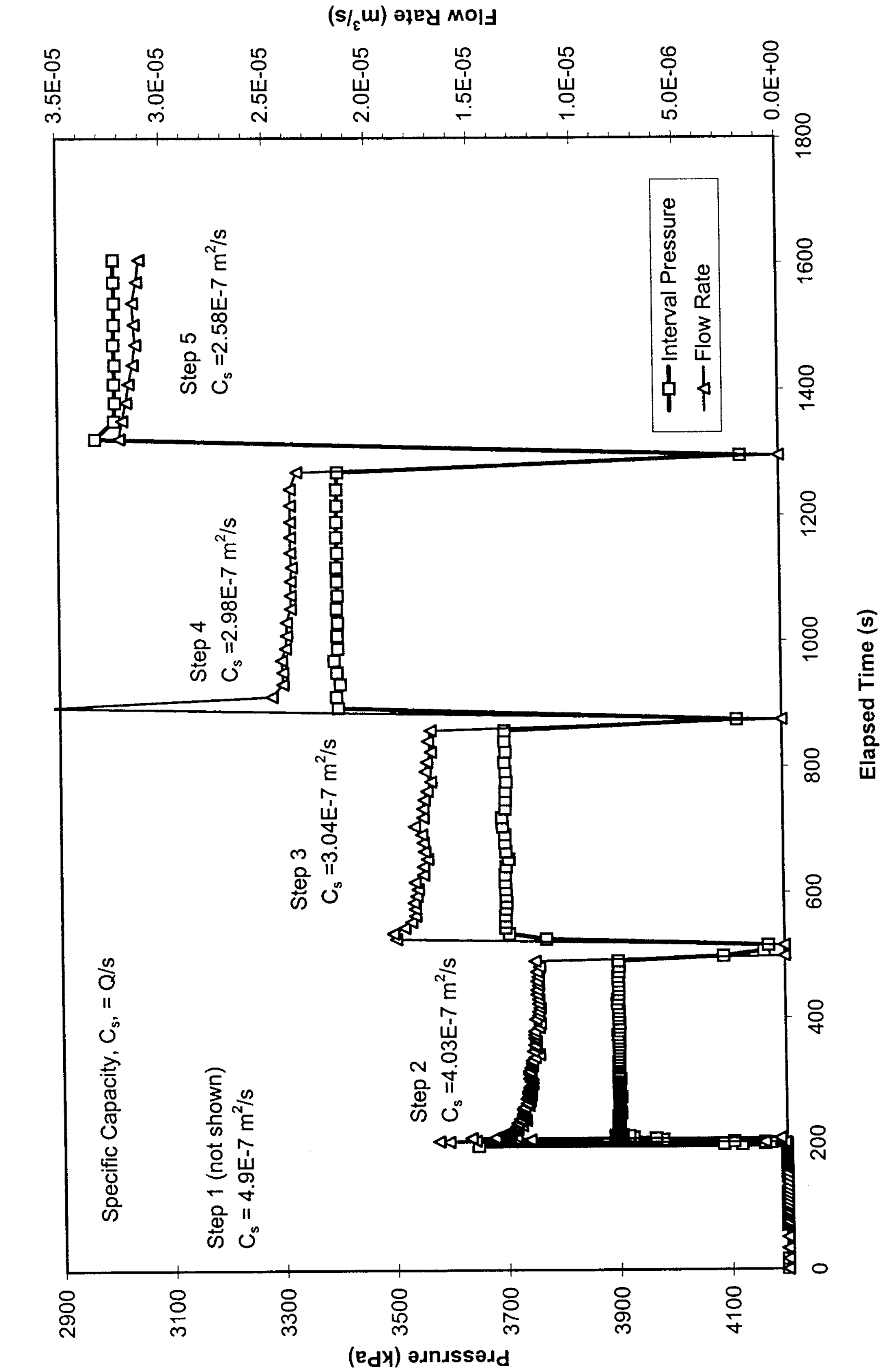
Input Values

m = 10.359 kPa/LZ
t_o = 3.E-07 Sek
L = 1.00 m
Q_{end} = 0.28 l/min
r_w = 0.038 m
t_p = 2606 Sek
S_{est} = 1.0E-07 -

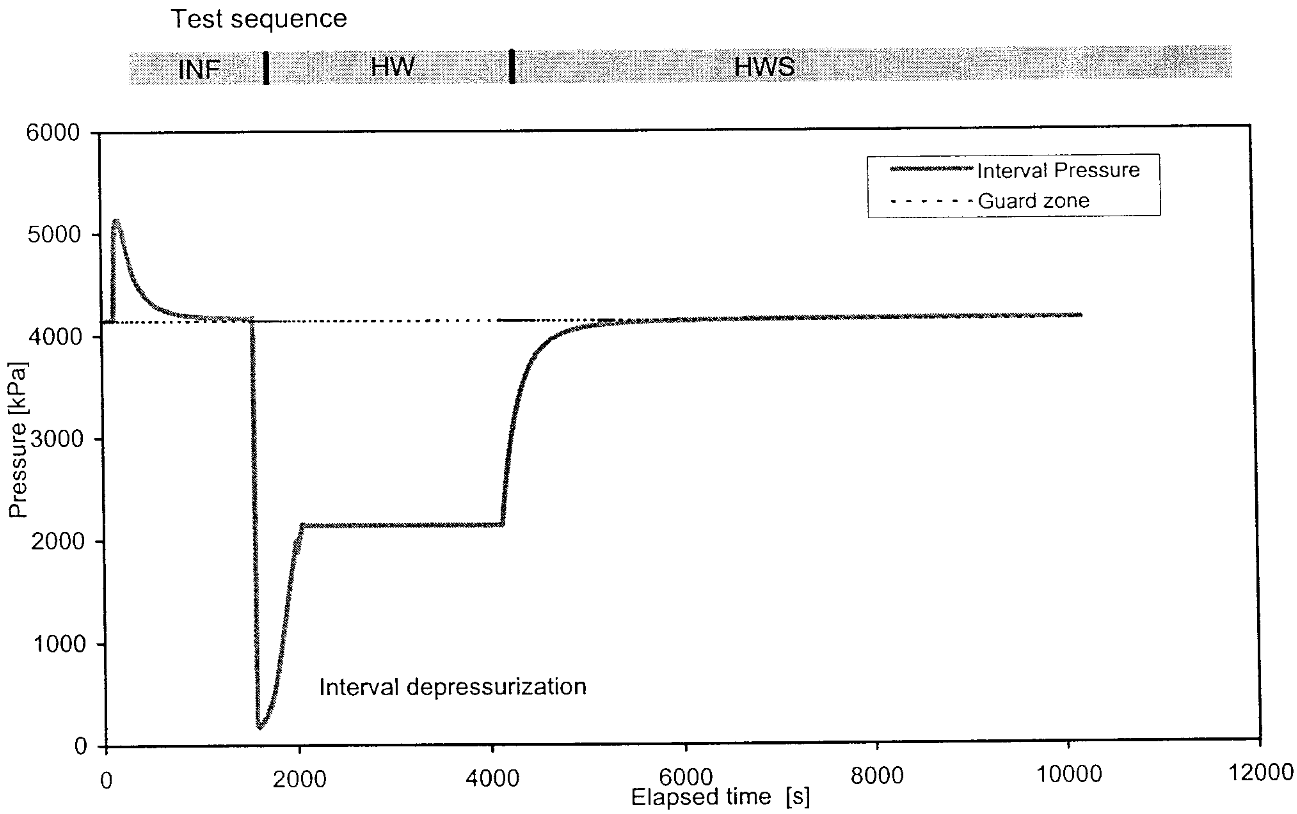
Results

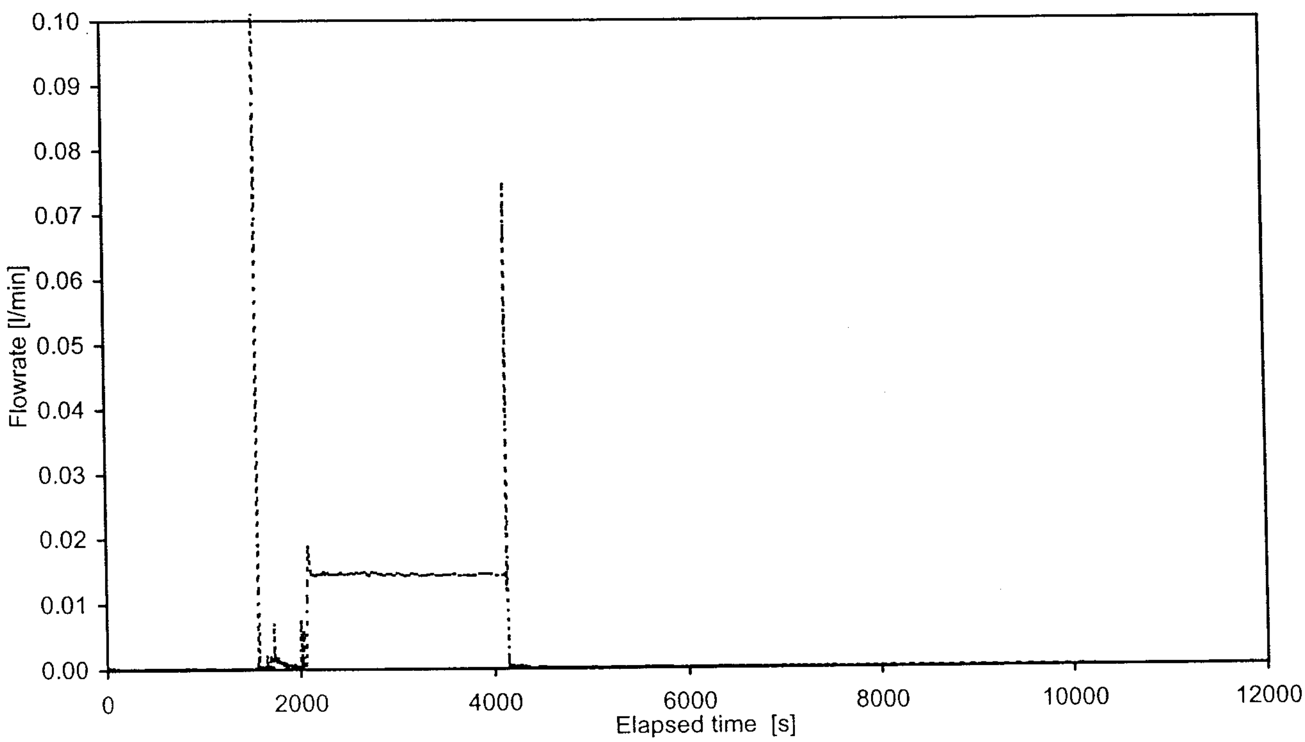
T = 8.1E-07 m^2/s
K = 8.1E-07 m/s
sf = 2.9 -
R_i = 217.8 m
u = 4.5E-06 -

Figure 7c: Interval 7 (70.4 - 71.4 m) Step-Drawdown Test



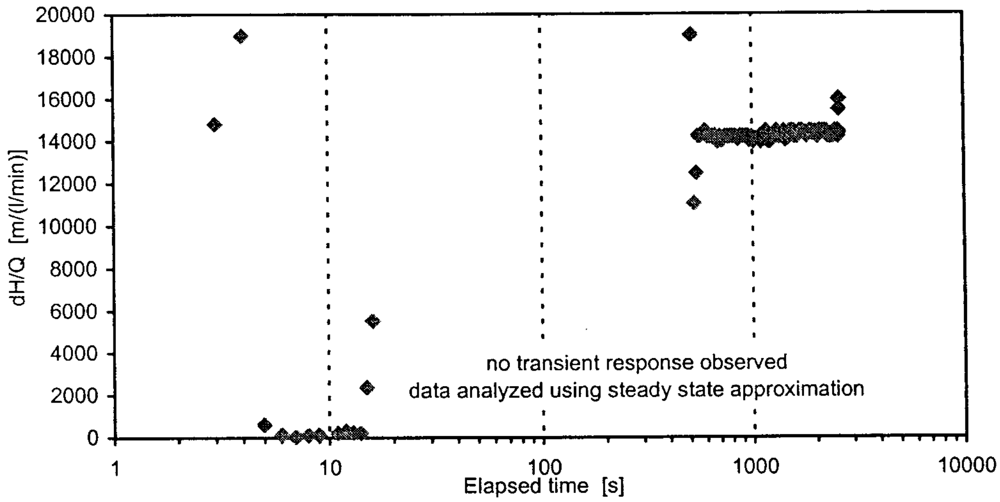
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B8a: KI0023B Interval 8 (75.1 - 76.1 meter depth)	RG	1179	12.3.98	c8.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B8b: KI0023B Interval 8 (75.1 - 76.1 meter depth)	RG/JA	1179	08.06.98	hw8-JA.xls

HW Phase Semi-log analysis:



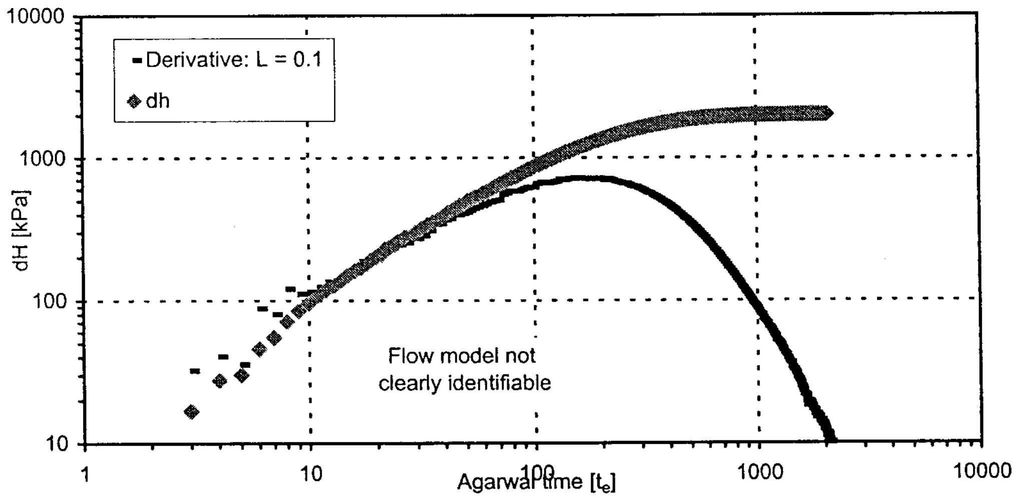
Input Values

dP = 2021.2 kPa
q = 0.013 l/min
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

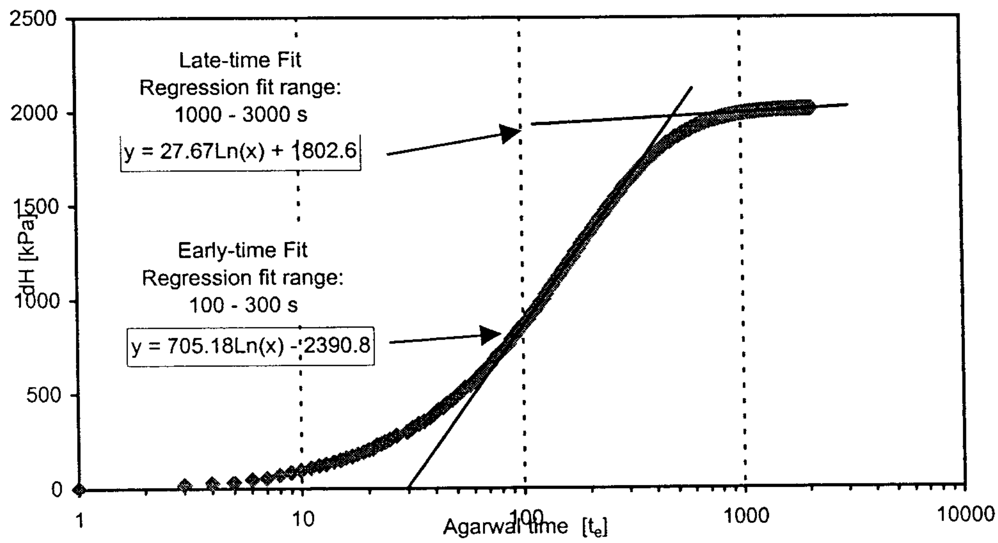
Results

T = 8.8E-10 m^2/s
K = 8.8E-10 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



Input Values

m_{early} = 1623.37 kPa/LZ
$t_{o\text{-}early}$ = 3.E+01 sec
m_{late} = 63.6963 kPa/LZ
$t_{o\text{-}late}$ = 5.E-29 sec
L = 1.00 m
Q_{end} = 0.013 l/min
r_w = 0.038 m
t_p = 2570 sec
S_{est} = 1.0E-07 -

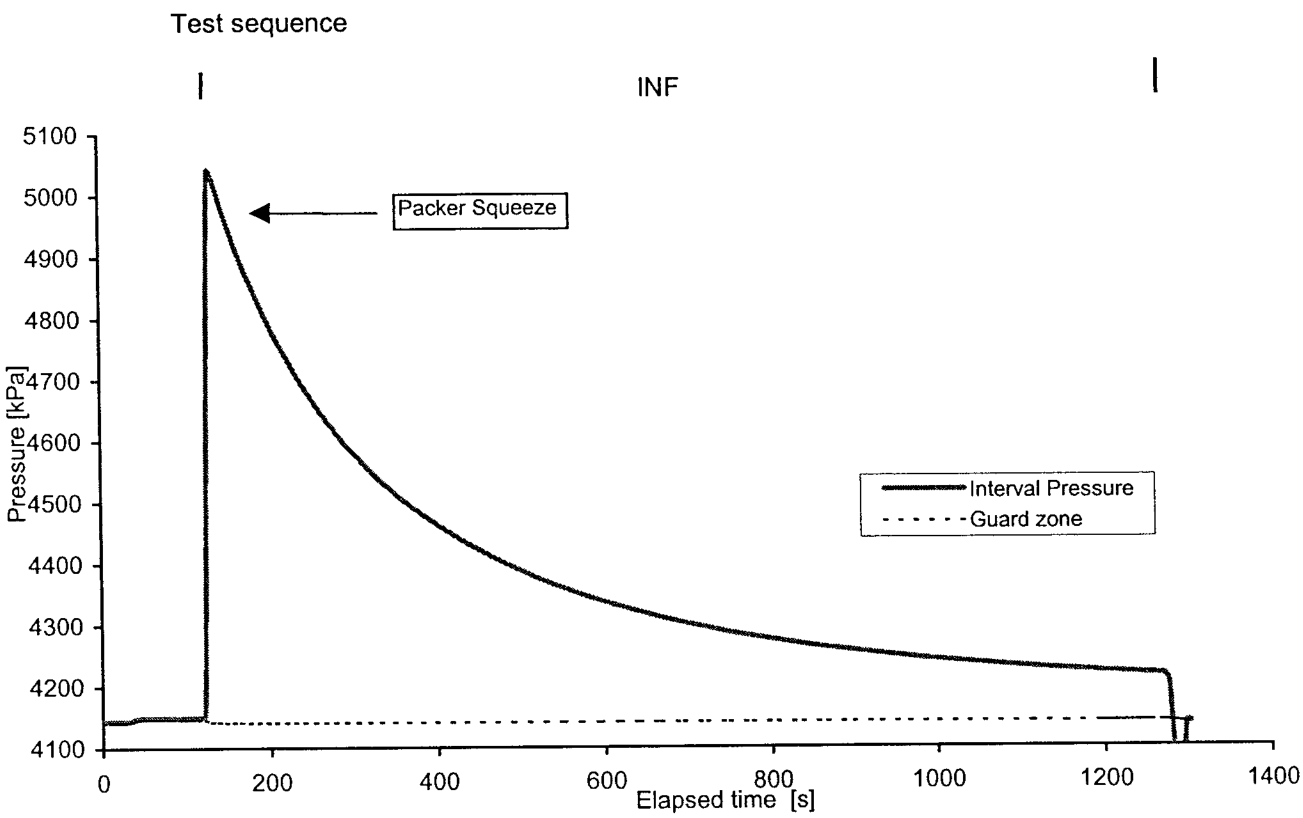
Early-Time Match

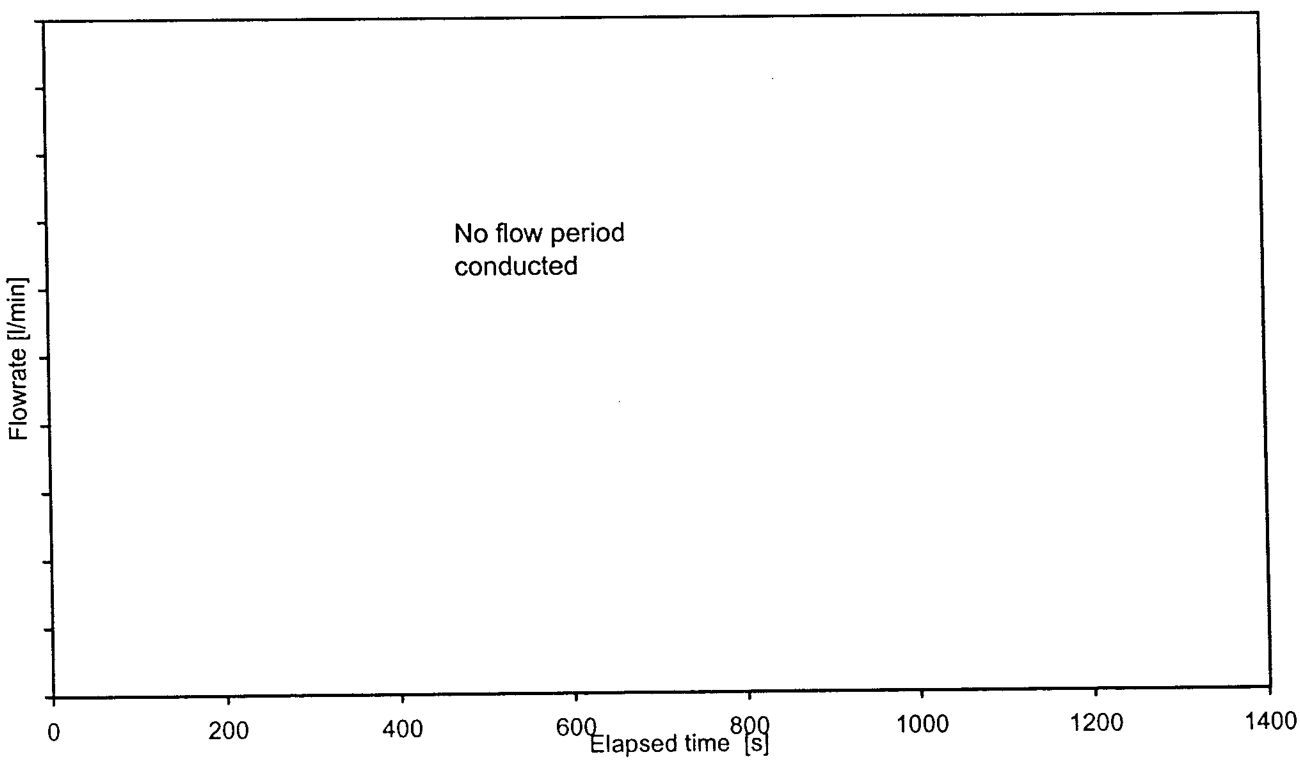
T = 2.4E-10 m^2/s
K = 2.4E-10 m/s
sf = -2.4 -
u = 2.E-03 -

Late-Time Match

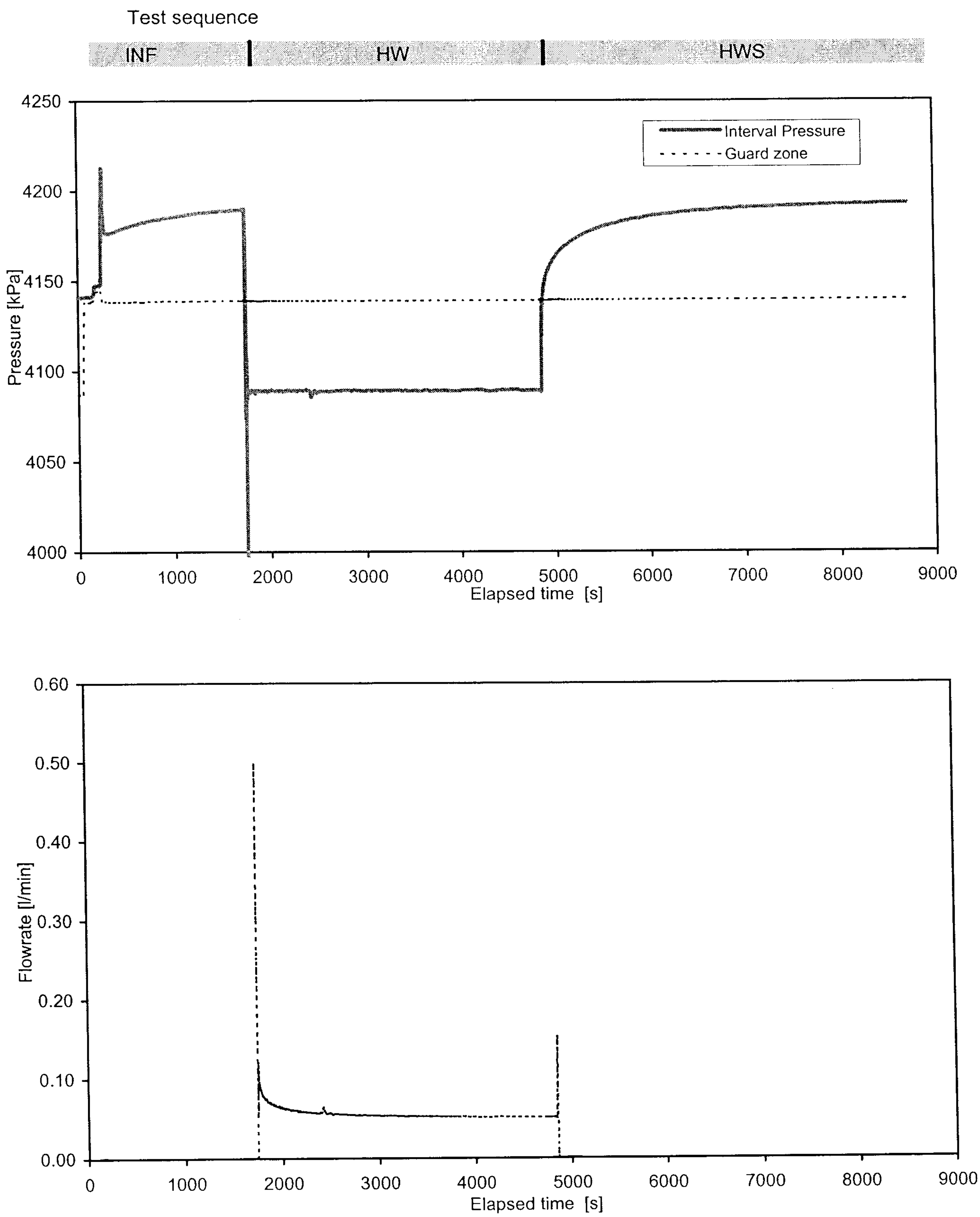
T = 6.1E-09 m^2/s
K = 6.1E-09 m/s
sf = 30.3 -
R_i = 18.8 m
u = 6E-06 -

True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B9a: KI0023B Interval 9 (78.6 - 79.6 meter depth)	JA	1179	11.6.98	c9.xls



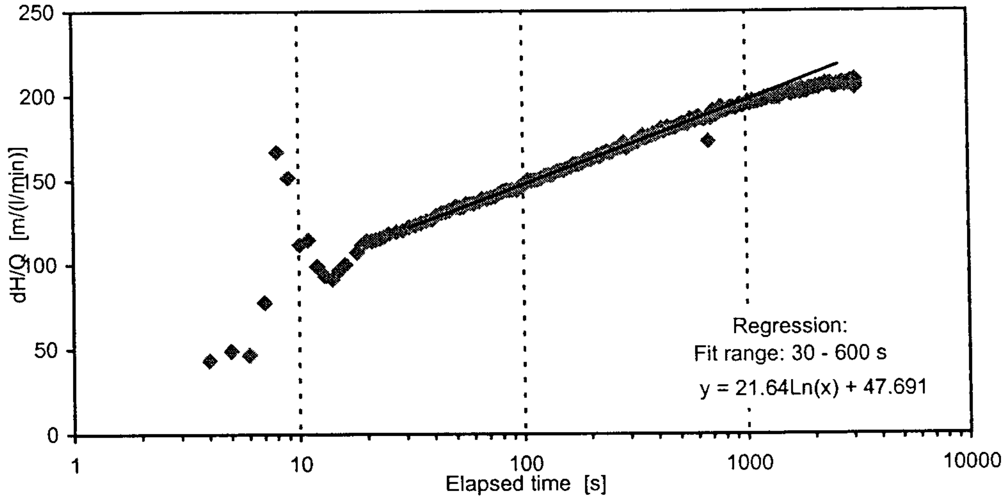


True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B10a: KI0023B Interval 10 (85.0 - 86.0 meter depth)	RG	1179	13.3.98	c10.xls



True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B10b: KI0023B Interval 10 (85.0 - 86.0 meter depth)	RG/JA	1179	8.6.98	hw10-JA.xls

HW Phase Semi-log analysis:

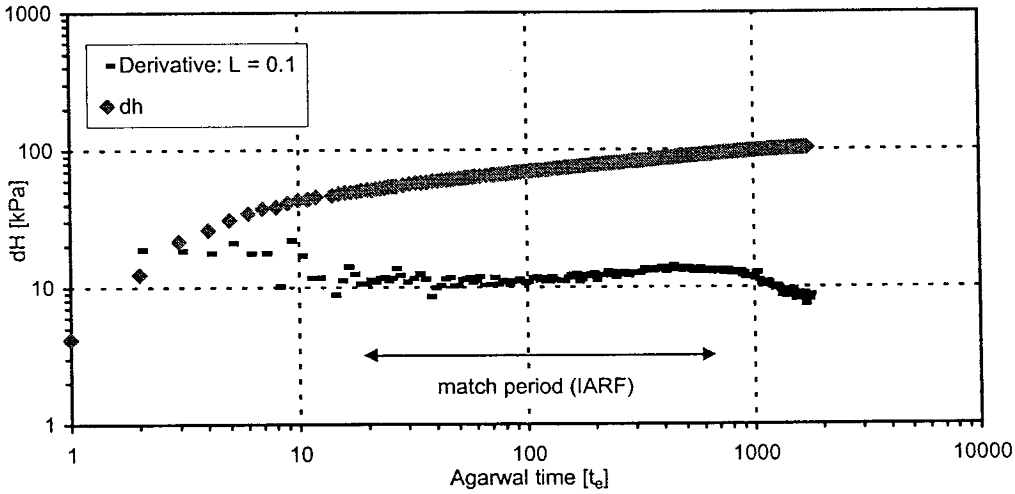


Input Values
dP = 104.00 kPa
q = 0.051 l/min
m = 49.8153 /LZ
t_o = 1.E-01 Sek
L = 1.00 m
r_w= 0.038 m
S_{est} = 1.0E-07 -

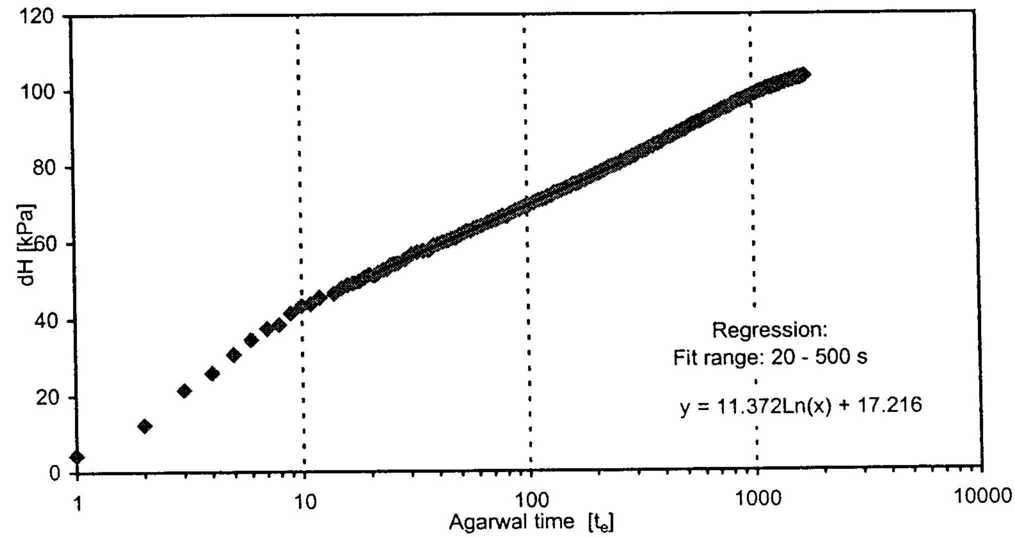
Results transient
T = 6.1E-08 m^2/s
K = 6.1E-08 m/s
sf = -2.3

steady state
T = 9.8E-08 m^2/s
K = 9.8E-08 m/s

HWS Phase : Log-Log Diagnostic Plot



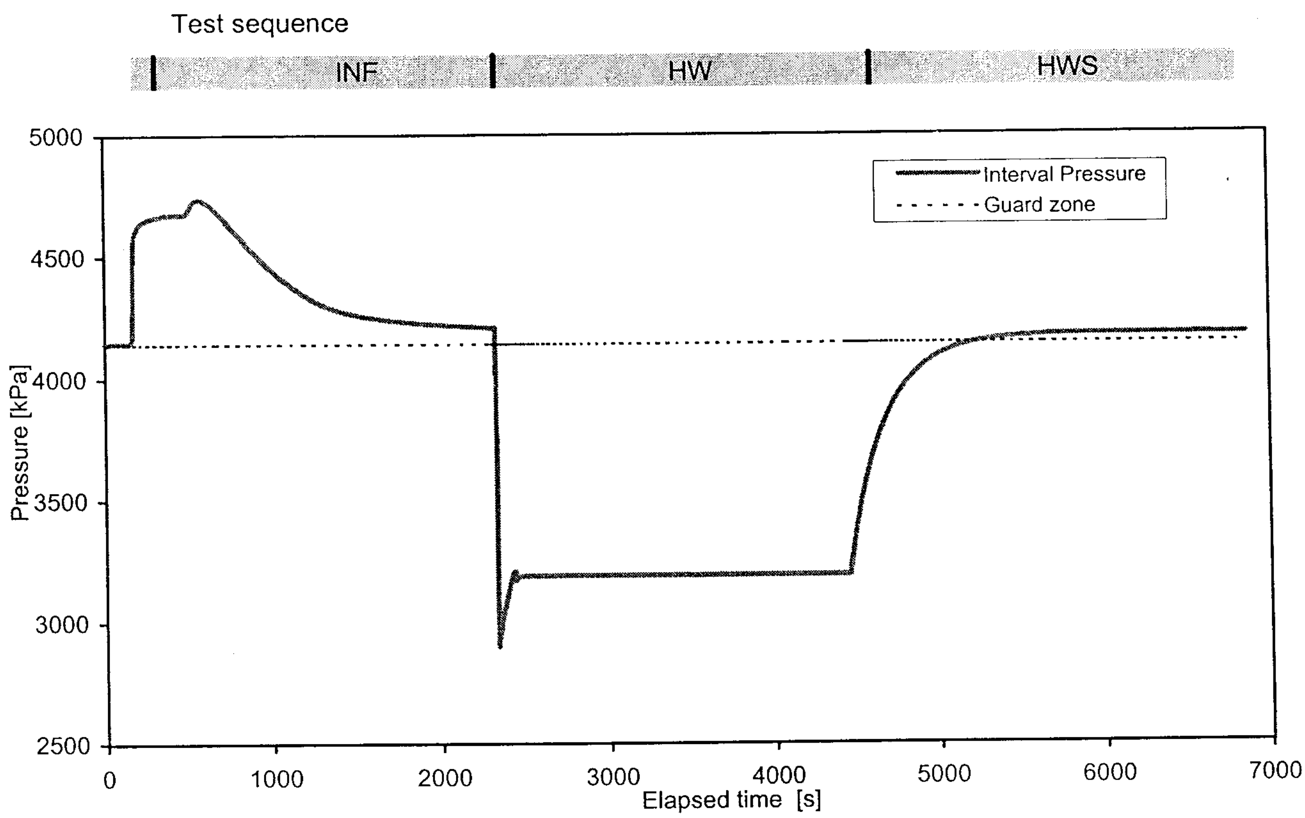
HWS Phase Semi-log analysis:

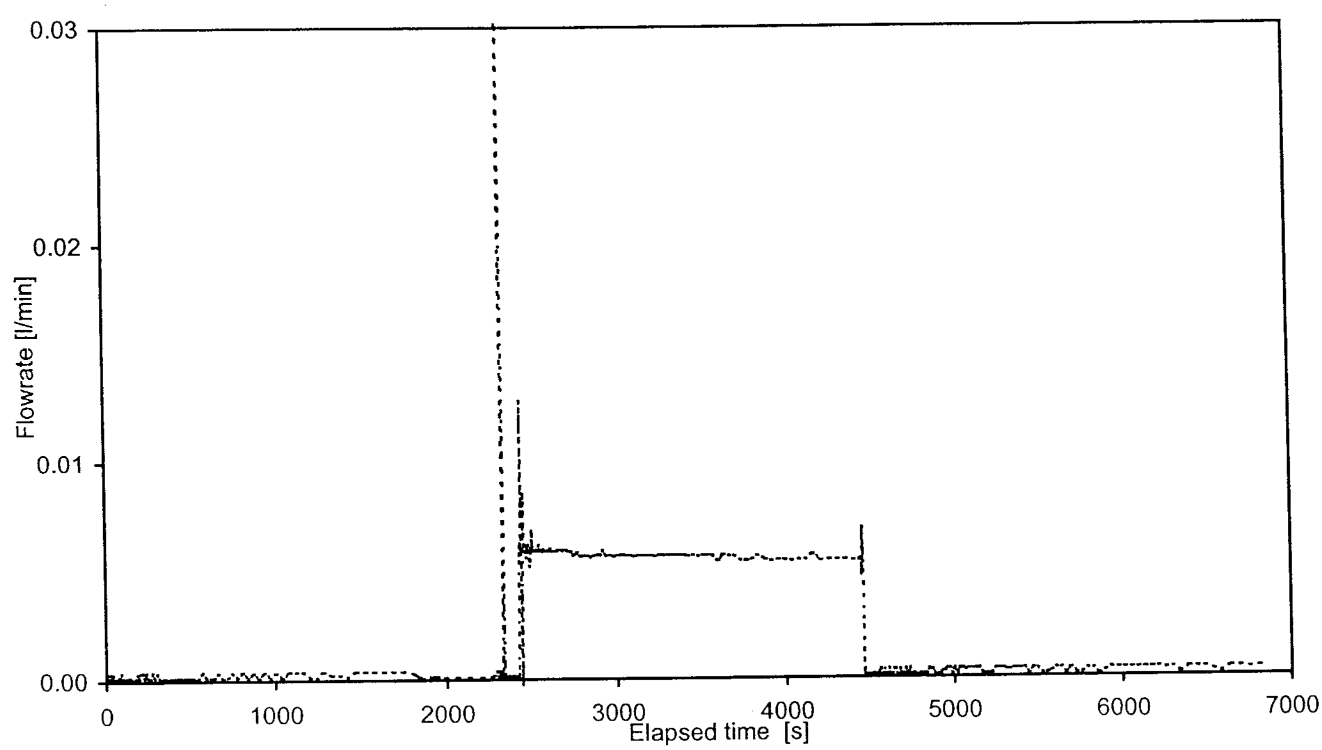


Input Values
m = 26.1737 kPa/LZ
t_o = 2.2E-01 Sek
L = 1.00 m
Q_{end} = 0.051 l/min
r_w= 0.038 m
t_p = 3103 Sek
S_{est} = 1.0E-07 -

Results
T = 5.8E-08 m^2/s
K = 5.8E-08 m/s
sf = 0.6 -
R_i = 63.8 m
u = 3.1E-05 -

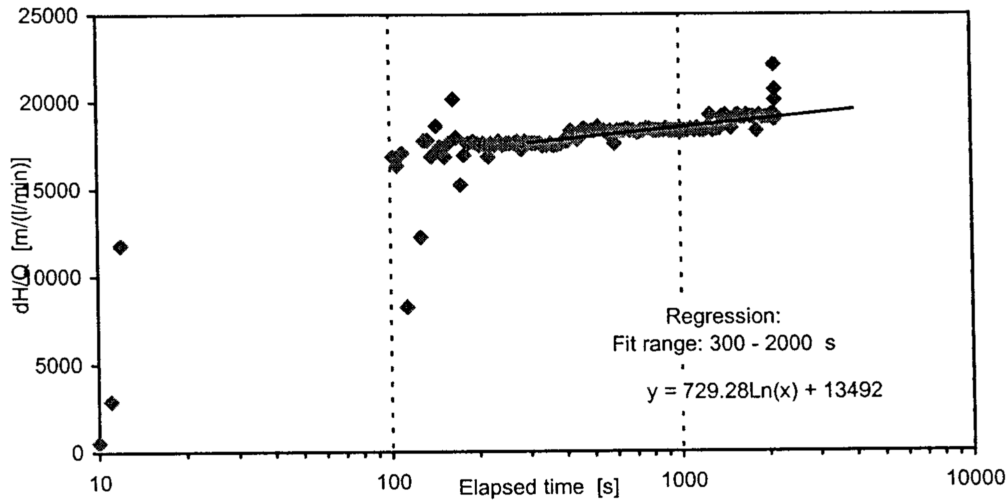
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B11a: KI0023B Interval 11 (87.1 - 88.1 meter depth)	RG	1179	13.3.98	c11.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B11b: KI0023B Interval 11 (87.1 - 88.1 meter depth)	RG/JA	1179	8.6.98	hw11-JA.xls

HW Phase Semi-log analysis:



Input Values

dP = 1013 kPa
q = 0.005 l/min
m = 1678.85 /LZ
t_o = 9.E-09 Sek
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

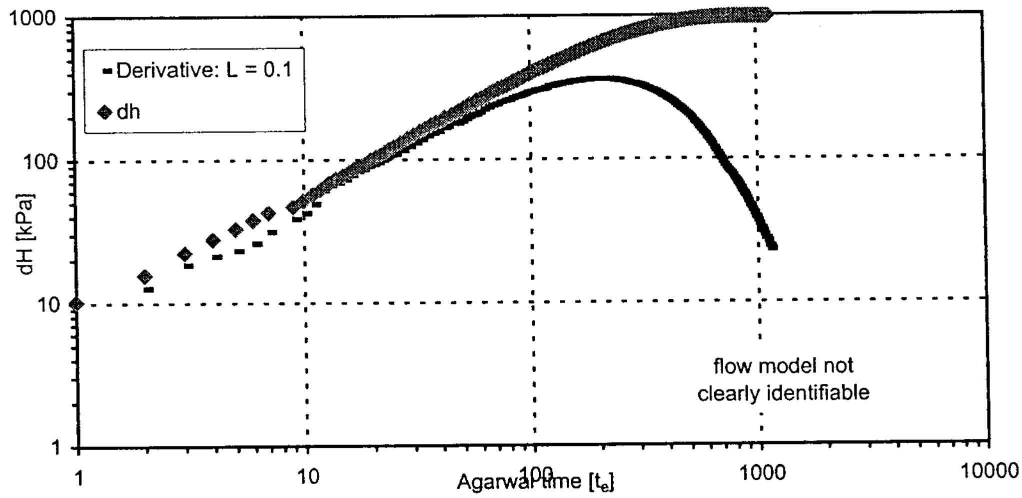
Results transient

T = 1.8E-09 m^2/s
K = 1.8E-09 m/s
sf = 7.6

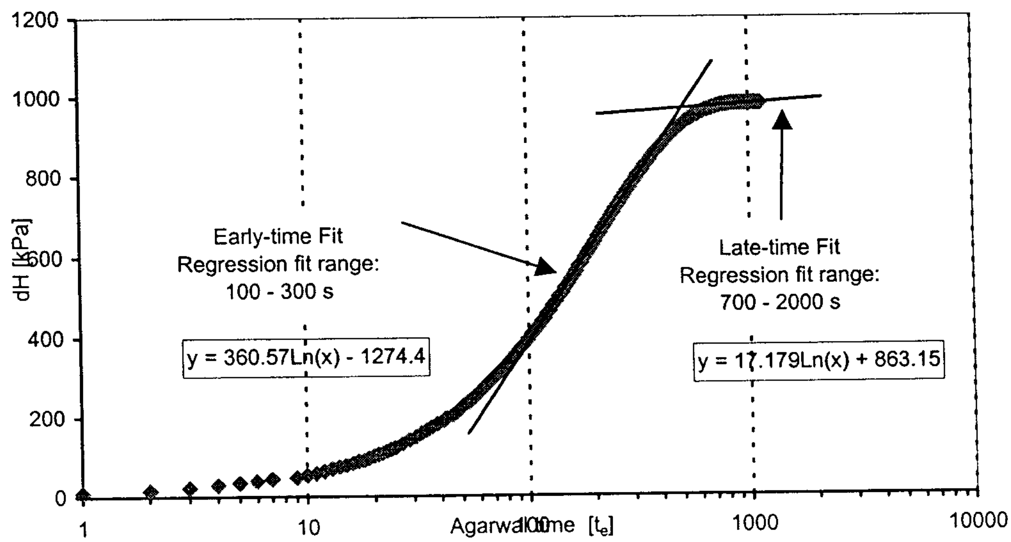
steady state

T = 6.4E-10 m^2/s
K = 6.4E-10 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



Input Values

m_{early} = 830.032 kPa/LZ
$t_{o-early}$ = 3.E+01 sec
m_{late} = 39.5484 kPa/LZ
t_{o-late} = 1.E-22 sec
L = 1.00 m
Q_{end} = 0.005 l/min
r_w = 0.038 m
t_p = 2130 sec
S_{est} = 1.0E-07 -

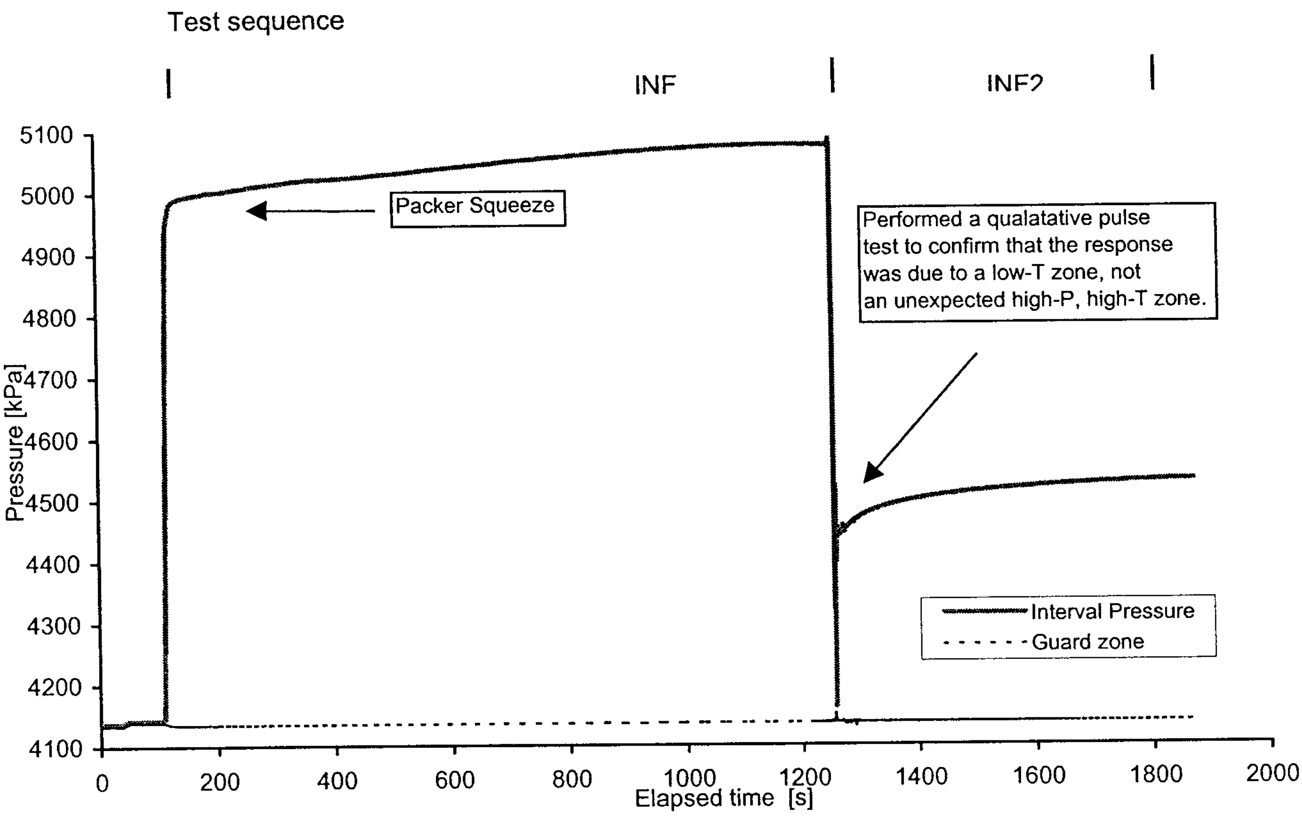
Early-Time Match

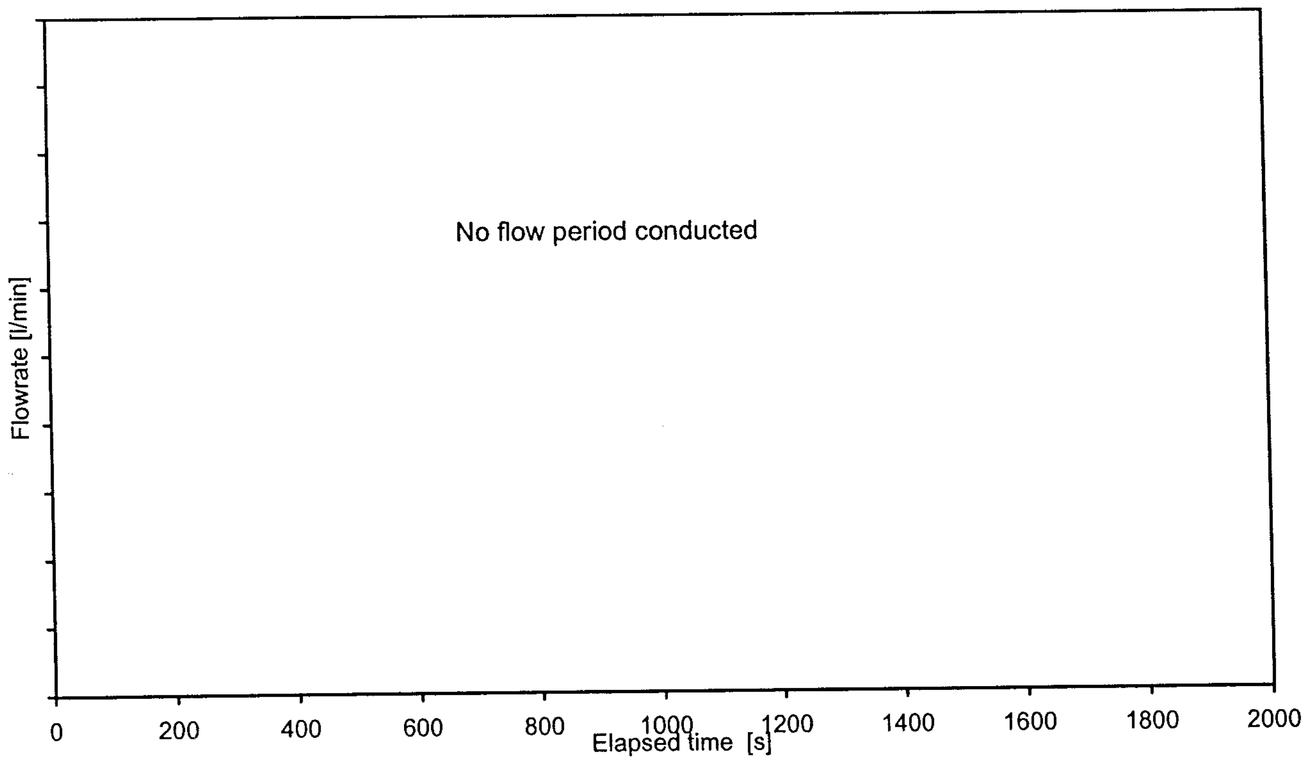
T = 1.8E-10 m^2/s
K = 1.8E-10 m/s
sf = -2.3 -
u = 2.E-03 -

Late-Time Match

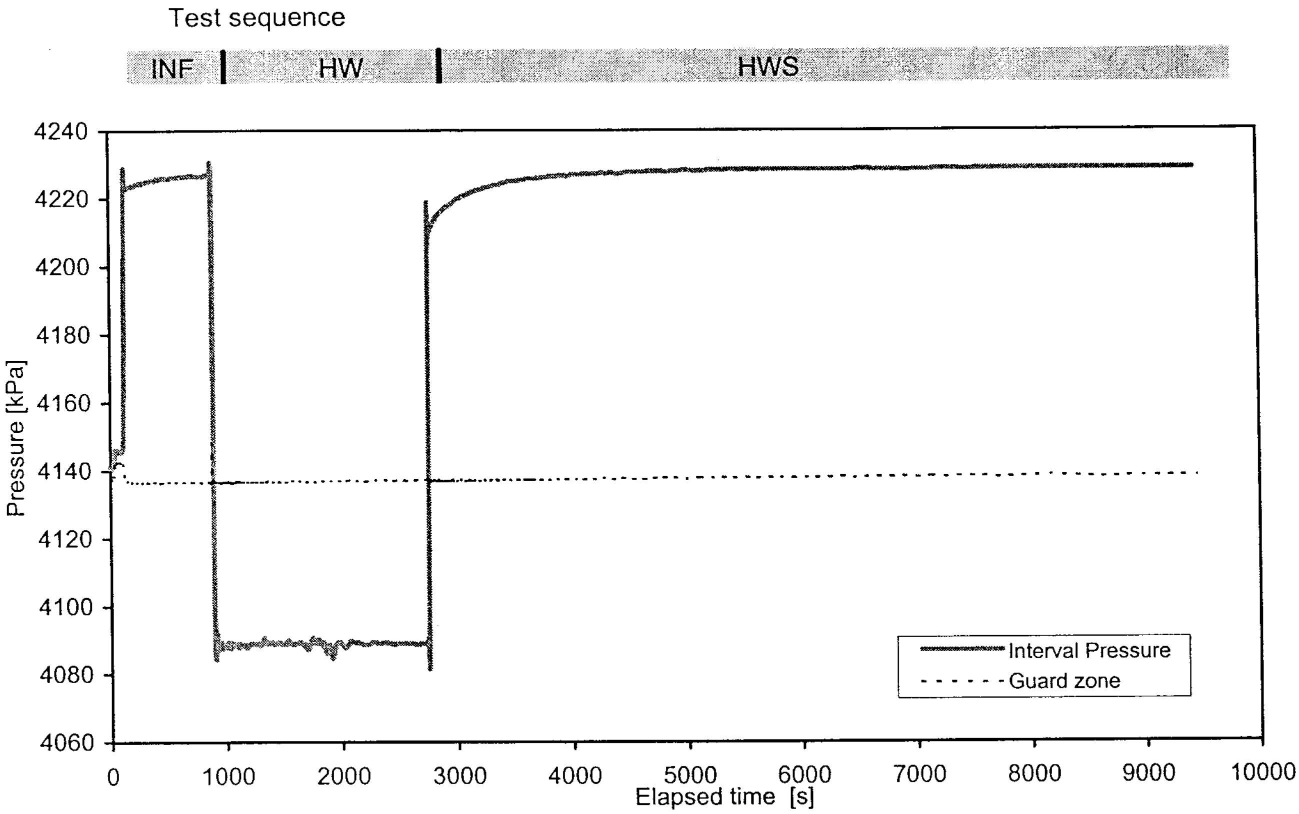
T = 3.8E-09 m^2/s
K = 3.8E-09 m/s
sf = 23.1 -
R_i = 13.5 m
u = 1.4E-05 -

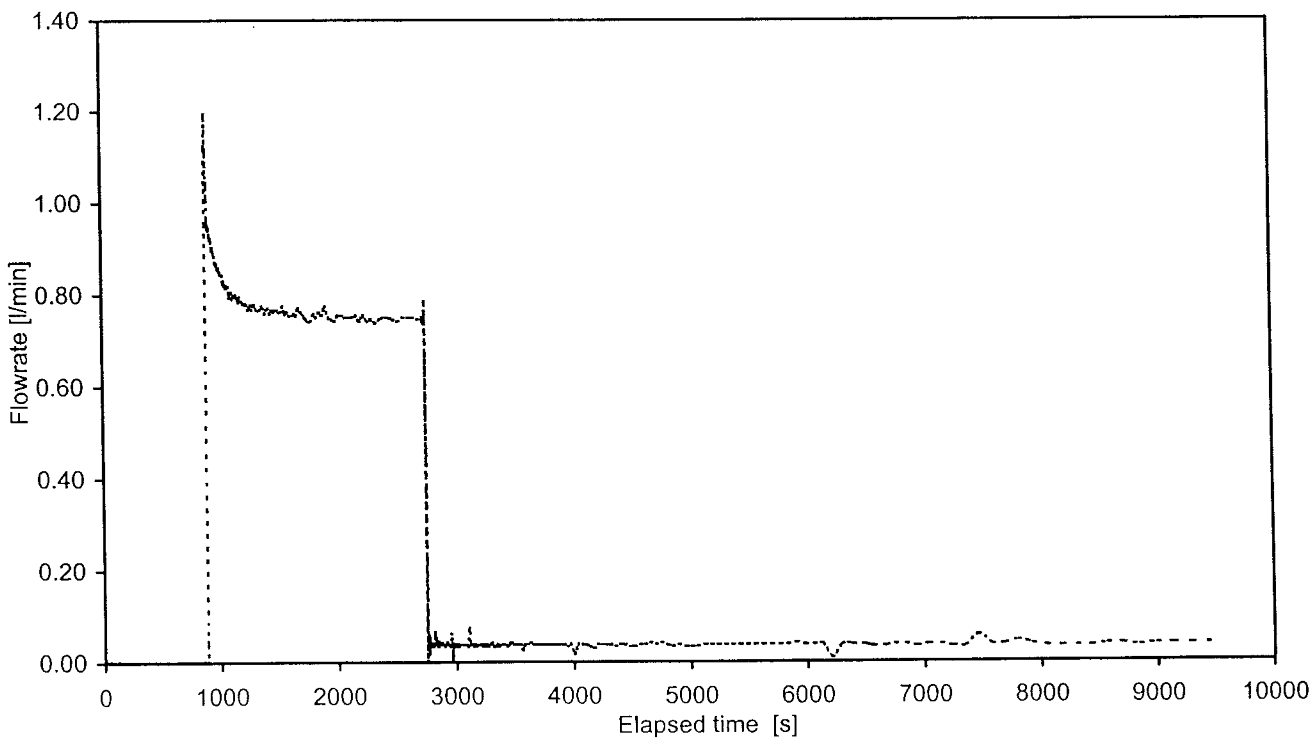
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B12a: KI0023B Interval 13 (109.5 - 110.5 meter depth)	JA	1179	11.6.98	c13.xls





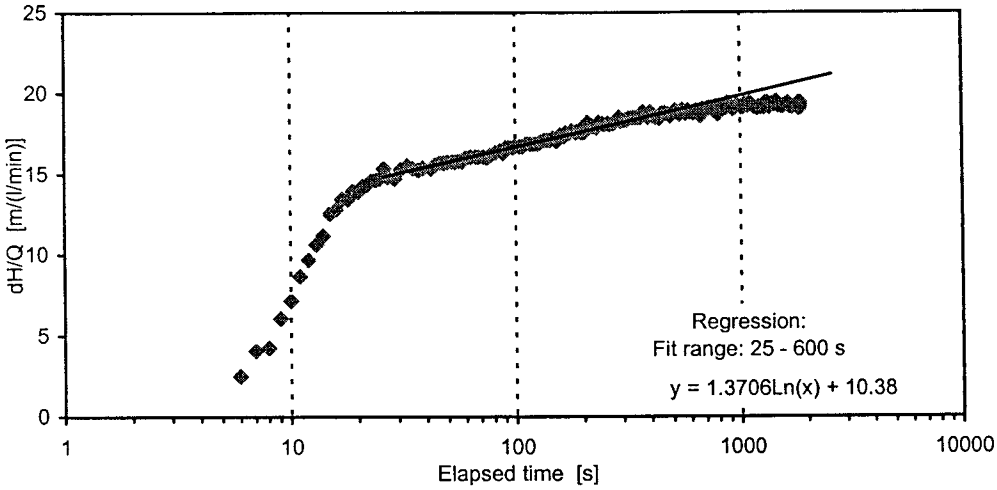
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B13a: KI0023B Interval 14 (111.45 - 112.45 meter depth)	RG	1179	13.3.98	c14.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B13b: KI0023B Interval 14 (111.45 - 112.45 meter depth)	RG/JA	1179	8.6.98	hw14-JA.xls

HW Phase Semi-log analysis:



Input Values

dP = 141.00 kPa
q = 0.72 l/min
m = 3.15374 /LZ
t_o = 5.E-04 Sek
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

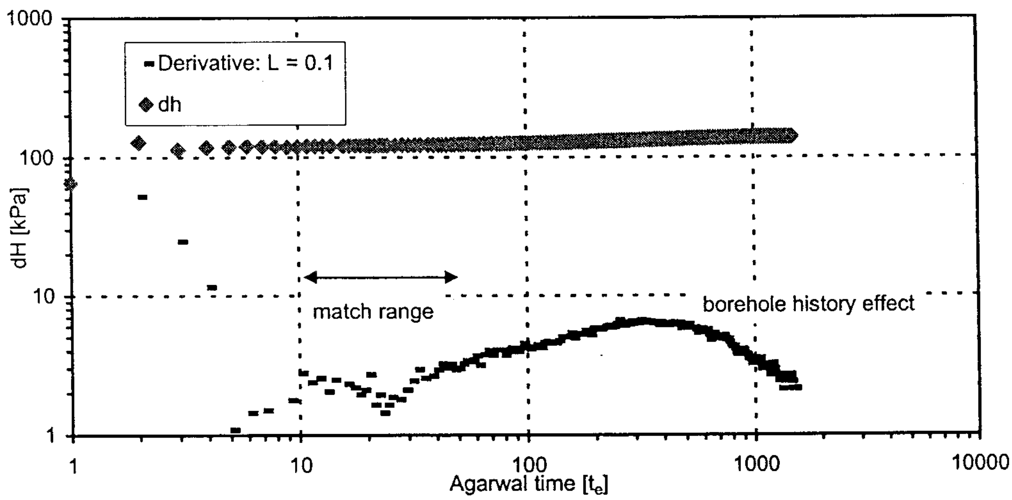
Results transient

T = 9.7E-07 m^2/s
K = 9.7E-07 m/s
sf = -1.0

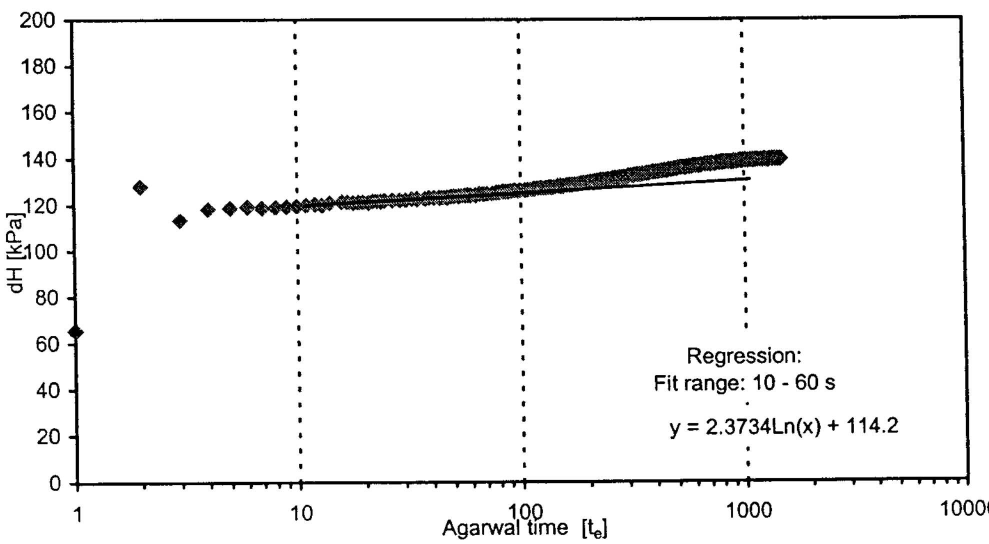
steady state

T = 1.2E-06 m^2/s
K = 1.2E-06 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



Input Values

m = 5.46265 kPa/LZ
t_o = 1.E-21 Sek
L = 1.00 m
Q_{end} = 0.72 l/min
r_w = 0.038 m
t_p = 1864 Sek
S_{est} = 1.0E-07 -

Results

T = 3.9E-06 m^2/s
K = 3.9E-06 m/s
sf = 21.8 -
R_i = 406.7 m
u = 9.2E-07 -

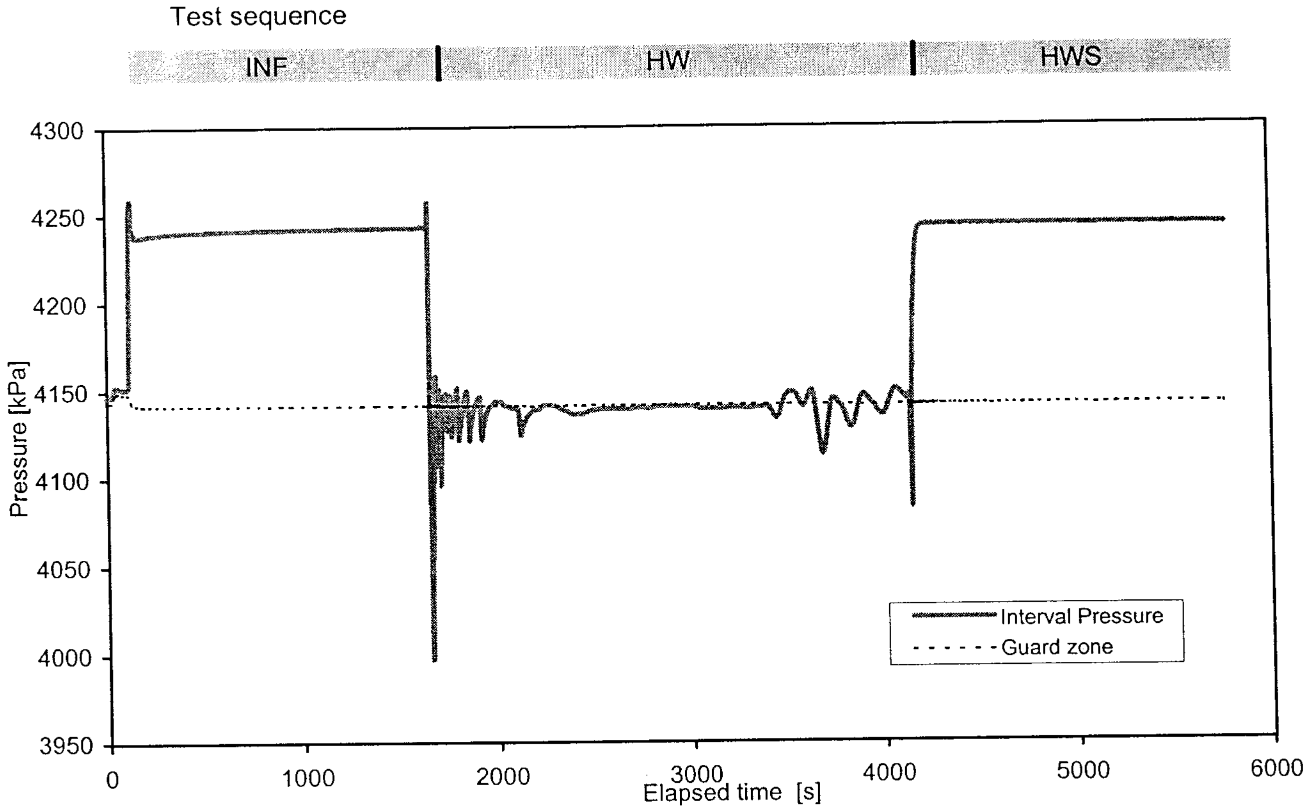
True Block Scale Experiment:

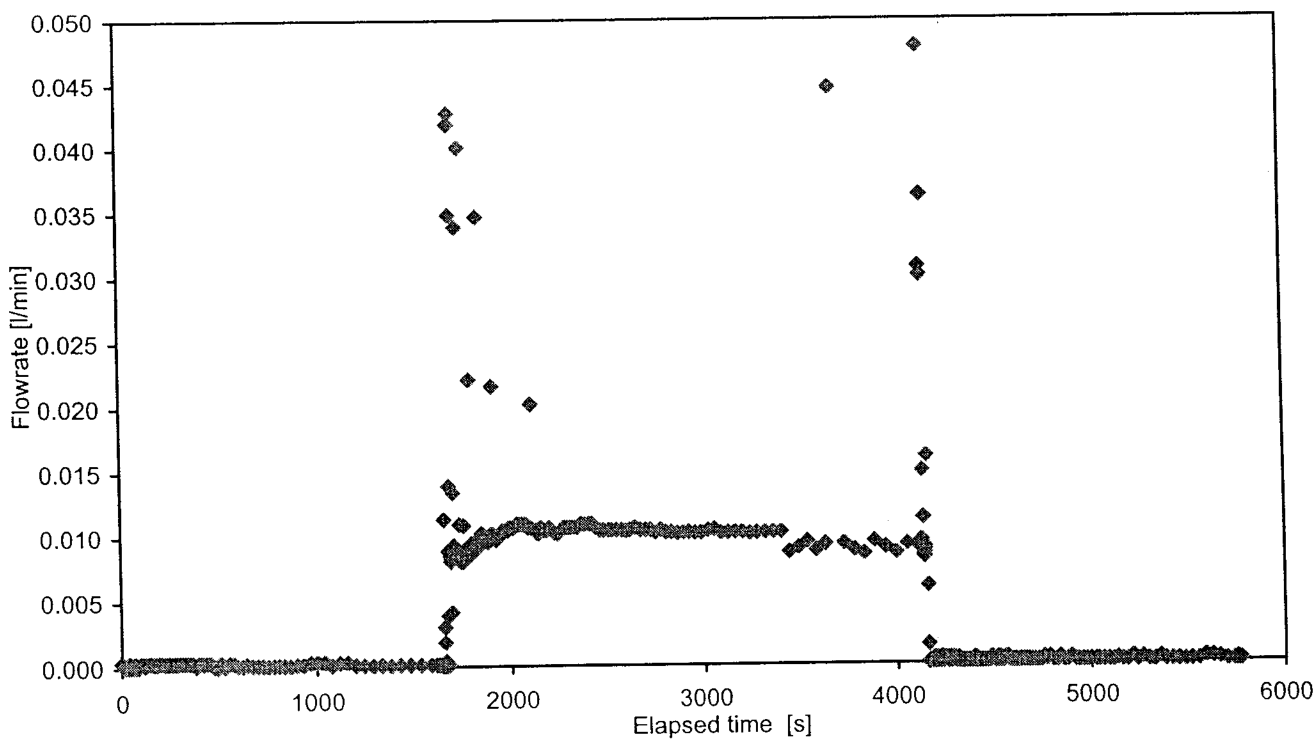
SOL EXPERTS AG

Selective Flow and Pressure Build-up Tests

Visum:	Proj. #	Date	Filename
RG	1179	16.3.98	c19.xls

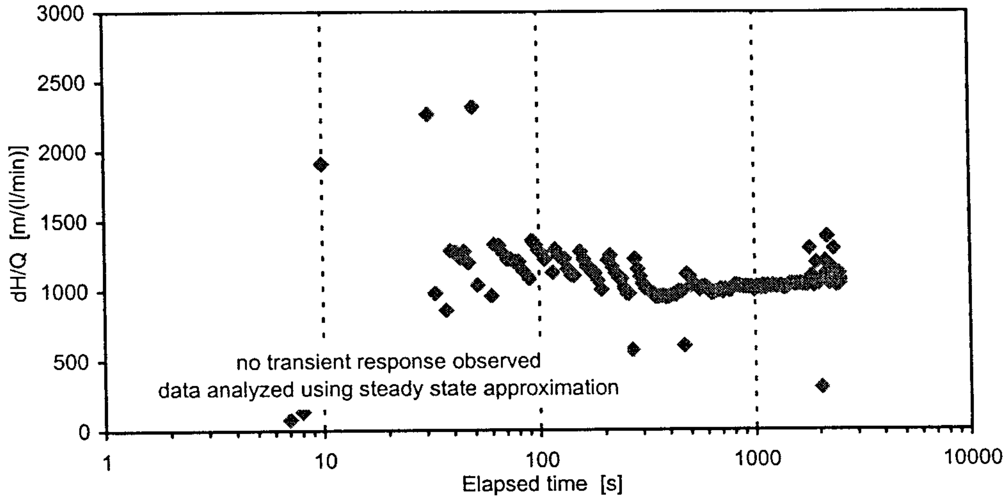
Figure B14a: KI0023B Interval 19 (168.1 - 169.1 meter depth)





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B14b: KI0023B Interval 19 (168.1 - 169.1 meter depth)	RG/JA	1179	8.6.98	hw19-JA.xls

HW Phase Semi-log analysis:



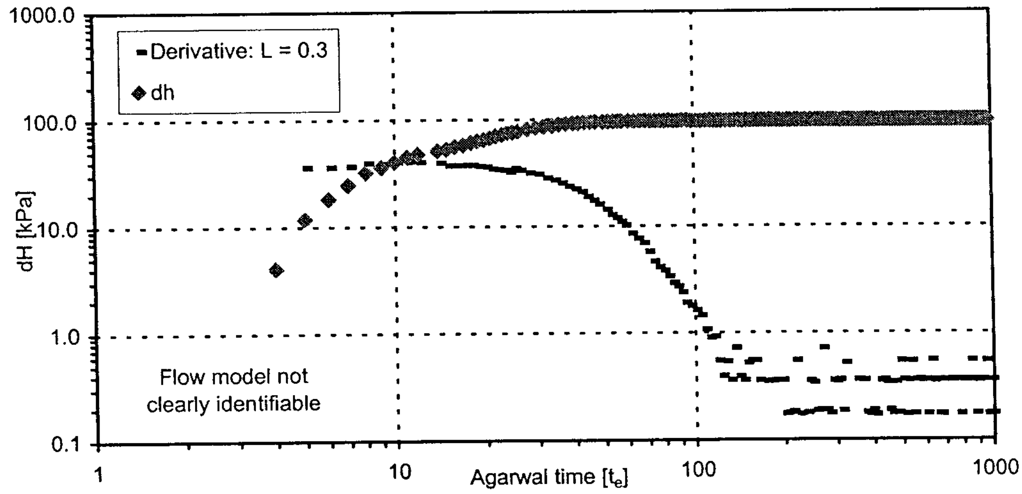
Input Values

dP = 96.00 kPa
q = 0.009 l/min
L = 1.00 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

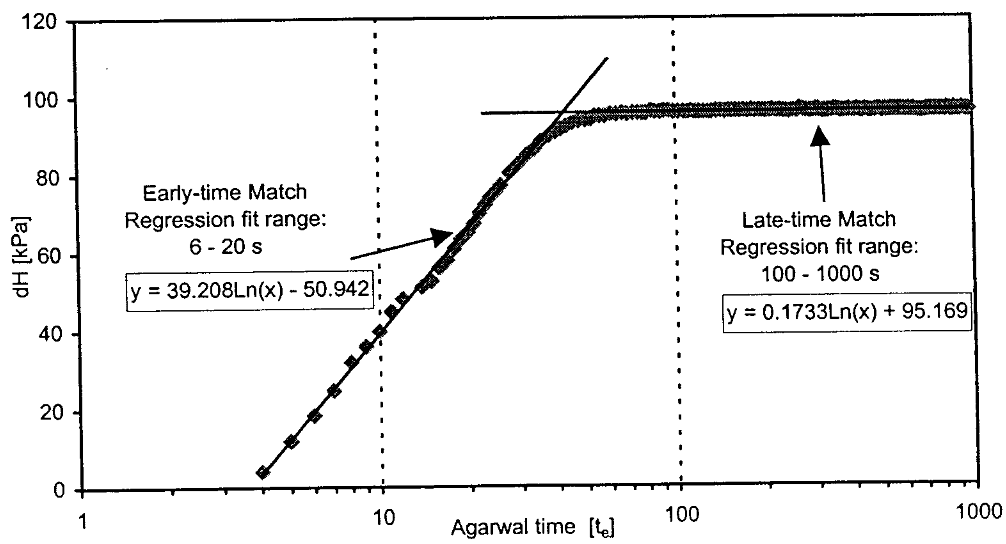
Results

T = 1.6E-08 m^2/s
K = 1.6E-08 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



Input Values

m_{early} = 90.2384 kPa/LZ
$t_{o\text{-}early}$ = 4.E+00 sec
m_{late} = 0.39894 kPa/LZ
$t_{o\text{-}late}$ = 3.E-239 sec
L = 1.00 m
Q_{end} = 0.009 l/min
r_w = 0.038 m
t_p = 2487 sec
S_{est} = 1.0E-07 -

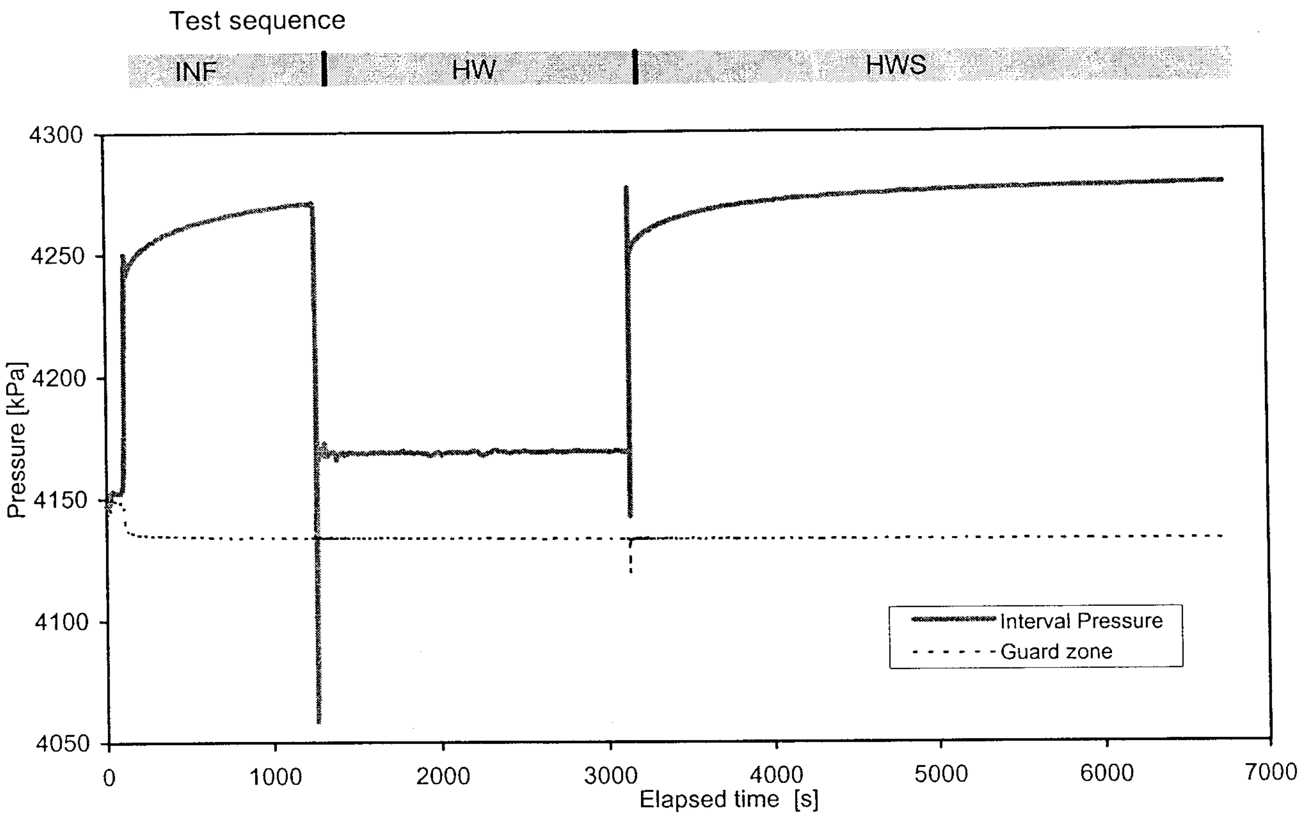
Early-Time Match

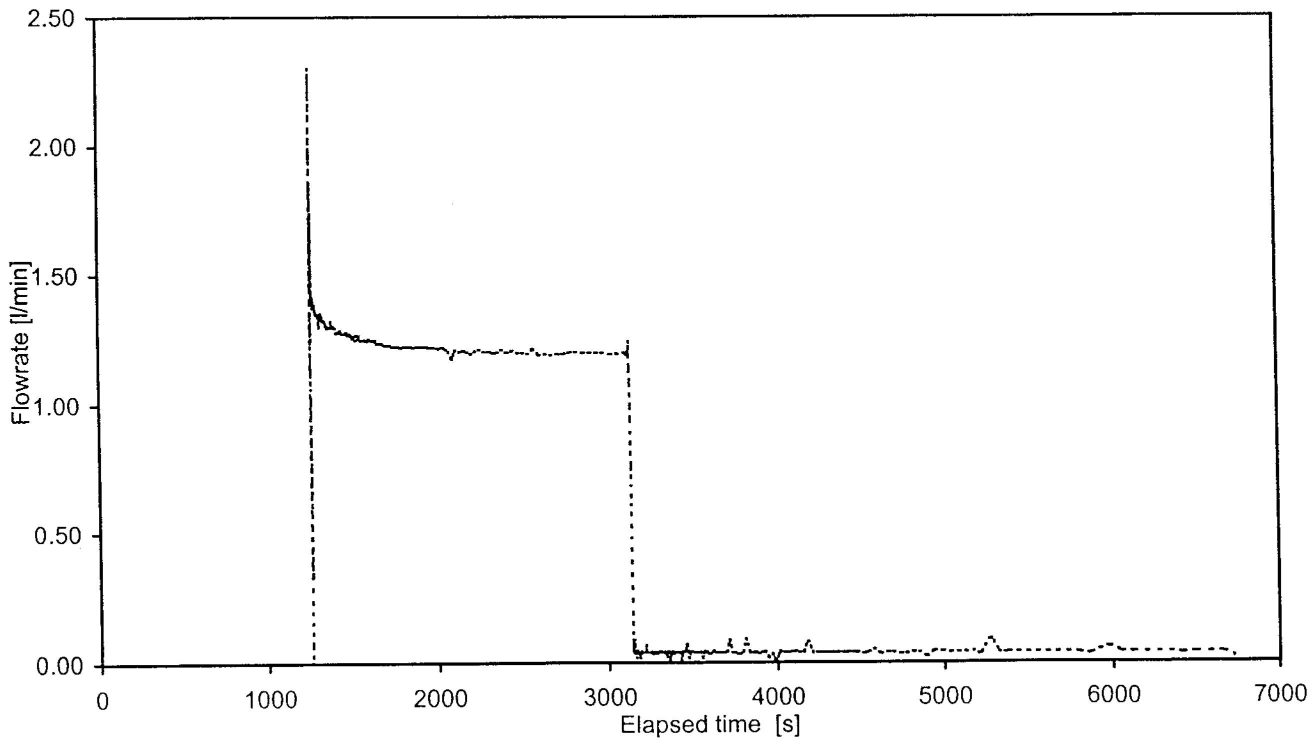
T = 3.0E-09 m^2/s
K = 3.0E-09 m/s
sf = -2.6 -
u = 3.0E-03 -

Late-Time Match

T = 6.8E-07 m^2/s
K = 6.8E-07 m/s
sf = 270.0 -
R_i = 194.3 m
u = 5.3E-07 -

True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B15a: KI0023B Interval 20 (170.2 - 171.2 meter depth)	RG	1179	16.3.98	c20.xls





True Block Scale Experiment

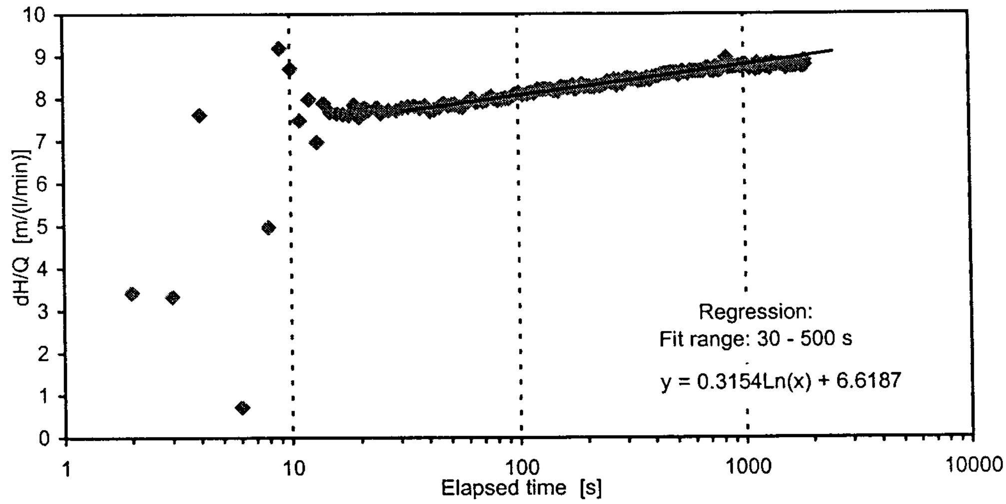
Selective Flow and Pressure Build-up Tests

Figure B15b: KI0023B Interval 20 (170.2 - 171.2 meter depth)

SOL EXPERTS AG

Visum:	Proj. #	Date	Filename
RG/JA	1179	8.6.98	hw20-JA.xls

HW Phase Semi-log analysis:



Input Values

dP = 104.00 kPa
q = 1.20 l/min
m = 0.72283 /LZ
t_o = 7.E-10 Sek
L = 1.00 m
r_w= 0.038 m
S_{est} = 1.0E-07 -

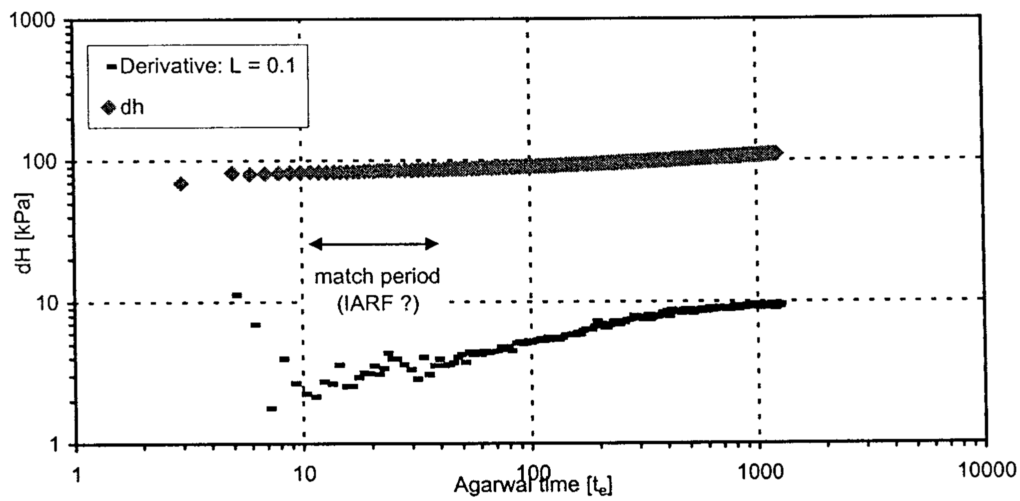
Results
transient

T = 4.2E-06 m^2/s
K = 4.2E-06 m/s
sf = 5.0 -

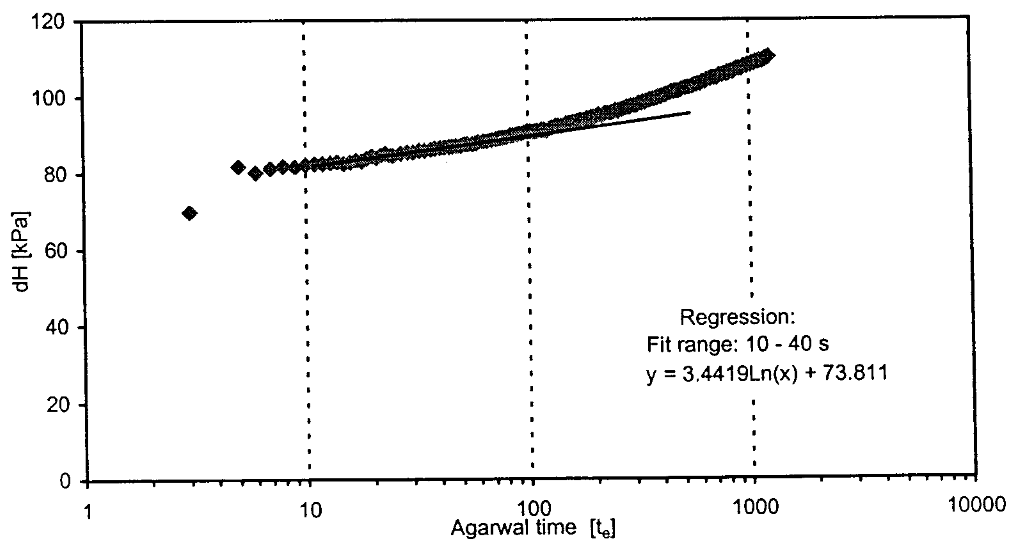
steady state

T = 2.7E-06 m^2/s
K = 2.7E-06 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



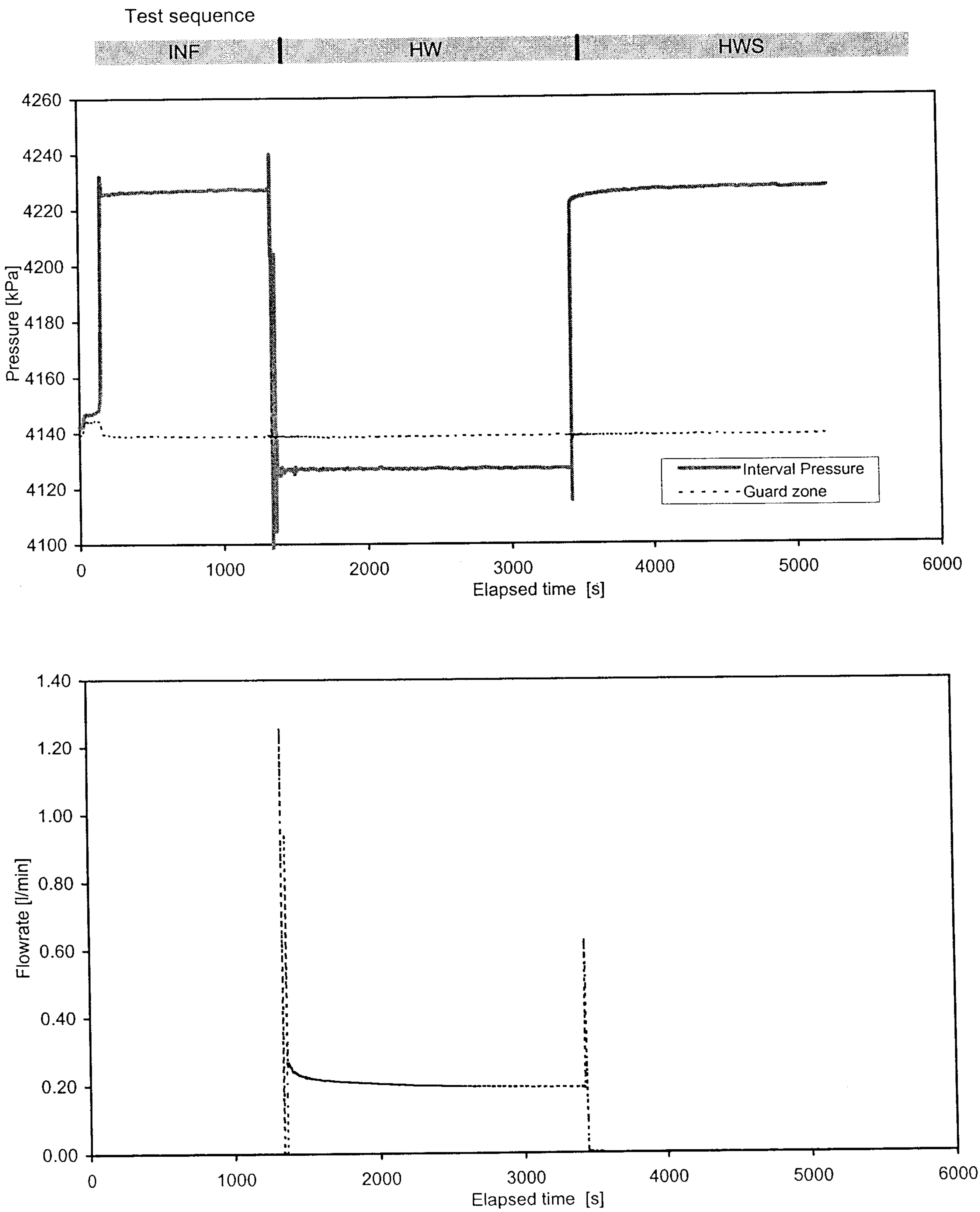
Input Values

m = 7.91888 kPa/LZ
t_o = 5.E-10 Sek
L = 1.00 m
Q_{end} = 1.2 l/min
r_w= 0.038 m
t_p = 1872 Sek
S_{est} = 1.0E-07 -

Results

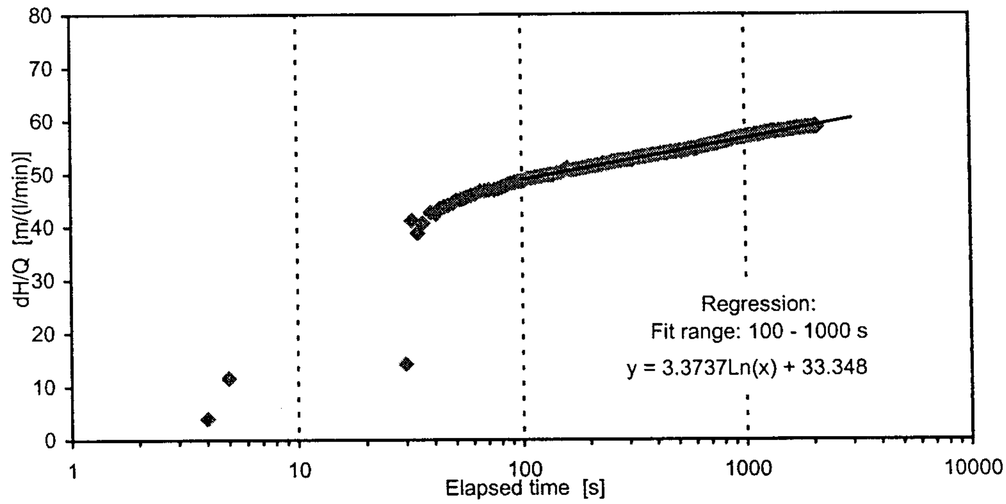
T = 4.5E-06 m^2/s
K = 4.5E-06 m/s
sf = 8.4 -
R_i = 437.0 m
u = 8.0E-07 -

True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B16a: KI0023B Interval 21 (111.2 - 111.7 meter depth)	RG	1179	16.3.98	c21.xls



True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B16b: KI0023B Interval 21 (111.2 - 111.7 meter depth)	RG/JA	1179	8.6.98	hw21-JA.xls

HW Phase Semi-log analysis:



Input Values

dP = 110.50 kPa
q = 0.19 l/min
m = 7.75774 /LZ
t_o = 5.E-05 Sek
L = 0.50 m
r_w= 0.038 m
S_{est} = 1.0E-07 -

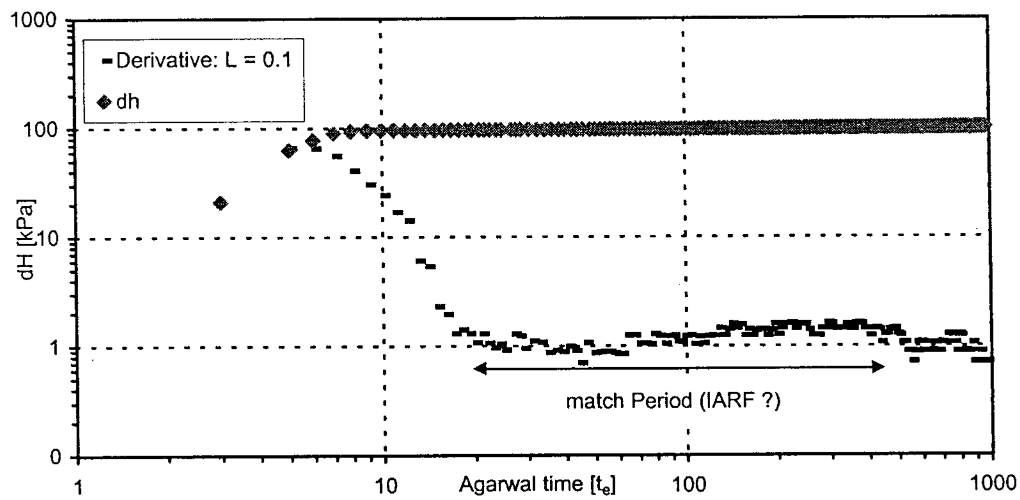
Results transient

T = 3.9E-07 m^2/s
K = 7.9E-07 m/s
sf= 0.6

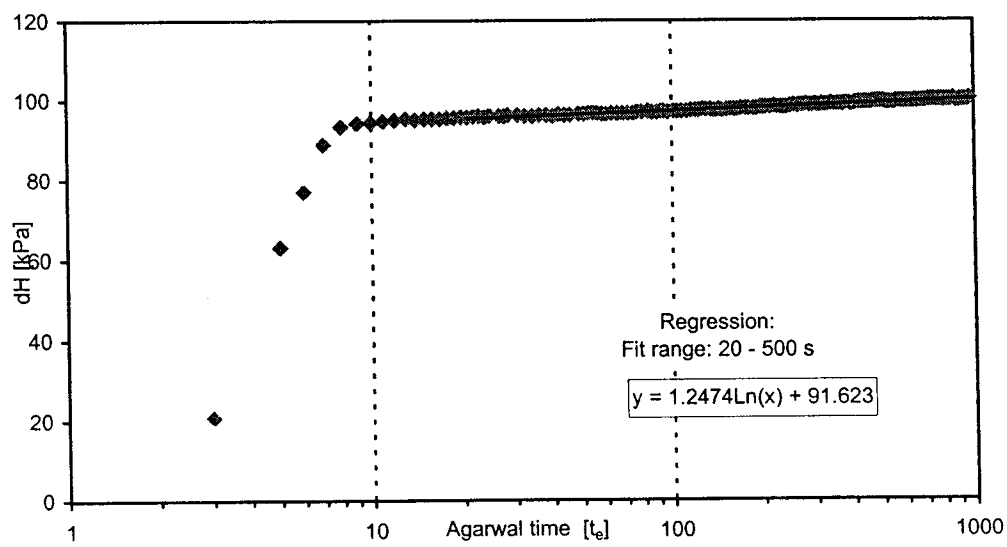
steady state

T = 3.6E-07 m^2/s
K = 7.3E-07 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



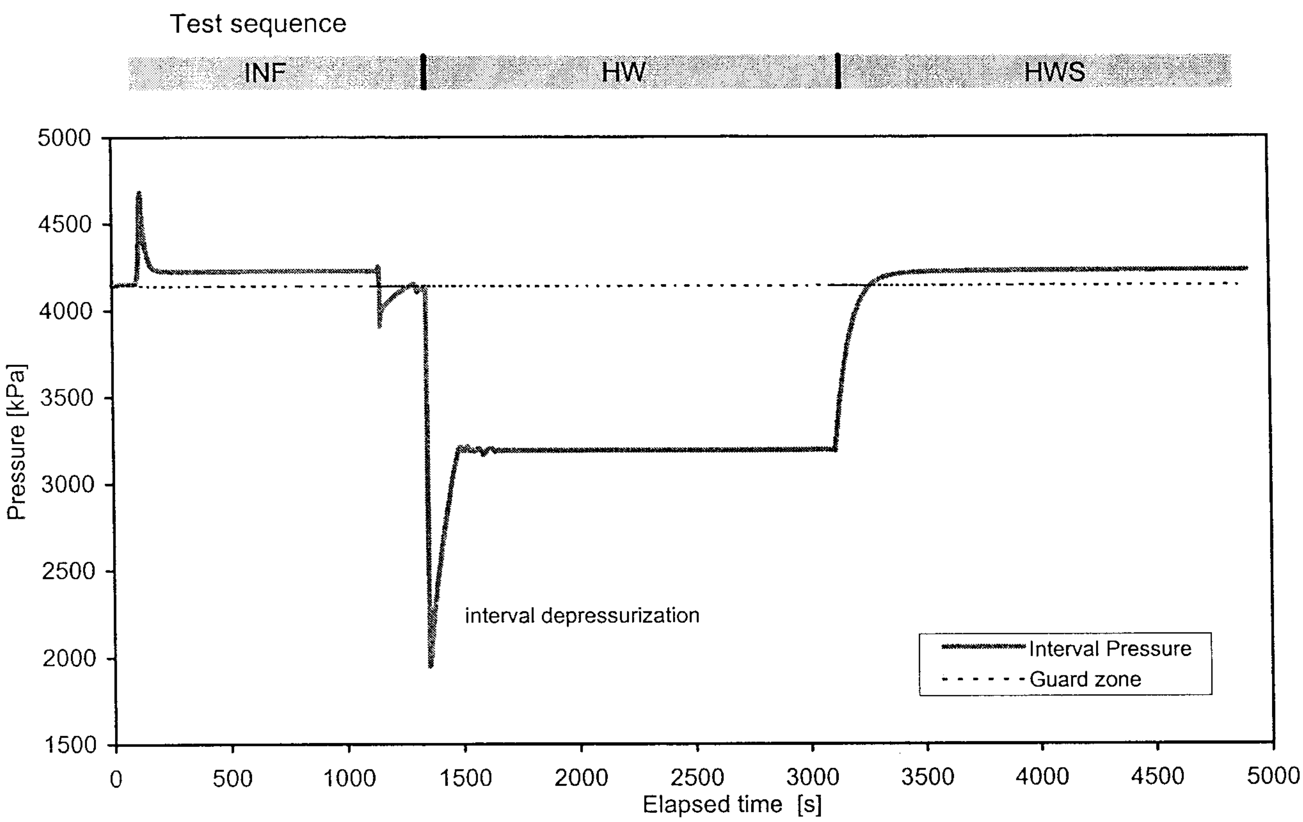
Input Values

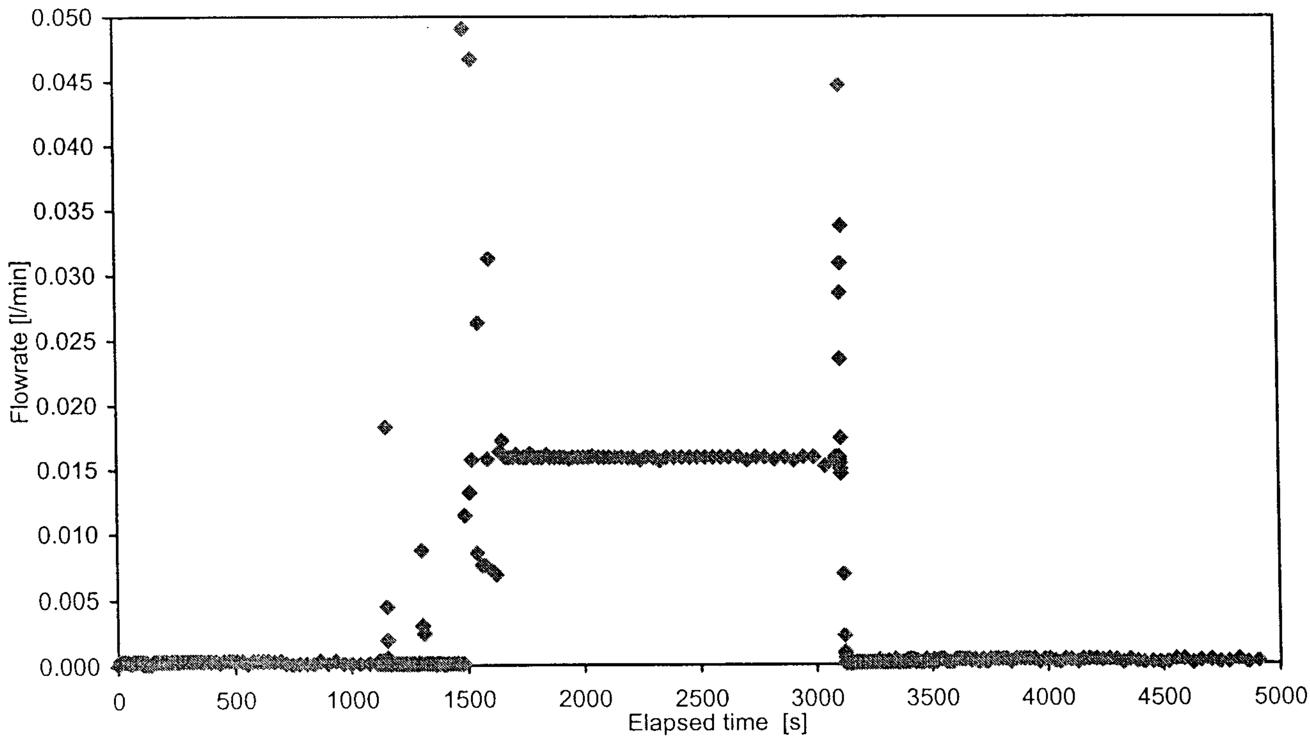
m = 2.85448 kPa/LZ
t_o = 8.E-33 Sek
L = 0.50 m
Q_{end} = 0.19 l/min
r_w= 0.038 m
t_p = 2088 Sek
S_{est} = 1.0E-07 -

Results

T = 2.0E-06 m^2/s
K = 4.0E-06 m/s
sf = 34.4 -
R_i = 305.9 m
u = 9.1E-07 -

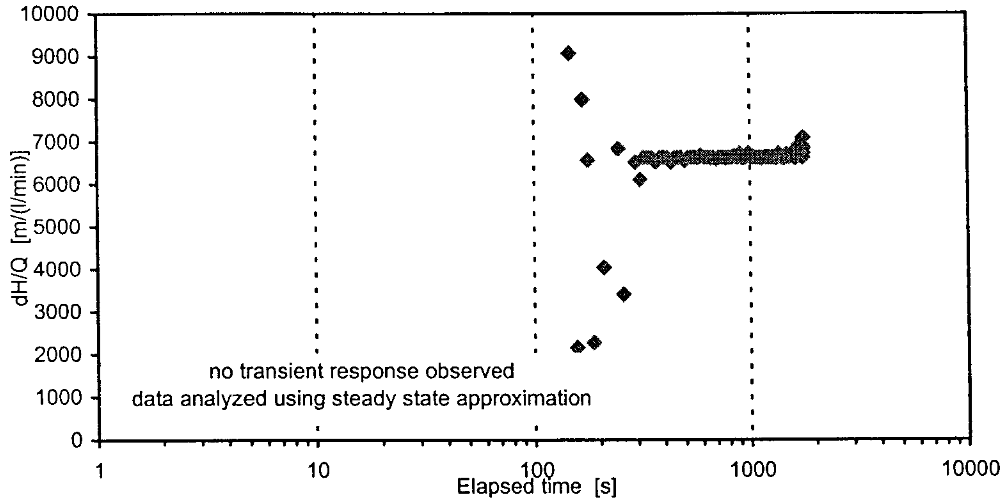
True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B17a: KI0023B Interval 22 (111.7 - 112.2 meter depth)	RG	1179	16.3.98	c22.xls





True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B17b: KI0023B Interval 22 (111.7 - 112.2 meter depth)	RG/JA	1179	8.6.98	hw22-JA.xls

HW Phase Semi-log analysis:



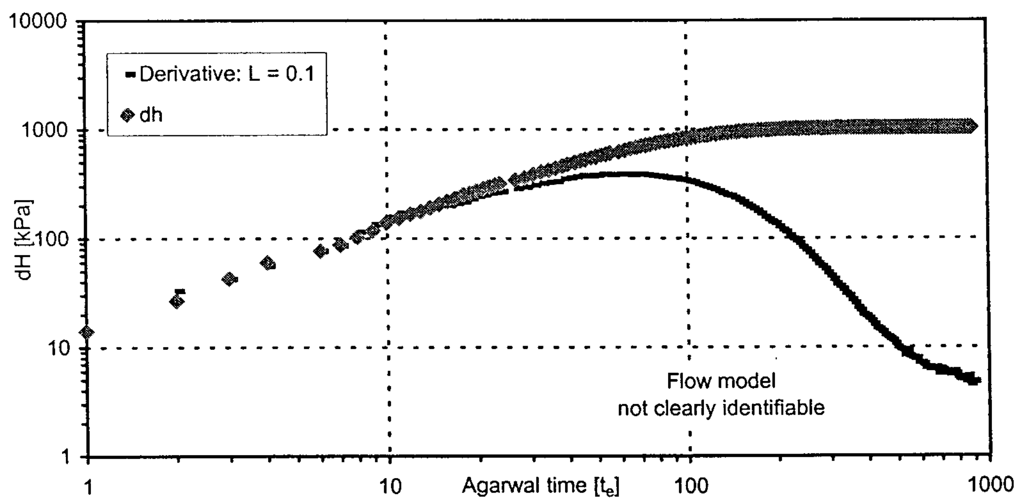
Input Values

dP = 1035 kPa
q = 0.015 l/min
L = 0.50 m
r_w = 0.038 m
S_{est} = 1.0E-07 -

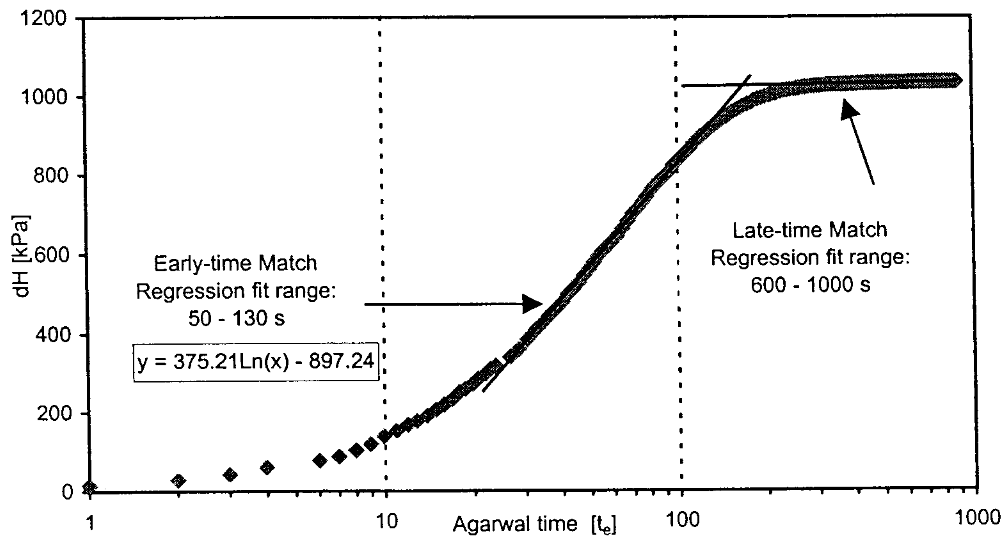
Results

T = 2.1E-09 m^2/s
K = 4.1E-09 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



Input Values

m_{early} = 863.71 kPa/LZ
$t_{o\text{-}early}$ = 1.E+01 sec
m_{late} = 11.0079 kPa/LZ
$t_{o\text{-}late}$ = 8.E-92 sec
L = 1.00 m
Q_{end} = 0.015 l/min
r_w = 0.038 m
t_p = 1765 sec
S_{est} = 1.0E-07 -

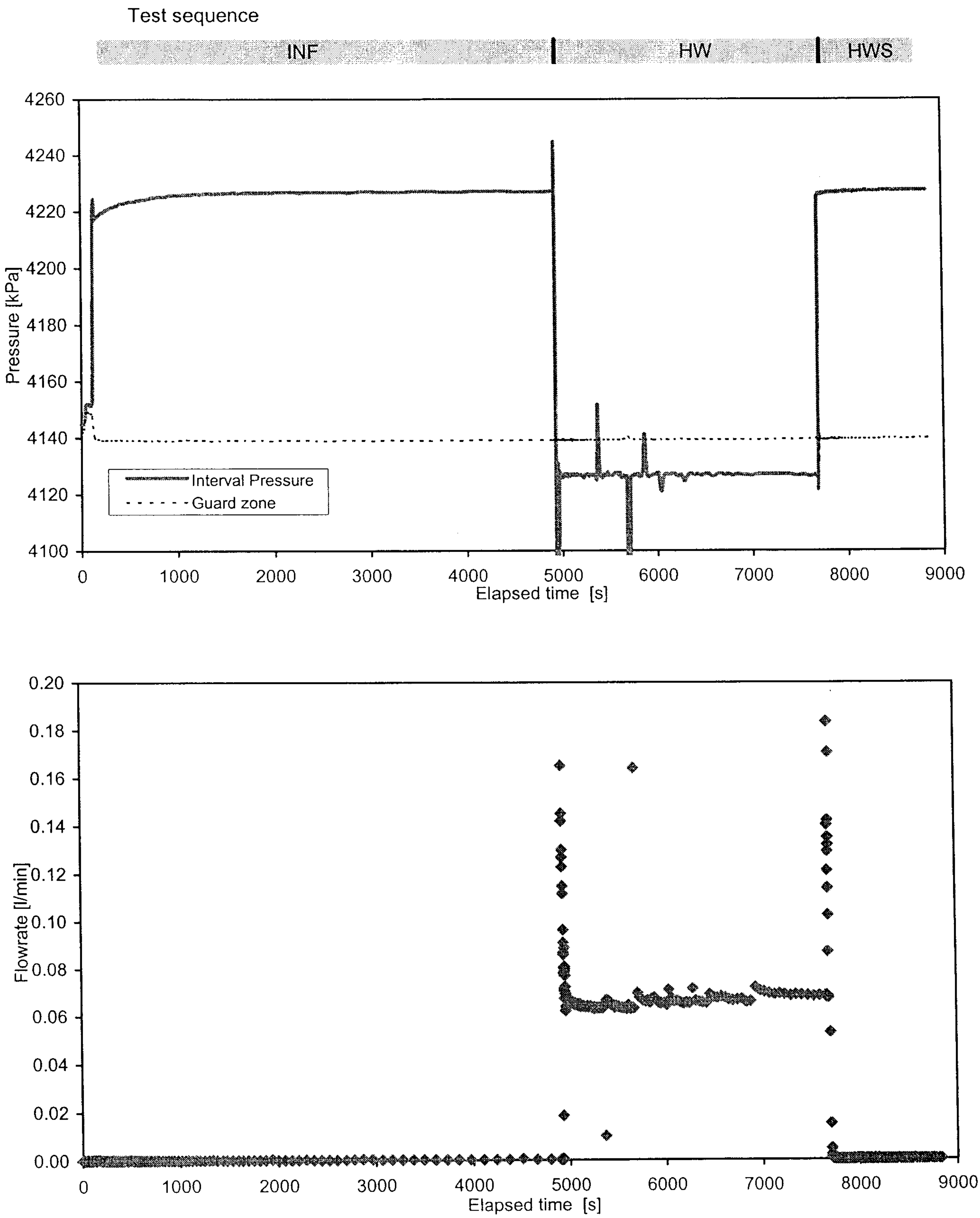
Early-Time Match

T = 5.2E-10 m^2/s
K = 5.2E-10 m/s
sf = -2.2 -
u = 1.E-03 -

Late-Time Match

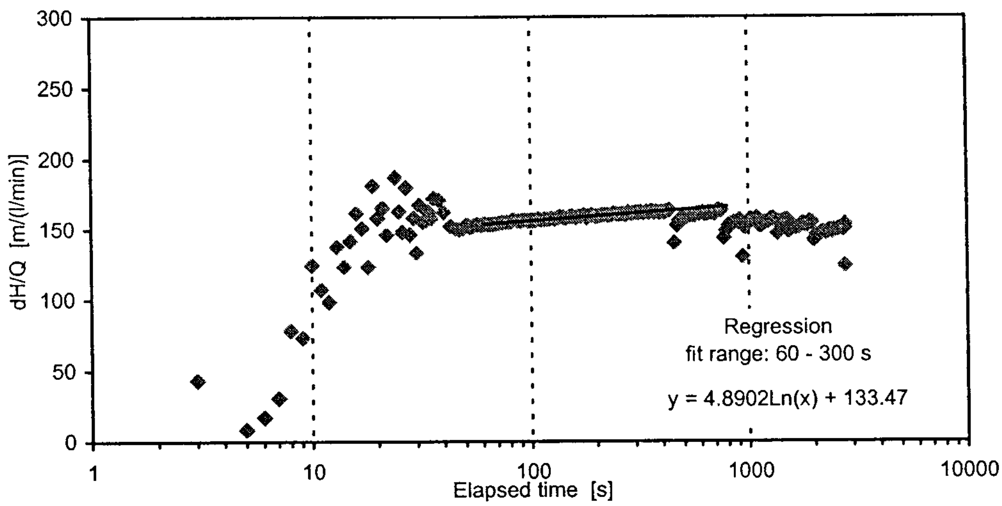
T = 4.1E-08 m^2/s
K = 4.1E-08 m/s
sf = 101.6 -
R_i = 40.2 m
u = 1.E-06 -

True Block Scale Experiment:	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B18a: KI0023B Interval 23 (112.2 - 112.7 meter depth)	RG	1179	16.3.98	c23.xls



True Block Scale Experiment	SOL EXPERTS AG			
Selective Flow and Pressure Build-up Tests	Visum:	Proj. #	Date	Filename
Figure B18b: KI0023B Interval 23 (112.2 - 112.7 meter depth)	RG/JA	1179	8.6.98	hw23-JA.xls

HW Phase Semi-log analysis:

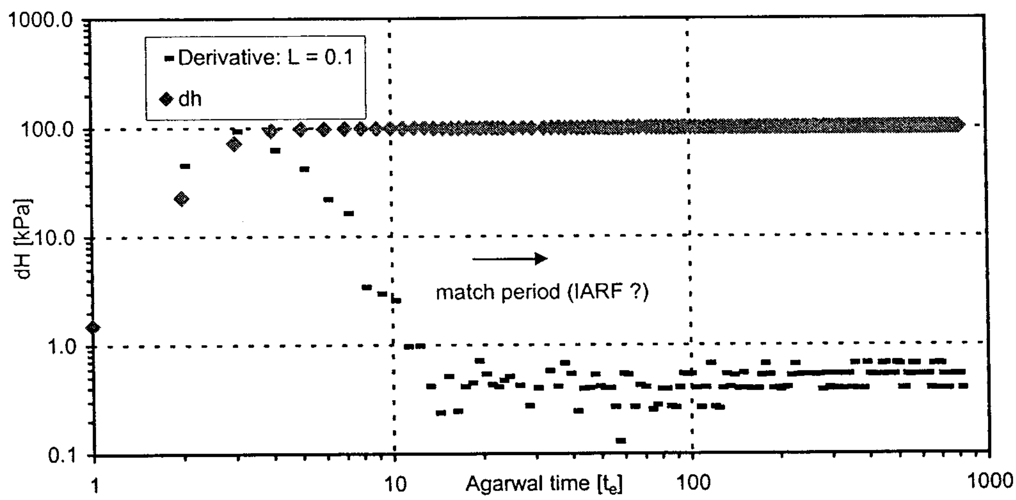


Input Values
dP = 100.50 kPa
q = 0.068 l/min
m = 11.2568 /LZ
t_o = 1.E-12 Sec
L = 0.50 m
r_w= 0.038 m
S_{est} = 1.0E-07 -

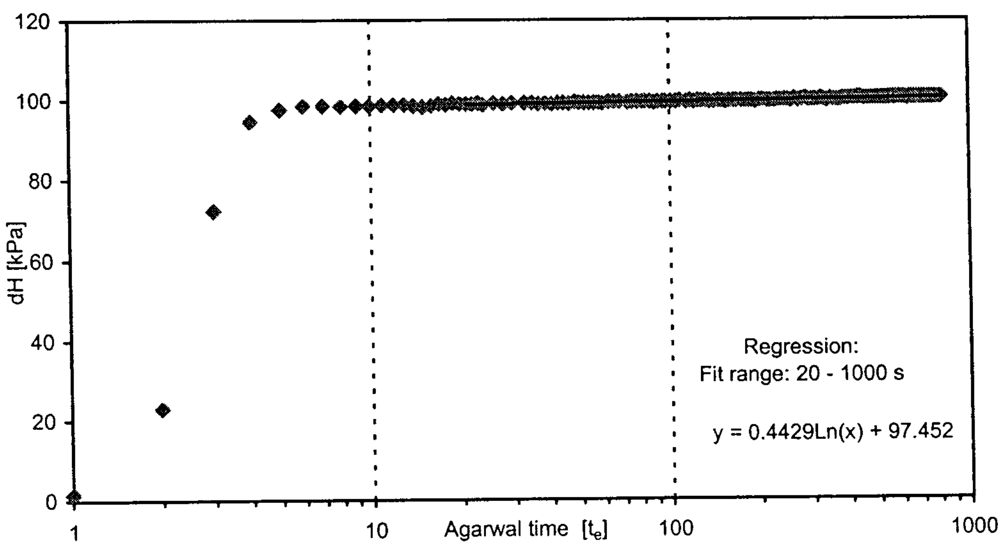
Results
transient
T = 2.7E-07 m^2/s
K = 5.4E-07 m/s
sf= 9.5 -

steady state
T = 1.4E-07 m^2/s
K = 2.7E-07 m/s

HWS Phase : Log-Log Diagnostic Plot



HWS Phase Semi-log analysis:



Input Values
m = 1.01956 kPa/LZ
t_o = 3.E-96 Sek
L = 0.50 m
Q_{end} = 0.068 l/min
r_w= 0.038 m
t_p = 2762 Sek
S_{est} = 1.0E-07 -

Results
T = 2.0E-06 m^2/s
K = 4.0E-06 m/s
sf = 107.4 -
R_i = 352.2 m
u = 9.0E-07 -