HALLIBURTON

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Large Scale Polymer Shear Degradation Test Post Job Report

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Content

Executive summary

A large scale polymer degradation test was this autumn successfully performed by Halliburton at the IRIS test facilities in Stavanger. The test was part of research on IOR within the National IOR research Centre of Norway.

Polymer flooding is one of the more promising EOR methods. The most frequently used EOR polymers are the high molecular weight HPAM based polymers which however are known to be sensitive to shear degradation. It is therefore critical to be able to quantify the extent of degradation these polymers may undergo, under realistic conditions. It is also highly desirable to investigate any mitigation actions that may potentially minimize degradation.

The test program included two different polymers; high molecular weight HPAM polymer (FP 3630 supplied by SNF) which is regarded as the reference EOR polymer and a low molecular weight AMPS co-polymer (AN125, also supplied by SNF). AN125 was considered, from previous work, to be less shear sensitive. The polymers were tested in following four different choke valves:

1. Halliburton Standard adjustable choke valve, Type CH2M choke. (Choke 1)
2. Matek choke valve type 3254-7 (Choke 2)
3. SNF Linear pressure reducer, LPR, (Choke 3)

Tests were also performed on Halliburton Fixed choke valve - Orifice with fixed ID of 20/64" (Choke 4) and 24/64" (Choke 5). Prior to testing the general understanding was that the SNF Linear pressure reducer, LPR, which consists of a long coiled tube would be superior to the other choke types. Further on, it was assumed that the low molecular weight AN125 polymer would behave better than the high molecular weight 3630polymer.

As expected, test results with Choke 3 and polymer 3630 at 40 bar pressure drop over 400-600 meter showed viscosity loss of only 6.6%. The viscosity loss from a corresponding test with Choke 1 was 76%.

The Matek choke (Choke 2) was found to perform slightly worse than Choke type 1. The Matek choke degraded the 1000 ppm 3630 polymer 82% while Choke 1 degraded the same polymer to 76%. For 1000 ppm AN125 and Matek choke, the degradation was 73%. The corresponding test with Choke 1 resulted in 69% degradation.

The effect of the polymer concentration on polymer degradation was evident. In Choke 1, the 3630 polymer was degraded by 76% at concentration of 1000 ppm and by 66% at 2000 ppm. The AN125 polymer was degraded 69% and 64%, respectively. However, when increasing the 3630 polymer concentration to 10000 ppm, the polymer degradation was reduced to less than 10%.

Tests, with multiple choke valves rigged in series to evaluate the effect of stepwise choking revealed that multiple small step choking is better than a single large step choking. In one test using three serially mounted chokes at differential pressure of 15, 15 and 25 bar resulted in similar degradation as in a single choke test with 55 bar pressure drop. However, when the differential pressures were lowered to 5, 5, and 5 bar for each choke, the total degradation was significantly better than the degradation from a single choke test with 15 bar pressure drop. We conclude that standard choke valves at differential pressure up to 50 bar will severely degrade synthetic polymers. This test addressed the following three possible methods to reduce the polymer degradation:

- Reduce the pressure gradient by increasing the choke length, e.g. LPR choke.
- Choke polymer concentrate and brine separately and perform dilution of polymer after chokes.
- Use of multiple chokes with each choke set at sufficiently lower differential pressure that is below critical level.

In addition, the knowledge acquired from this test may contribute to improvements of commercial choke valves.

Polymer samples prepared at large scale and laboratory scale revealed same rheological properties. Some of the large scale mixing tests however suffered from poor water quality, which revealed poor filterability in the filtration tests. With acceptable water quality, the filterability of the two polymers were excellent and similar to the laboratory scale filterability tests. For determination of polymer viscosity and polymer degradation, the poor water quality was not critical, but will be critical in porous media flood experiments (which is planned in a later phase of this project).

Filtration rate or screen factor was found to depend strongly on the viscosity and thereby on the degradation. Upscaled to field conditions this means that some degradation will improve the injectivity.

For all polymer samples pH was measured and was found to be relatively constant.

Background

The main purpose of the large scale yard test was to determine the potential damage to polymers when pumped through a choke valve. Therefore, a more specific large scale test was planned and carried out using two variants of polyacrylamide polymers and four commercially available choke valves, with the objective of determining polymer degradation at constant rates and different pressure drops.

Several polymer systems are in use by the oil and gas industry for enhanced oil recovery purpose. In general, the polymer systems are prepared by mixing polymer powder either in sea water or fresh water to higher concentration polymeric fluid. Then the concentrate is injected on the fly into the water injection line and diluted to the desired final concentration. Finally the diluted polymer solution is injected into the formation.

One major challenge in using synthetic polymer systems, particularly in multiple subsea wells is the risk of shear degradation caused by pumps, lines, valves and chokes. Polymer degradation lowers the polymer viscosity of the injected fluid and this obviously reduce the potential to enhance the oil recovery. In order to avoid shear degradation, suppliers have made some recommendations on the selection of pumping equipment, size and geometry of flow lines etc. Although suppliers do provide polymer specification and some general guide lines on how to avoid degradation, there are still some important questions to be answered.

Injecting polymers in multiple wells, in a subsea environment requires the use of chokes on each well, in order to control pressure and injection rates. However, some chemical suppliers categorically reject the use of choke valves at any point between high pressure pumps and the formation. This means, unless a separate, dedicated polymer injection line is constructed for each well, polymer based Improved Oil Recovery cannot be realized in multiple subsea wells.

Although several researchers have been engaged in studying polymer degradation at small and medium scale, the only large scale polymer shear test we are aware of is a test performed at IRIS facility by Statoil, Halliburton, and IRIS in 2008. This test was performed by circulating a so called Linked Polymer System (LPS), a polyacrylamide polymer solution with a cross linker, via a choke valve, at different rates and varying choke closure percentage. Samples were taken both before and after the choke and a filtration tests as well as rheological measurement were performed. The observation from this test gave no significant reduction in viscosity takes place before choke was set at 90 % closed position. However, since the shear test was only one small part of the large scale testing, it lacked depth and focus to produce conclusive and useful data.

The national IOR Research Center of Norway decided to plan and implement a realistic large scale test to determine the degree of polymer degradation as a result of mechanical shear.

The operation required the contribution from Halliburton, IRIS, Polymer suppliers (SNF), and Choke supplier (Matek).

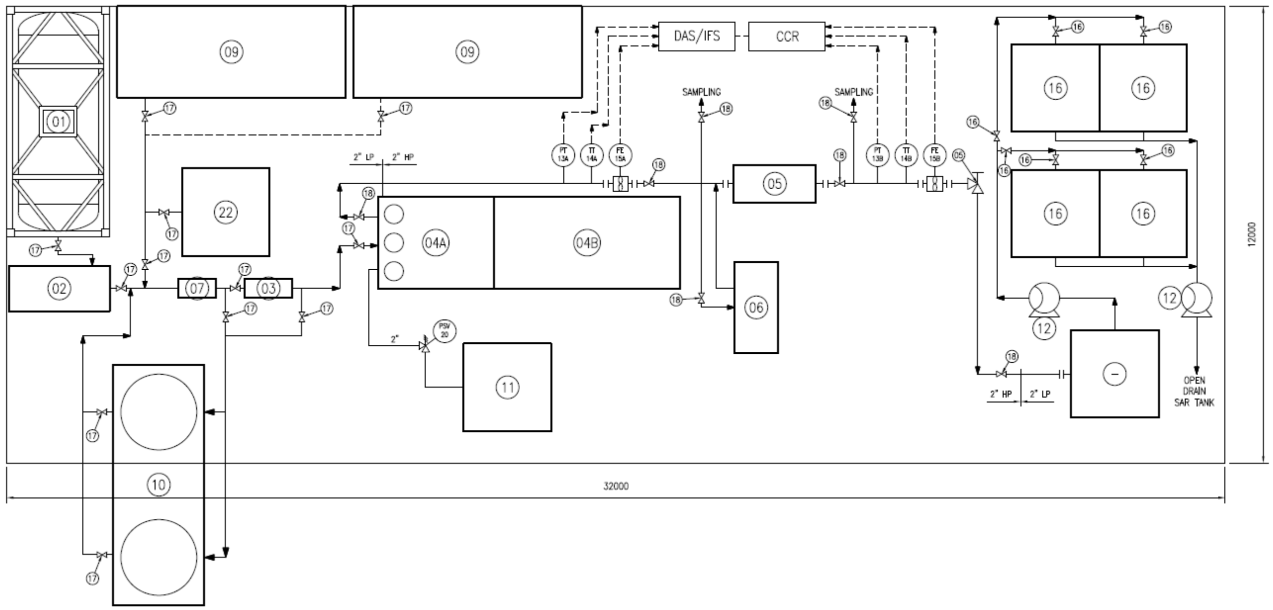
Preparation & Test set up

Preparation

An operational plan was developed and circulated to all members of the technical committee, long before operation start. This operation plan was revised several times based on input from all participants. A pre operation workshop was held on 25-08-15 at Halliburton's Tananger facility in order to go through the operation plan and make necessary improvements. The workshop was attended by all project participants. A separate Procedure for QC and laboratory testing was developed by IRIS and SNF. Finally the operation plan and the QC procedure were distributed to all active participants as well as to the technical committee of the IOR center.

Events prior to testing:

1) 24.09.15 Halliburton started to mobilize equipment to test site
2) 28.09.15. A detail pre-job operational procedure and safety review took place at IRIS with IRIS research team, IRIS site rep and all key operational personnel from Halliburton. Several other smaller meetings also took place while the operation was going.
3) 01.10.15 SNF delivered polymer
4) 05.10.15 Rig up was completed according to the rig up drawing shown in Figure 1.
5) 05.10.15 Pressure testing completed
6) 06.10.15. The water source was the firefighting system at the IRIS facility. Apparently, the system has not been used for a long time and a lot of rust has been accumulated in the pipe line. The water was far from clean and very brownish. Therefore, the water was allowed to flow for a long time, until it was visually clean. At this point a laboratory test, using Iron kit was performed to determine the iron content. The iron content was well below 10 ppm hence acceptable.
7) 06.10.15 Based on the iron content measurement the use of Citric acid to clean lines was abandoned.
8) 06.10.15 Based on discussion with SNF, a decision was taken to make changes to pumping schedule. The volume of the final solution to be pumped for each stage was increased thereby increasing the pumping time. 7.5 min pumping time was necessary for the online viscometer to measure the viscosity. The increase in volume for each stage did not increase the total polymer waste volume as Matek communicated that one choke valve with one insert will be delivered instead of two exchangeable inserts.
9) 07.10.15. Matek delivered only one choke with one insert. The size of the valve was not according to plan. Therefore the pumping rate for the specific test had to be reduced.
10) 07.10.15 Operational procedure was updated and distributed accommodating the changes.



EQUIPMENT LIST			
ITEM	DESCRIPTION	INLET/OUTLET	SIZE (L x W x H)
01	20m³ WATER TANK	4" FM/4" FM	6060x2690x3030
02	WATER PUMP	4"/4"	2650x1200x2250
03	INTERNAL MIXER		
04A	HT-400 PUMP	4"/2"-1502	3050x2400x2650
04B	POWER PACK		4900x2400x2700
05	SNF CHOKE 30m³/h-50BAR	2"-600# RF x 2	
06	ONLINE VISCOMETER	1/2"-1500# RF x 2	
07	SKRU PUMP POSSITIVE DISPLACEMENT		
08			
09	POLYMER MOTHER SOLUTION TANK 21m³	3" BSP	6000x2400
10	2 x 3 BBL BATCH BLENDER		6320x2400x2700
11	SLOP TANK 4.5m³		
12	SANDPIPER PUMP		
13	PRESSURE TRANSMITTER 2"-1502 (2ea)	2"-1502	
14	TEMPERATURE TRANSMITTER (2ea)		
15	FLOWMETER (2ea)		
16	2" LP VALVE (10ea & 6ea)		
17	4" LP VALVE (4ea)		
18	2" HP LO-TORQUE VALVE		
19	X-OVER HP/LP		
20	PRV		
21	x-over 4"-206 x 2" CAMLOCK		
22	CHEMICAL TANK		

EL/WATER/AIR/DIV.		
ITEM	DESCRIPTION	
05	SNF CHOKE 30m³/h-50BAR	220AC, SINGLE PHASE 50Hz, 0,5kw
06	ONLINE VISCOMETER	220AC, SINGLE PHASE 50Hz, 0,5kw
07	SKRU PUMP POSSITIVE DISPLACEMENT	

SCALE 1 : 75 AT A1

TITLE HALLIBURTON

RIG-UP DRAWING
POLYMER SHEAR TEST

CAD FILE CODE:

SKETCH No. HNI-21-SKETCH-001

REV. 5

Figure 1 – Large-scale Test- equipment Rig Up

Experimental Test Set Up

Test fluids
The following fluids were made available for the test

1) Ulandhaug Tap water from supplied by IRIS
2) Citric acid
3) Polyacrylamide polymer requirement from SNF
    a. 22 m3 of 15 000ppm standard polymer (FP 3630).
    b. 22 m3 of 15 000ppm enhanced polymer (AN125).
    c. Expected waste at the end of project 163 m3

Equipment
The following essential equipment was rigged up at IRIS facility for the test

1) HP pump
2) Centrifugal pump (for water supply)
3) Low pressure Positive displacement pump (for polymer feed)
4) Positive displacement pump (progressive cavity pump)
5) Polymer mixing equipment
6) Choke valves from different suppliers
7) LP hoses, HP lines, manifold, etc.
8) Data logging cabin
9) Pressure gauges, flow meters, temp gauges.
10) Storage Tanks
11) Slope tanks
12) SNF supplied online viscometer
13) SNF supplied sampling devices, one for before the choke and one for after
14) Matek supplied choke valve
15) Halliburton supplied choke valve
16) SNF supplied LPV choke
17) Halliburton supplied fixed orifice chokes

For Major equipment, the equipment rig up is shown in Figures 1

Actual Large Scale Test

Quality control

Prior to the large scale test a laboratory test was performed on samples taken from 15000 ppm mother solutions supplied to the project. The mother solutions were diluted to 1000, 2000 and 10000 ppm and viscosity was compared with solutions made from powder in the laboratory. Further, all tests were repeated on samples collected from storage tanks as well as sampling bottles installed before and after each choke valve, during the shear degradation test. The laboratory measurements were comprised of physical observation, pH control, viscosity measurement and filter ratio tests.

Mixing

The polymer solution was prepared first by preparing 0.5 % NaCl brine in the compartment 1 of the Mix Tank C1 (Figure 3). The required amount of brine was thereafter transferred to compartment 2 of Mix tank C1 (Figure 3) via an internal mixer (Figure 2) while the exact volume of the mother solution was injected before the internal mixer. The internal mixer was designed to assure a uniform polymer - water mix. The agitator in the compartment 2 of Mix tank C1 was kept running slowly (maximum tip velocity of 3 m/s), until solution was uniformly mixed. The formulation of each polymer solution is provided in Table 1.

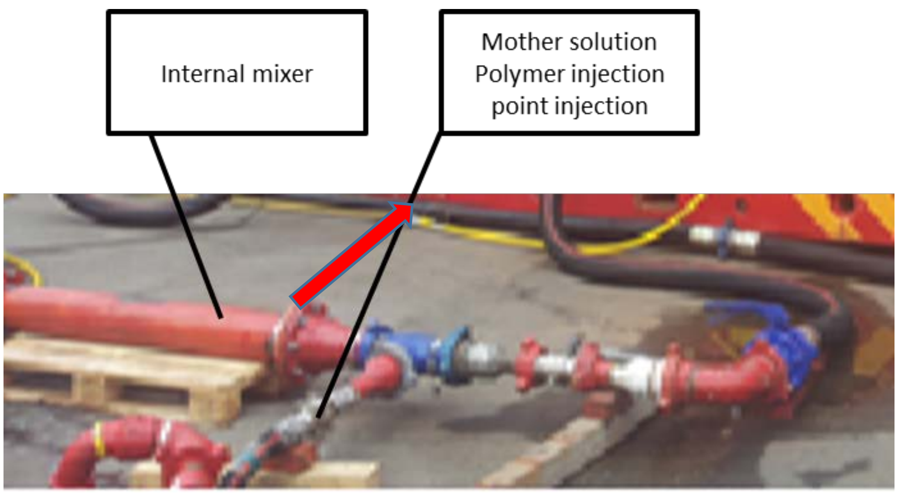


Figure 2 – Mother solution injection point and Internal mixer

Figure 3 – Mix Tank C1

The Mother solution of the polymer was stored in Tank B1 and B2. These tanks were connected to a low shear displacement pump.

Table 1 Polymer mixing - volumes and concentrations.

Standard Polymer

Mother solution (ppm)	Final solution (ppm)	Volume of Final solution required for one choke in combination with one type of polymer (liter)	Volume ratio mother solution/final solution (m3/m3)	Volume ratio 0,5 % NaCl brine/final solution (m3/m3)	Volume of 0,5 % NaCl brine required (liter)	Volume of Mother solution required (liter)	Pumping rate of 0,5 % NaCl brine During mixing (liter/min)	Pumping rate of Mother solution during mixing (liter/min)	Nr of chokes	Type of polymers	Total Consumption of 15000 ppm polymer solution (m3)
15 000,00	1 000,00	12 000,00	0,07	0,93	11200,00	800,00	700,00	50,00	3	1	2,40
15 000,00	2 000,00	12 000,00	0,13	0,87	10400,00	1600,00	650,00	100,00	3	1	4,80
15 000,00	10 000,00	12 000,00	0,67	0,33	4000,00	8000,00	150,00	300,00	1	1	8,00
Sum		36 000,00									**15,20**

Enhanced Polymer

Mother solution (ppm)	Final solution (ppm)	Volume of Final solution required for one choke in combination with one type of polymer (liter)	Volume ratio mother solution/final solution (m3/m3)	Volume ratio 0,5 % NaCl brine/final solution (m3/m3)	Volume of 0,5 % NaCl brine required (liter)	Volume of Mother solution required (liter)	Pumping rate of 0,5 % NaCl brine During mixing (liter/min)	Pumping rate of Mother solution during mixing (liter/min)	Nr of chokes	Type of polymers	Total Consumption of 15000 ppm polymer solution (m3)	Total vol of final solution (m3)
15 000,00	1 000,00	12 000,00	0,07	0,93	11200,000	800,000	700,000	50,00	3	1	2,40	36
15 000,00	2 000,00	12 000,00	0,13	0,87	10400,000	1600,000	650,000	100,00	3	1	4,80	36
15 000,00	10 000,00	0,00	0,67	0,33	0,000	0,000			0	0	0,00	0
Sum		24 000,00									**7,20**	**72,00**

Figure 4 shows viscosity of the received 3630 sample diluted to 1000, 2000 and 10000 ppm and compared with polymer viscosity on samples prepared and diluted at laboratory scale.

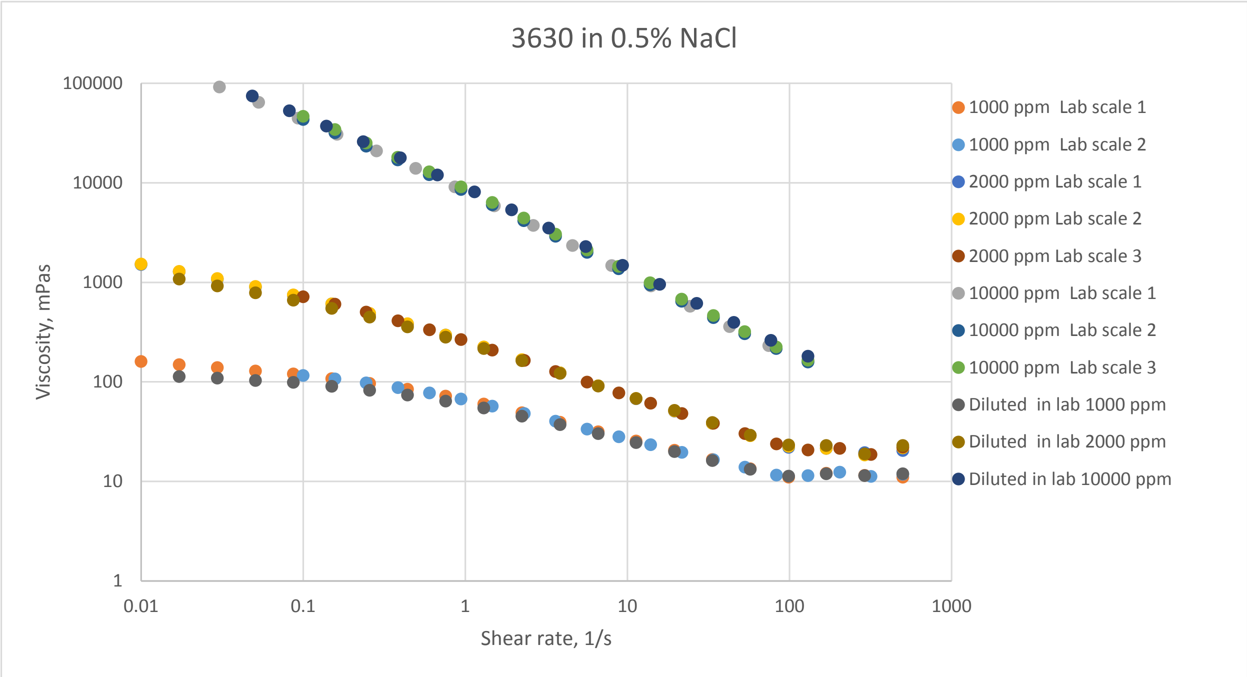


Figure 4 – Viscosity of 3630 polymer measured on Anton Paar Physica MCR 301 Rheometer at 20°C.

As can be seen from Figure 4, the large scale and lab scale mixing and dilution provided samples with the same rheological properties.

Similar observation were made for the AN 125 polymer, see Figure 5. It should however be noted that the diluted tank sample revealed somewhat higher viscosity than the samples prepared in the laboratory.

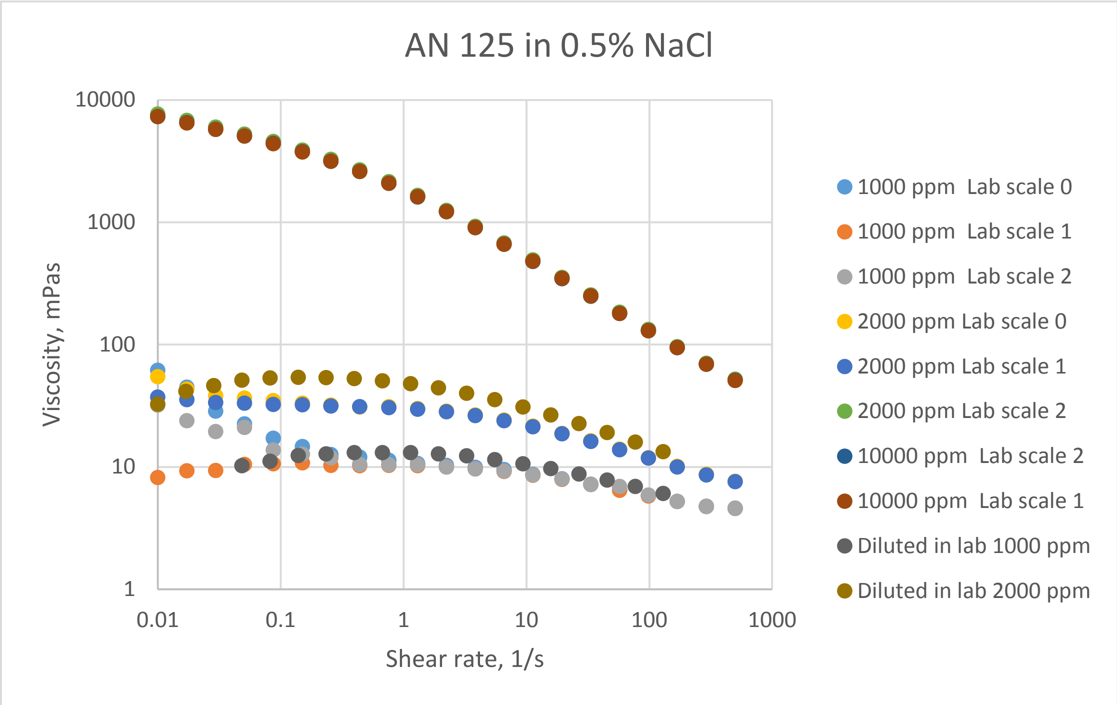


Figure 5 – Viscosity of AN125 polymer measured on Anton Paar Physica MCR 301 Rheometer at 20°C.

Polymer shear test

After the final polymer solution was mixed according to specification and found to be satisfactory, the next step was to perform the polymer shear test.

This time, the final solution stored in Mix tank C1, was delivered to the HP pump using the positive displacement pump (Figure 6) and then pumped with a Triplex High Pressure pump (Figure 7) through the choke valve into a holding tank. Pumping rate, pressure drop across the choke valve and temperature was recorded continuously. In addition, an online viscometer from SNF was installed. This equipment was disconnected after the first shear test due to malfunctioning. However, the results from this test proved that the online viscometer was able to reproduce the degradation derived from bulk rheology measurements.

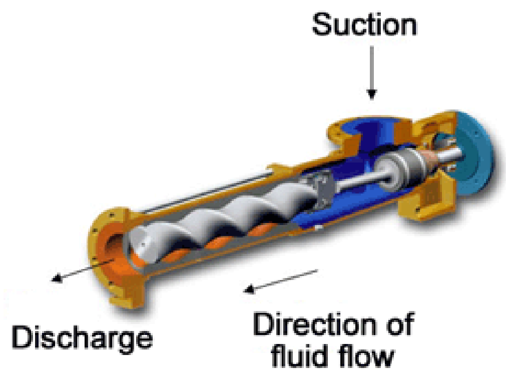


Figure 6 – Positive displacement polymer feed pump

Figure 7 – High pressure pump

This polymer shear degradation process was repeated several times with different types of choke valves at different pressure drops. Although the pumping rates and the pressure drops provided in Table 2 were to be used for all choke valves, pumping rate had to be reduced significantly for the choke valve provided by Matek. As mentioned earlier, the specific valve was found not to be appropriate for 400 lpm pumping rate. For SNF choke valve, rate was increased up to 600 lpm in order to reach the desired pressure drop. Otherwise, the differential pressure in Table 2 were applied. The actual differential pressures were calculated from the pressure gauge measurements and are reported separately for each of the tests.

The pressure data was recorded continuously via pressure transducers installed before and after the choke valves. The flow rates were also recorded continuously. According to specific request made by Matek, a backpressure of 50 bar was applied on the Choke 2. The same backpressure was applied for the standard choke.

Prior to the each polymer shear test, test was performed using only water. This test was designed to adjust the choke opening for the desired pressure drop, ahead of the actual test.

Table 2 – Polymer shear test plan for each specific polymer solution/choke type combinations

Pumping time	7,5	min at each rate	
Test nr	**Pumping Rate (lpm)**	**Pressure drop across choke (Bar)**	**Volume (liter)**
1	400,00	10,00	3 000,00
2	400,00	20,00	3 000,00
3	400,00	30,00	3 000,00
4	400,00	50,00	3 000,00
SUM			**12 000,00**

Sampling

Samples were collected both before and after the choke valve. A sampling device from SNF was used according to instructions by SNF, see Figure 8. In this procedure:
Valve 1, 2 and 3 were opened slowly to full-open position. Next, Valve 4 was first opened sufficiently to expel gas. Then Valve 4 was opened more to allow a slow and steady fluid stream for some time in order to purge all flow lines and fittings. Finally, sample was collected according to the attached Sampling procedure QC-PR-140-01 and delivered to the IRIS laboratory for analysis. Further, viscosity was measured and polymer degradation across the choke valve was reported.

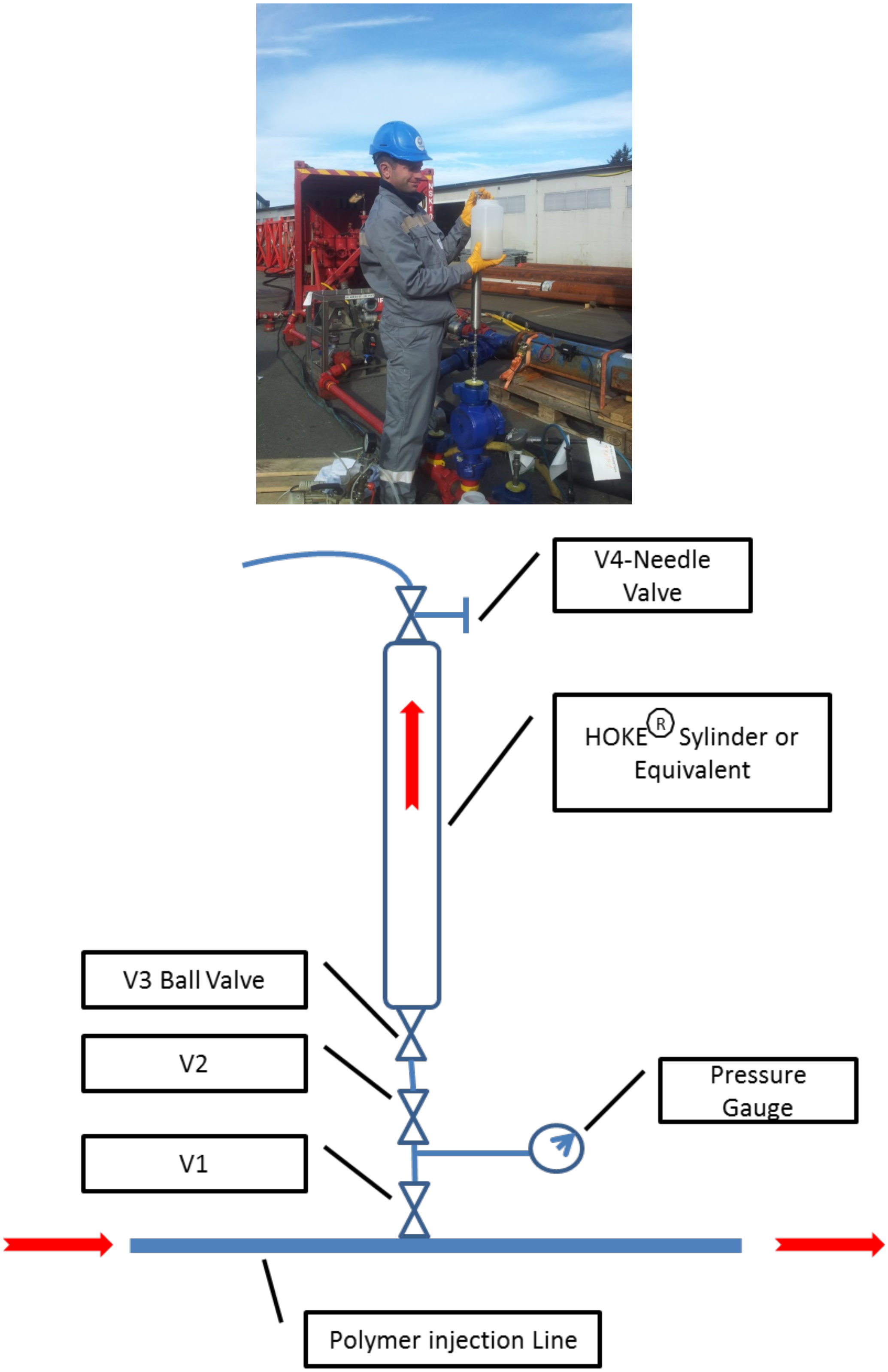


Figure 8 – Sampling apparatus from SNF.

Results

Table 3 below shows the test matrix.

Table 3 – Test Matrix.

Test	Test conditions
1	1 000ppm 3630 with Halliburton standard adjustable choke (Choke 1)
2	2 000ppm 3630 with Halliburton standard adjustable choke (Choke 1)
3	10 000ppm 3630 with Halliburton standard adjustable choke (Choke 1)
4	1 000 ppm AN125 with Halliburton standard adjustable choke (Choke 1)
5	2 000 ppm AN125with Halliburton standard adjustable choke (Choke 1)
6	1 000 ppm AN125with Matek choke (Choke 2)
7	2 000 ppm AN125with Matek choke (Choke 2)
8	1 000 ppm 3630 with Matek choke (Choke 2)
9	1 000 ppm 3630 with fixed Halliburton chokes 20/64"and 24/64"
10	1 000ppm 3630with SNF choke system (Choke 3)
11	2 000 ppm AN125 and 1 000 ppm 3630 with SNF choke system (Choke 3)
12	1 000 ppm 3630 through 3 fixed chokes (1st round)
13	1 000 ppm 3630 through 3 fixed choke (2nd round control test)

These tests are reported separately, including the following:

- Operation event log including pressure, rate and temperature plots with brief notes
- Pump chart
- Polymer sample viscosity
- Polymer degradation
- Filter ratio and screen factor

Finally, the different test results are summarized and discussed.

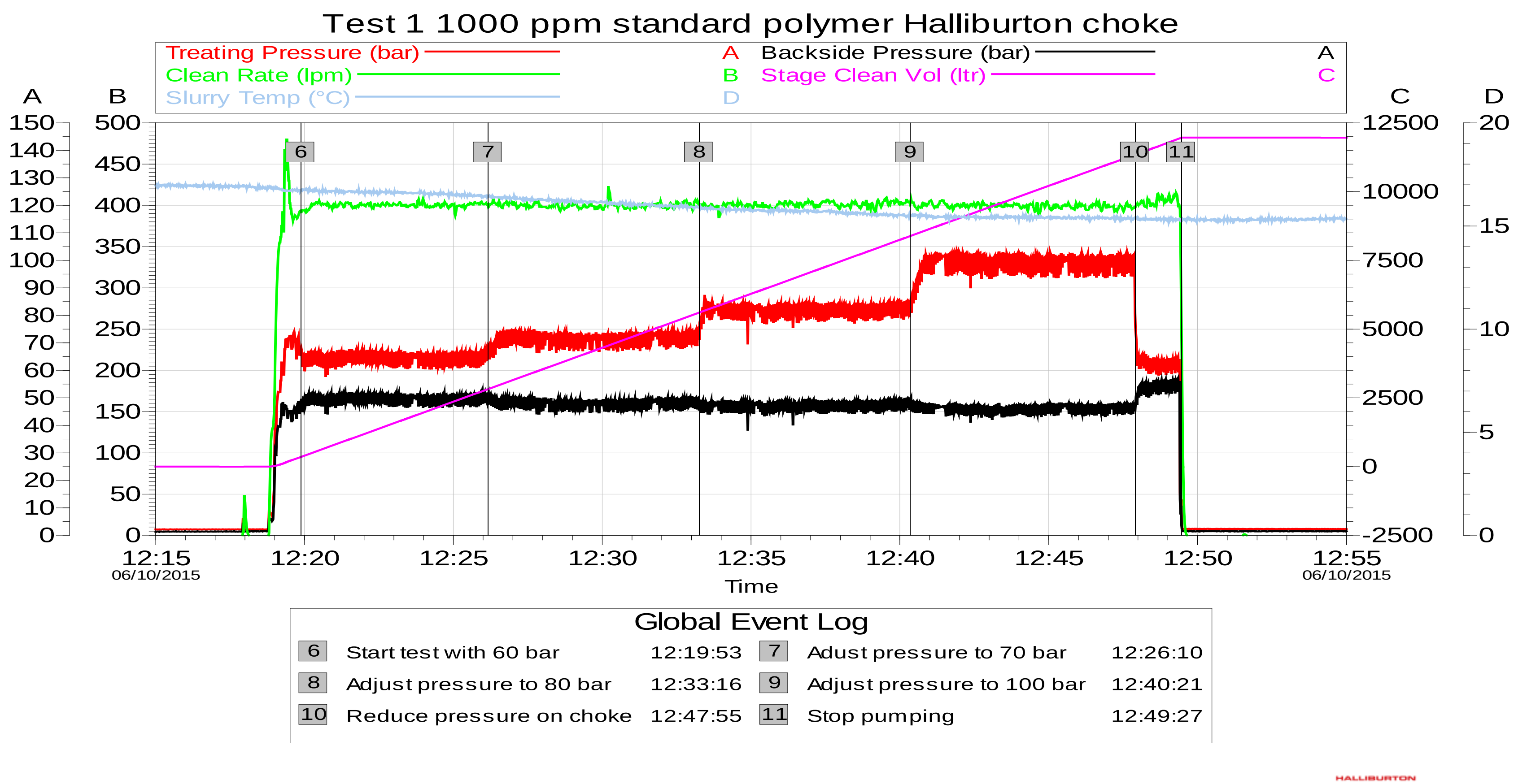
Test 1 – 1 000ppm 3630 with Halliburton standard adjustable choke (Choke 1)

Job Event Log Test 1

Start Time	06-Oct-15 10:33:55	
End Time	06-Oct-15 12:55:44	
Volume	12.211	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	06-Oct-15 10:33:53	Start Job	Starting Job	0.0	0.0	0	-
	2	10:35:07	Other	Transferring polymer to 4.5m3 tank	2.2	1.5	-1	14.4
	3	10:44:08	Other	Finish transferring polymer to 4.5m3 tank	2.1	1.5	-1	14.5
	4	10:45:00	Other	Start mixing polymer/NaCl	2.1	1.6	-1	14.5
	5	11:09:07	Other	Finish mixing	2.2	1.5	-1	14.8
1		12:16:54	Stage 1	NEXT STAGE	2.2	1.4	-1	17.0
		12:16:55	Start Averaging	Start Avg Trt 1	2.2	1.3	-1	16.9
	6	12:19:52	Other	Start test with 60 bar	68.2	48.9	394	16.7
	7	12:26:10	Other	Adjust pressure to 70 bar	68.5	51.5	402	16.4
	8	12:33:15	Other	Adjust pressure to 80 bar	73.3	46.6	397	15.9
	9	12:40:20	Other	Adjust pressure to 100 bar	82.8	47.9	402	15.5
	10	12:47:54	Other	Reduce pressure on choke	77.8	46.3	397	15.4
	11	12:49:27	Other	Stop pumping	8.4	6.8	288	15.2
		12:55:44	End Averaging	End Avg Trt 1	2.3	1.4	-1	15.4
	12	12:55:46	End Job	Ending Job	2.3	1.4	-1	15.4

Pump chart – Test 1



Polymer sample analysis – Test 1

Polymer samples were taken at the sampling points before and after choke. The viscosity of the samples are in Table 4 reported for each of the actual differential choke pressures. Viscosity was measured and the viscosity data for Test – 1 is presented and discussed below. Viscosity was measured on Anton Paar Physica MCR301 rheometer using cone and plate geometry at temperature of 20°C and as shear rate scan from 0.01 to 500 s^{-1}.

Polymer degradation is defined in two different ways, relative to tank viscosity, η_{DT}, or relative to sampling point before choke, η_{DC}, both as the viscosity difference at shear rate of 6.6 s^{-1}, i.e.,

$$\eta_{DT} = \frac{\eta_{Tank} - \eta_{after\ choke}}{\eta_{Tank} - \eta_{brine}}$$

$$\eta_{DC} = \frac{\eta_{before\ choke} - \eta_{after\ choke}}{\eta_{\eta_{before\ choke}} - \eta_{brine}}$$

Table 4 Polymer viscosity – Test 1.

	Diluted in lab	Tank	ΔP = 15 Bar Before	ΔP = 15 Bar After	ΔP = 23 Bar After	ΔP = 35 Bar After	ΔP = 53 Bar After	ΔP = 53 Bar Before
Polymer	3630	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000	1000
Choke type		1	1	1	1	1	1	1
Shear rate	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity
1/s	mPas	mPas	mPas	mPas	mPas	mPas	mPas	mPas
500	11.9	10.4	8.33	5.68	5.4	5.18	4.8	8.33
291	11.4	10.9	8	6.34	6	5.68	5.12	7.82
169	11.9	10.8	9.12	7.4	6.92	6.45	5.66	8.88
98.7	11.3	10.8	10.9	8.71	7.98	7.3	6.22	10.6
57.4	13.2	13.3	13.2	10.2	9.15	8.19	6.75	12.8
33.4	16.2	16.3	16.1	11.9	10.3	9.01	7.18	15.6
19.5	19.9	20.1	19.7	13.7	11.4	9.71	7.51	19.1
11.3	24.5	24.7	24.2	15.3	12.3	10.2	7.68	23.4
6.6	30.2	30.6	29	16.8	13	10.6	7.84	28.7
3.84	37.1	37.8	35.2	17.7	13.4	10.7	7.77	34.7
2.24	45.3	46.4	42.1	18.4	13.7	10.8	7.72	41.3
1.3	54.5	56.2	49.3	18.8	13.9	10.8	7.75	48.1
0.758	64.2	66.5	55.8	19	13.9	10.9	7.69	54.1
0.441	73.6	76.7	61	19.2	14.1	11	7.77	58.8
0.257	82.5	86	65.4	19.5	14.1	11	7.9	62.4
0.15	90.4	95.5	67.8	19.6	14.2	11.2	7.75	64.6
0.0871	99	105	70.3	18.1	14.4	12.1	8.12	66.5
0.0507	103	112	72.9	22.8	14.5	13.1	9.24	68.8
0.0295	109	122	74.7	24.6	18.3	14.5	9.41	70.7
0.0172	113	138	77.3	26.9	21	16.8	11.3	74.3
0.01	115	153	82.2	40	21.2	22.5	15.4	78.9

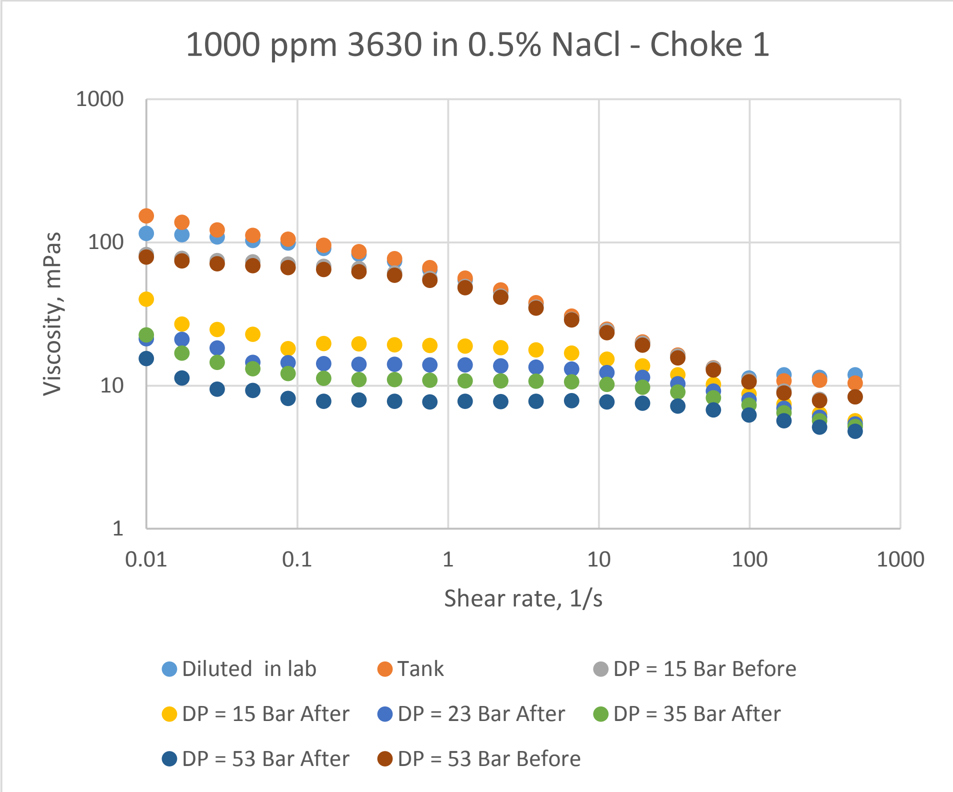


Figure 9 – Polymer viscosity – Test 1.

Table 5 Polymer degradation – Test 1.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
1	1	3630	1000	Tank	30.6	0	-
	1	3630	1000	0	29	5.4	0.0
	1	3630	1000	15	16.8	46.6	43.6
	1	3630	1000	23	13	59.5	57.1
	1	3630	1000	35	10.6	67.6	65.7
	1	3630	1000	53	7.84	76.9	75.6

As seen from Table 5 above, the polymer is severely degraded even at 15 bar differential pressure across the choke valve. At 53 bar differential pressure the polymer is degraded to more than 70%.

Filter ratio tests were performed by filtration of the polymer samples through a 5 µm Millipore filter, type TMTP, at constant pressure of 2 bar. Filter ratio, FR is defined as the following:

$$FR = \frac{t_{300} - t_{200}}{t_{200} - t_{100}}$$

Where t_i is the time to filter i gram of solution. The total time to filter 300 gram solution is also reported, and the Screen factor, SF defined as the ratio between filtration time of polymer solution and brine. The filtration time for 0.5wt% NaCl was constant and close to 30 s for all the tests.

The shear rate through the filter was calculated from the following equation:

$$\dot{\gamma} = \frac{4\alpha v}{r} = \frac{4\alpha q}{\varphi \pi R^2 r}$$

Here q is the flow rate, φ is filter porosity (φ = 0.125). R is the effective filter radius (R = 2.0 cm) and r is pore size radius (r = 5/2 μm).

Table 6 Polymer filtration – Test 1

Sample	ΔP, bar	Polymer	Conc, ppm	Choke 1 FR	Choke 1 Time, s	Choke 1 Shear rate	SF
Diluted lab		3630	1000	1.04	1483	5.16E+03	
Brine lab		NaCl	5000		30		1.00
Tank		3630	1000	4.695	5291	1.45E+03	176.37
Brine Tank		NaCl	5000	1.2	33	2.32E+05	1.10
Before choke	15	3630	1000	3.33	2349	3.26E+03	78.30
Before choke	23	3630	1000	-	-	-	
Before choke	35	3630	1000	-	-	-	
Before choke	53	3630	1000	-	-	-	
After choke	15	3630	1000	3.879	929	8.24E+03	30.97
After choke	23	3630	1000	2.762	458	1.67E+04	15.27
After choke	35	3630	1000	2.403	310	2.47E+04	10.33
After choke	53	3630	1000	2.926	246	3.11E+04	8.20

Table 7 Polymer viscosity after filtration – Test 1.

	Filtrate Diluted in lab	Filtrate Tank	Filtrate ΔP = 15 Bar Before	Filtrate ΔP = 15 Bar After	Filtrate ΔP = 23 Bar After	Filtrate ΔP = 35 Bar After	Filtrate ΔP = 55 Bar After
Polymer	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000
Choke type		1	1	1	1	1	1
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	10.5	8.71	7.95	5.61	5.34	5.11	4.7
291	10.9	9.02	7.48	6.24	5.91	5.59	5
169	11.2	8.44	8.72	7.27	6.79	6.32	5.5
98.7	10.6	9.76	10.4	8.51	7.8	7.12	6.02
57.4	13	11.8	12.5	9.96	8.89	7.95	6.51
33.4	15.8	14.2	15.2	11.5	9.95	8.69	6.89
19.5	19.4	17.2	18.5	13.1	10.9	9.31	7.18
11.3	23.8	20.8	22.6	14.5	11.7	9.74	7.33
6.6	29.2	25.3	27.4	15.8	12.3	10	7.43
3.84	35.7	30.4	32.8	16.6	12.5	10.1	7.42
2.24	43.4	36.2	38.5	17.1	12.7	10.2	7.4
1.3	51.9	42.2	44.2	17.5	12.9	10.3	7.47
0.758	60.5	47.9	48.9	17.6	12.9	10.4	7.48
0.441	68.5	52.8	52.6	17.7	13.1	10.4	7.62
0.257	76.2	56.9	55.2	17.9	13.4	10.6	7.74
0.15	82.2	59.5	56.8	17.8	13.5	10.4	7.87
0.0871	88.1	62.1	57.7	18	14.3	11	8.28
0.0507	92.7	63.1	59.6	19.2	15.3	11.8	9.6
0.0295	97.1	64.6	61	19.5	17.1	11.4	9.16
0.0172	99.6	65	61.3	21.7	22.4	12.9	11.7
0.01	105	64.4	62.5	28.1	30.2	19.7	14.9

The only difference between the viscosity data shown in Table 7 and Table 4 is that the polymer samples reported in Table 4 have been filtered through a 5 mm filter at shear rates as reported in Table 6. From Figure 10 it is seen that the viscosity before and after filtration is approximately the same. Shear rates through the filter of 1.4E+03 (Tank) and 3.1E+04 (53 bar through choke) did not further degrade the polymer. The reason the tank viscosity was not degraded in the filter ratio test was the poor tank water quality in this test (as indicated by FR = 4.7).

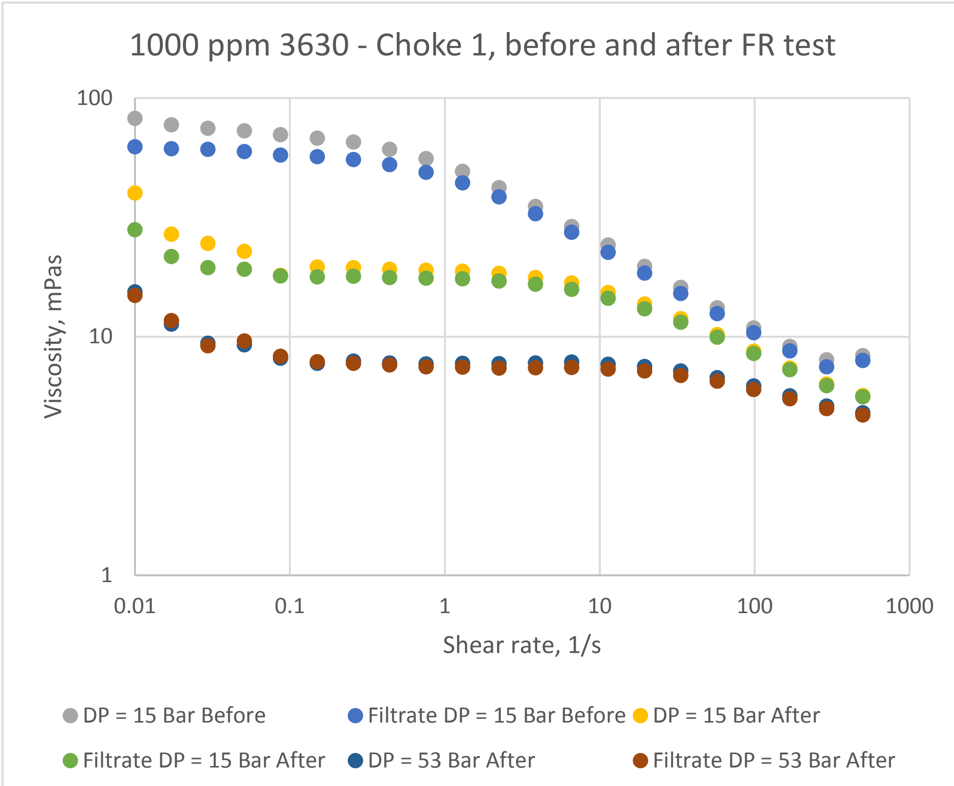


Figure 10 – Polymer viscosity, comparison of filtered and non-filtered – Test 1.

As can be seen from Figure 10, no significant polymer degradtion occurred during filtration of the polymer samples. There are two reasons for this:

1. In this test, the makeup water had poor filterability, which caused poor polymer filterability, FR > 4. This lowered the flow rate and corresponding shear rate through the filter. The degradation of the tank sample at filter shear rate of 1.5E+03 s^{-1} was marginal.
2. For the degraded polymer the filter shear rate increased, but since the polymer was already severely degraded through the choke, no further degradation took place in the filter at shear rates of approximately 2E+04 s^{-1}.

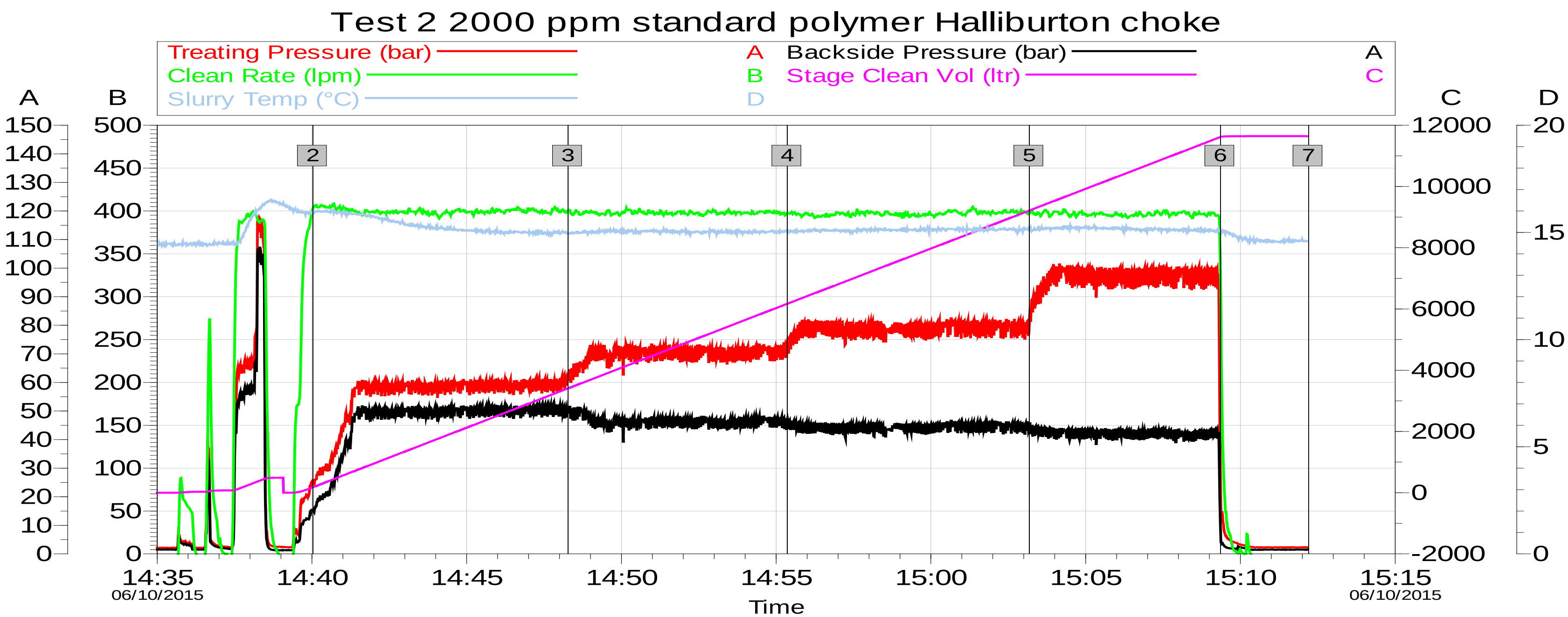
Test 2 – 2 000ppm 3630 with Halliburton Standard adjustable choke (Choke 1)

Job Event Log Test 2

Start Time	06-Oct-15 14:33:54	
End Time	06-Oct-15 15:12:09	
Volume	12.370	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	06-Oct-15 14:33:52	Start Job	Starting Job	0.0	0.0	0	
1		14:35:11	Stage 1	NEXT STAGE	2.1	1.5	-1	14.4
		14:35:12	Start Averaging	Start Avg Trt 1	2.1	1.5	-1	14.4
	2	14:40:02	Other	Start pumping @ 60 bar	24.7	15.2	402	15.9
	3	14:48:16	Other	Increase pressure to 70 bar	62.2	50.5	400	14.9
	4	14:55:21	Other	Increase pressure to 80 bar	74.2	47.0	397	15.1
	5	15:03:10	Other	Increase pressure to 100 bar	80.4	44.6	396	15.1
	6	15:09:21	Other	Stop pumping	29.4	10.6	338	15.1
		15:12:09	End Averaging	End Avg Trt 1	2.3	1.5	-1	14.6
	7	15:12:11	End Job	Ending Job	2.3	1.5	-1	14.6

Pump chart – Test 2



Global Event Log

2	Start pumping @ 60 bar	14:40:02	3	Increase pressure to 70 bar	14:48:17
4	Increase pressure to 80 bar	14:55:22	5	Increase pressure to 100 bar	15:03:11
6	Stop pumping	15:09:21	7	Ending Job	15:12:12

Polymer sample analysis – Test 2

Table 8 Polymer viscosity – Test 2.

	Diluted in lab	Tank	ΔP = 9 Bar Before	ΔP = 9 Bar After	ΔP = 24 Bar After	ΔP = 35 Bar After	ΔP = 53 Bar After	ΔP = 53 Bar Before
Polymer	3630	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	2000	2000	2000	2000	2000	2000	2000	2000
Choke type		1	1	1	1	1	1	1
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	23	18	15.3	11.8	10.2	9.73	9.32	14.9
291	18.9	18.6	16.3	13.6	12.4	11.8	11.2	15.9
169	23	20.9	17.3	16.9	15.3	14.4	13.5	17.2
98.7	23.2	22.9	22.2	21.4	19.1	17.7	16.2	22
57.4	29.2	30.6	28.4	27.3	24.1	21.6	19.2	28.2
33.4	39.1	40.3	36.8	35.3	30.2	26.1	22.3	36.5
19.5	51.6	53.2	48.2	46.2	37.6	30.9	24.9	47.6
11.3	68.3	70.8	63.6	60.9	46.1	35.8	27.2	62.7
6.6	91	94.9	84.4	80.6	55.2	40.3	29.1	83
3.84	122	128	112	106	64.1	44	30.5	110
2.24	163	172	148	138	72.1	46.8	31.4	144
1.3	216	229	193	177	78.7	48.8	32	187
0.758	281	301	246	219	83.3	50	32.3	237
0.441	358	385	303	261	86.2	50.6	32.7	291
0.257	447	482	364	301	87.8	51.2	33.1	346
0.15	548	591	425	335	89	51.5	33.7	402
0.0871	660	714	487	365	90.5	52.1	35.2	456
0.0507	785	848	546	390	92.5	54.5	37.7	507
0.0295	922	993	604	412	95.7	56.4	41.7	556
0.0172	1080	1150	661	428	102	58.8	49.5	602
0.01	1250	1330	716	449	109	66.9	65.2	650

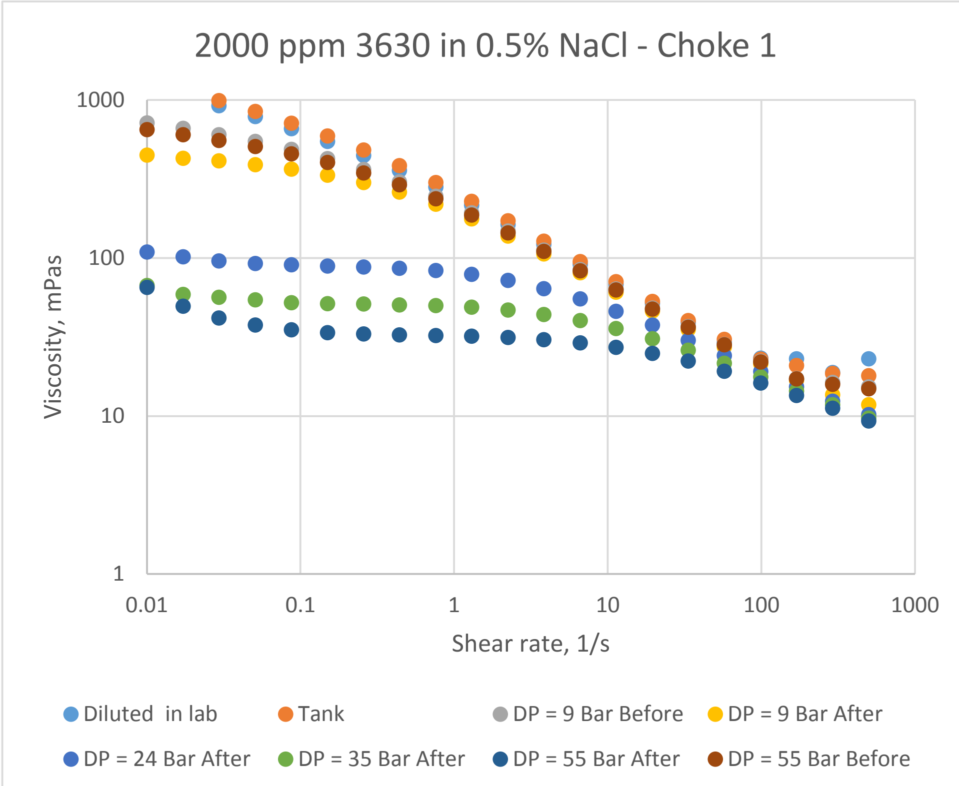


Figure 11 – Polymer viscosity – Test 2

Table 9 Polymer degradation –Test 2

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
2	1	3630	2000	Tank	94.9	0	-
	1	3630	2000	0	84.4	11.2	0.0
	1	3630	2000	9	80.6	15.2	4.6
	1	3630	2000	24	55.2	42.3	35.0
	1	3630	2000	35	40.3	58.1	52.9
	1	3630	2000	55	29.1	70.1	66.3

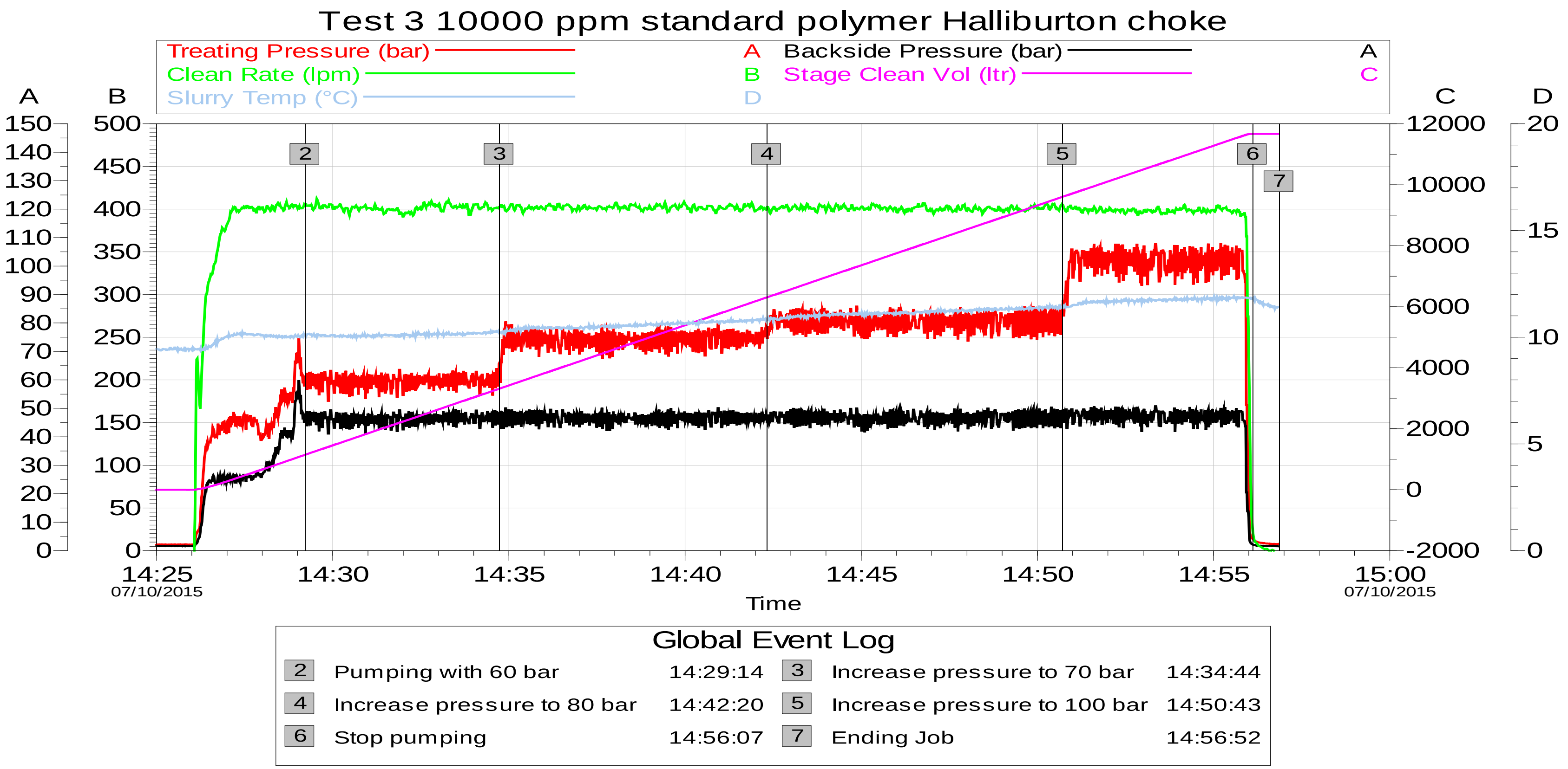
Test 3 - 10 000ppm 3630 with Halliburton standard adjustable choke (Choke 1)

Job Event Log Test 3

Start Time	07-Oct-15 14:14:36	
End Time	07-Oct-15 14:56:49	
Volume	11.906	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Stage Clean Vol ltr	Slurry Temp °C
	1	07-Oct-15 14:14:34	Start Job	Starting Job	2.1	1.5			
1		14:25:49	Stage 1	NEXT STAGE	2.2	1.6			
		14:25:50	Start Averaging	Start Avg Trt 1	2.1	1.6	-1	-3.232	9.4
	2	14:29:13	Other	Pumping with 60 bar	61.4	47.5	406	1147.547	10.1
	3	14:34:44	Other	Increase pressure to 70 bar	66.1	48.4	402	3309.359	10.2
	4	14:42:19	Other	Increase pressure to 80 bar	74.6	45.4	402	6303.997	10.8
	5	14:50:42	Other	Increase pressure to 100 bar	84.2	47.9	406	9598.409	11.4
	6	14:56:06	Other	Stop pumping	4.0	2.1	28	11667.405	11.8
		14:56:49	End Averaging	End Avg Trt 1	2.4	1.6	-1	11670.139	11.4
	7	14:56:52	End Job	Ending Job	2.4	1.6	-1	11670.124	11.4

Pump chart – Test 3



Polymer sample analysis – Test 3

Table 10 Polymer viscosity – Test 3.

	Diluted in lab	Tank	ΔP = 13 Bar Before	ΔP = 13 Bar After	ΔP = 28 Bar After	ΔP = 34 Bar After	ΔP = 54 Bar After	ΔP = 54 Bar Before
Polymer	3630	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	10000	10000	10000	10000	10000	10000	10000	10000
Choke type		1	1	1	1	1	1	1
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
130	181	170	166	165	169	169	172	169
76.8	262	251	244	244	250	249	252	250
45.4	397	383	368	369	378	376	372	378
26.8	614	592	562	561	575	568	552	578
15.8	954	918	860	855	876	859	821	886
9.36	1480	1420	1310	1300	1330	1300	1220	1360
5.53	2290	2190	2000	1980	2030	1970	1830	2070
3.27	3510	3370	3040	3010	3070	2970	2730	3150
1.93	5350	5140	4590	4550	4640	4470	4050	4770
1.14	8110	7810	6910	6860	6970	6700	5950	7200
0.674	12000	11700	10300	10200	10400	9910	8570	10700
0.398	17900	17400	15100	14900	15100	14300	12000	15800
0.235	26000	25300	21700	21400	21500	20300	16500	22700
0.139	37200	36300	30900	30400	30200	28400	22100	32300
0.0821	52900	51800	43600	42600	42000	39100	29200	45500
0.0485	74800	73500	61000	59200	57700	53300	37900	63700
0.0286	106000	104000	84900	81700	78700	72000	48600	88600
0.0169	149000	146000	118000	112000	107000	96800	61900	123000
0.01	211000	208000	164000	155000	146000	130000	78500	172000

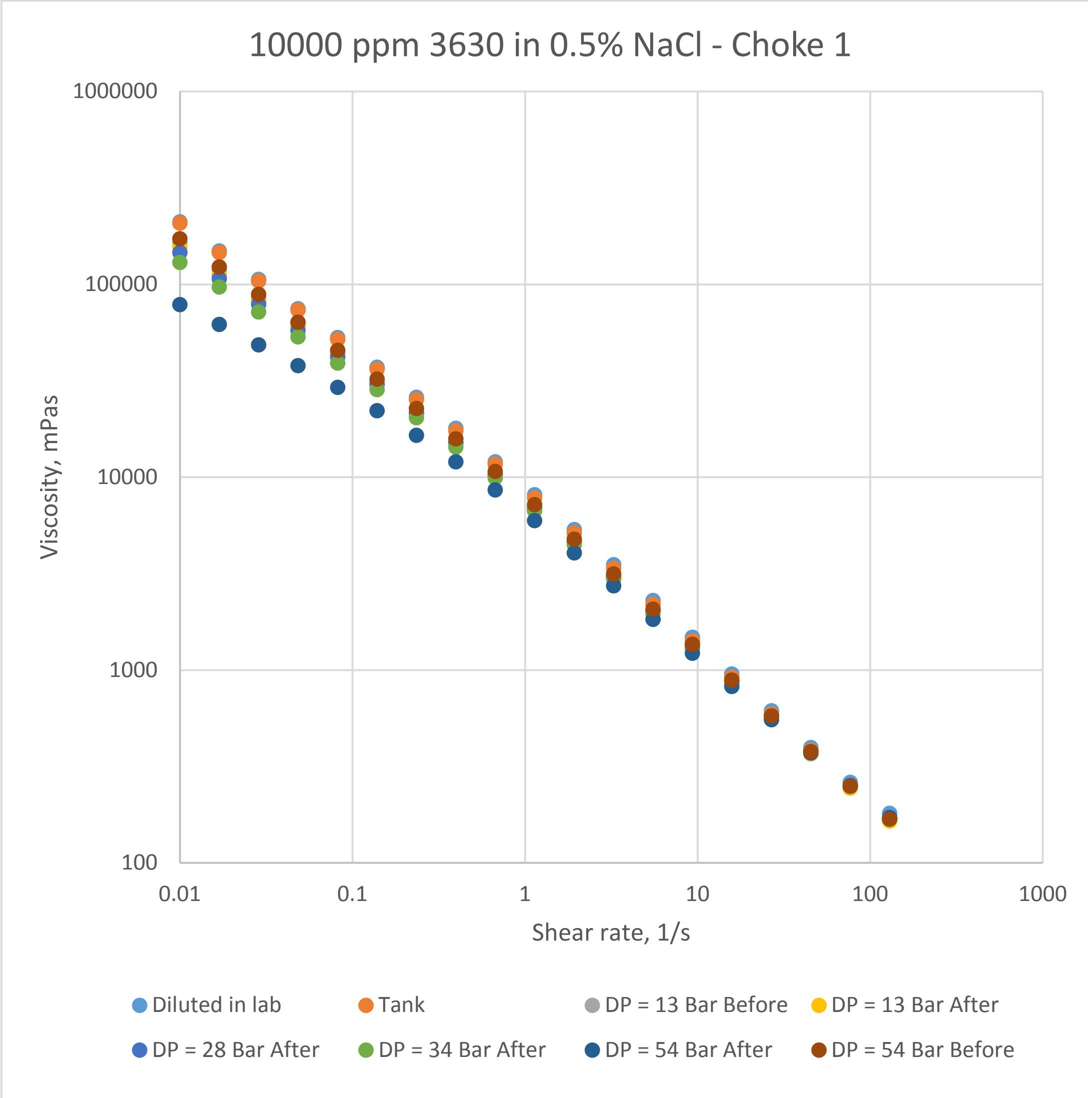


Figure 12 – Polymer viscosity – Test 3.

Table 11 Polymer degradation – Test 3

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
3	1	3630	10000	Tank	2190	0	-
	1	3630	10000	0	2000	8.7	0.0
	1	3630	10000	13	1980	9.6	1.0
	1	3630	10000	28	2030	7.3	-1.5
	1	3630	10000	34	1970	10.1	1.5
	1	3630	10000	54	1830	16.4	8.5

Table 12 Polymer viscosity – Test 3 (all samples in Table 10 diluted to 1000 ppm).

	Diluted in lab	Tank	ΔP = 13 Bar Before	ΔP = 13 Bar After	ΔP = 28 Bar After	ΔP = 34 Bar After	ΔP = 54 Bar After	ΔP = 54 Bar Before
Polymer	3630	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000	1000
Choke type		1	1	1	1	1	1	1
Shear rate	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity
1/s	mPas	mPas	mPas	mPas	mPas	mPas	mPas	mPas
500	11	8.99	7.85	7.73	6.9	6.67	6.09	8.58
291	11.6	9.59	7.16	7.21	7.07	6.92	6.66	8.35
169	11.9	8.83	8.07	8.25	8.21	8.02	7.71	9.19
98.7	11.3	9.98	9.55	9.79	9.72	9.48	9.07	11.1
57.4	13.3	12.1	11.4	11.7	11.6	11.3	10.8	13.4
33.4	16.3	14.6	13.6	14.1	14	13.6	12.8	16.2
19.5	20	17.7	16.4	17.1	16.9	16.4	15.2	19.8
11.3	24.6	21.6	19.6	20.7	20.4	19.6	17.8	24.2
6.6	30.2	26.3	23.5	25	24.6	23.4	20.5	29.4
3.84	37.2	31.9	27.6	29.8	29	27.3	23.1	35.3
2.24	45.3	38.4	32	34.9	33.5	31.1	25.4	41.8
1.3	54.5	45.2	36.3	40	37.7	34.7	27.3	48.4
0.758	64	51.8	39.8	44.2	41	37.2	28.5	54.3
0.441	73.3	57.8	42.5	47.6	43.4	39	29.4	59.2
0.257	82.1	62.9	44.5	50	45	40.3	30.1	63.1
0.15	89.5	66.5	45.7	51.4	45.7	40.8	30.3	65.8
0.0871	96.5	70.2	47	53.2	46.2	41.1	31.4	68.5
0.0507	102	72.8	48.5	55.3	48.6	42.9	33.4	70.7
0.0295	109	75.1	50	59.3	49.3	44.7	35.9	73.5
0.0172	114	74.6	52.3	62	51.9	46.3	40.5	76.6
0.01	119	84.4	60.1	71.3	53.3	52	49.5	86

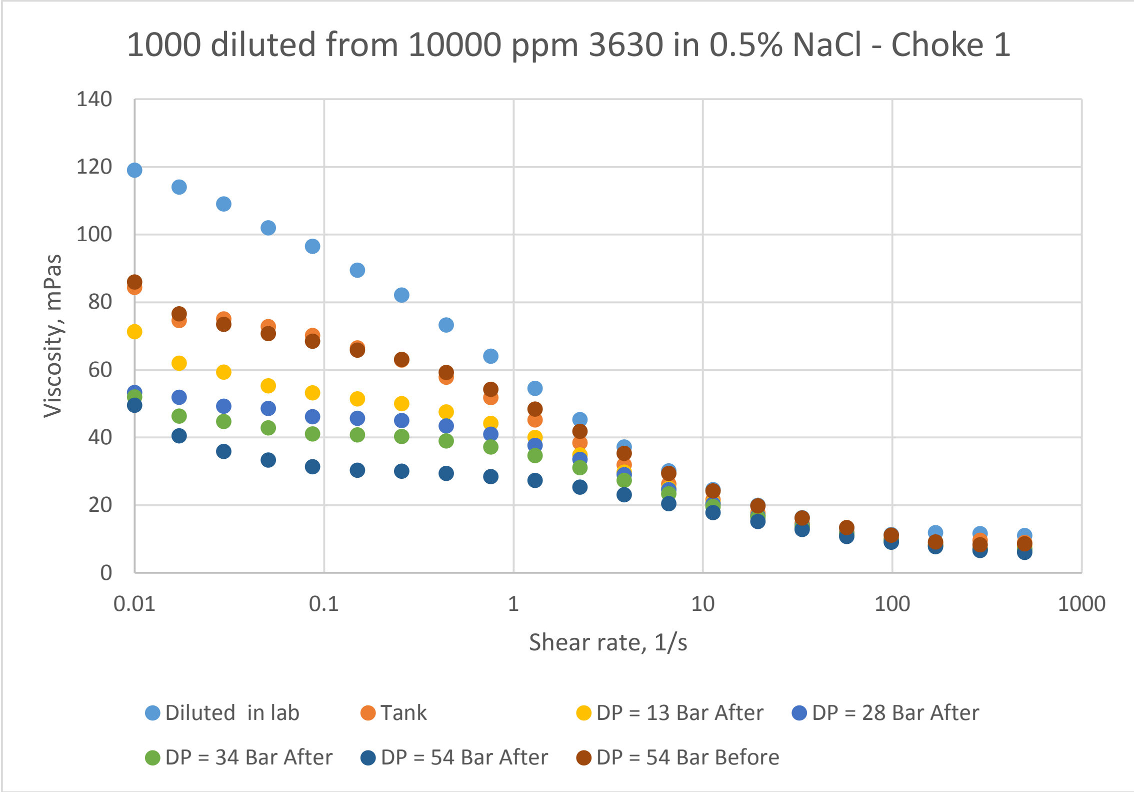


Figure 13 – Polymer viscosity of polymer samples diluted from 10000 to 1000 ppm – Test 3.

Table 13 Polymer degradation – Test 3.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
3	1	3630	1000	Tank	26.3	0	-
	1	3630	1000	0	23.5	11.1	0.0
	1	3630	1000	13	25	5.1	-6.7
	1	3630	1000	28	24.6	6.7	-4.9
	1	3630	1000	34	23.4	11.5	0.4
	1	3630	1000	54	20.5	22.9	13.3

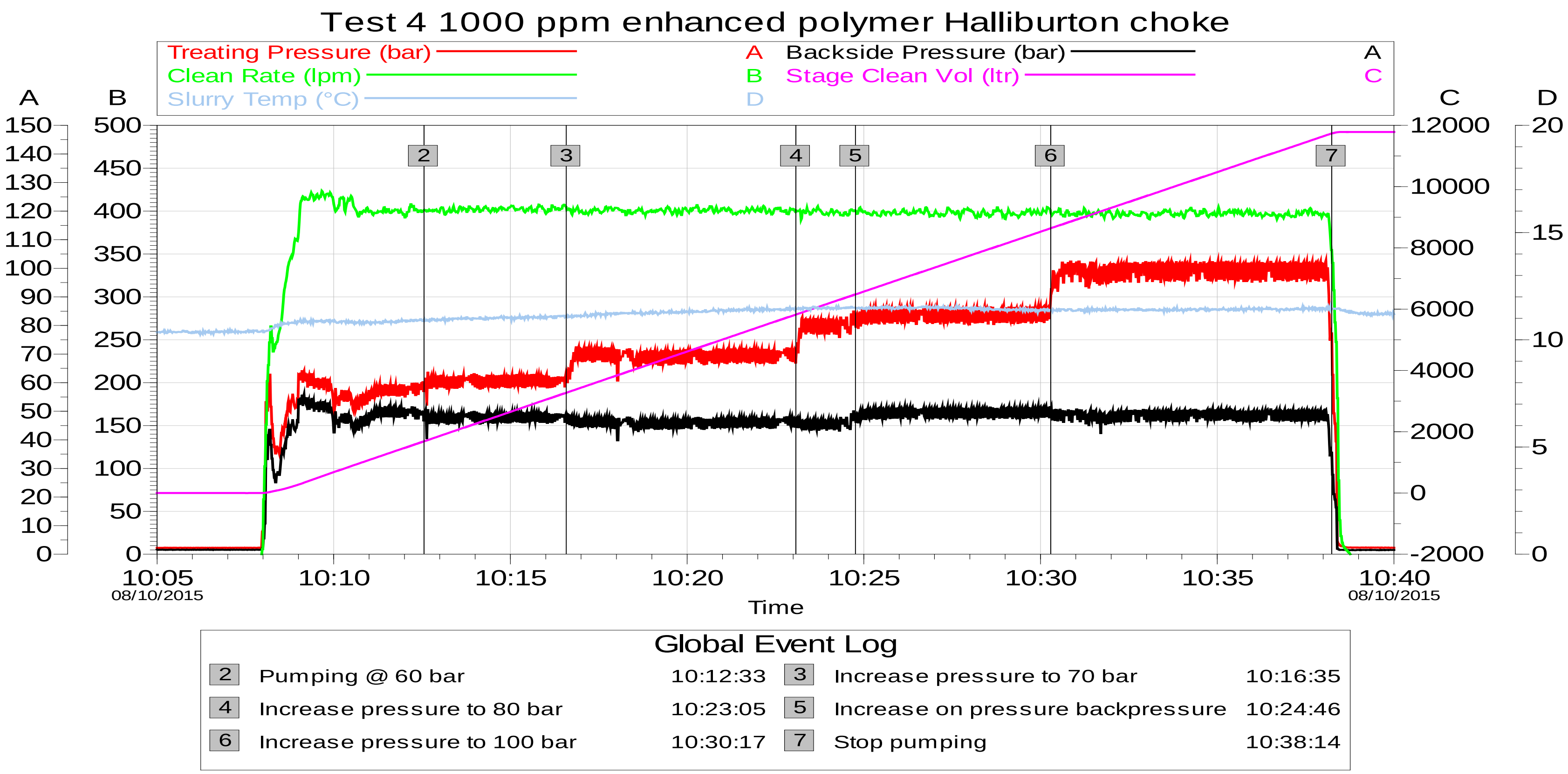
Test 4 – 1 000 ppm AN125 with Halliburton standard adjustable choke (Choke 1)

Job Event Log Test 4

Start Time	08-Oct-15 09:58:47	
End Time	08-Oct-15 10:40:28	
Volume	12.022	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	08-Oct-15 09:58:45	Start Job	Starting Job	0.0	0.0	0	
1		10:07:50	Stage 1	NEXT STAGE	2.3	1.6		10.4
		10:07:51	Start Averaging	Start Avg Trt 1	2.3	1.6		10.4
	2	10:12:33	Other	Pumping @ 60 bar	57.0	46.7	401	10.9
	3	10:16:35	Other	Increase pressure to 70 bar	63.4	49.2	405	11.1
	4	10:23:05	Other	Increase pressure to 80 bar	69.5	46.0	399	11.5
	5	10:24:45	Other	Increase on pressure backpressure	80.5	47.5	401	11.5
	6	10:30:17	Other	Increase pressure to 100 bar	90.3	50.8	398	11.4
	7	10:38:14	Other	Stop pumping	77.2	35.5	355	11.4
		10:40:28	End Averaging	End Avg Trt 1	2.4	1.4		11.2
	8	10:40:30	End Job	Ending Job	2.4	1.4		11.2

Pump chart – Test 4



Polymer sample analysis – Test 4

Table 14 Polymer viscosity – Test 4.

	Tank	ΔP = 13 Bar Before	ΔP = 13 Bar After	ΔP = 23 Bar After	ΔP = 35 Bar After	ΔP = 50 Bar After	ΔP = 50 Bar Before
Polymer	AN125	AN125	AN125	AN125	AN125	AN125	AN125
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000
Choke type	1	1	1	1	1	1	1
Shear rate	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity
1/s	mPas	mPas	mPas	mPas	mPas	mPas	mPas
500	7.93	7.05	6.31	5.77	5.55	5.23	7.09
291	8.15	7.85	7.16	6.46	6.14	5.66	7.91
169	9.51	9.13	8.4	7.42	6.96	6.27	9.21
98.7	11.2	10.7	9.89	8.47	7.81	6.87	10.8
57.4	13.3	12.7	11.6	9.55	8.64	7.4	12.8
33.4	15.8	15.1	13.5	10.5	9.34	7.8	15.2
19.5	18.7	17.8	15.4	11.4	9.87	8.08	18
11.3	22.1	20.9	17.1	12	10.2	8.23	21.2
6.6	26	24.3	18.5	12.4	10.4	8.28	24.7
3.84	30	27.6	19.5	12.5	10.5	8.33	28.2
2.24	34.1	30.7	20.2	12.6	10.6	8.37	31.5
1.3	38	33.4	20.6	12.7	10.7	8.5	34.3
0.758	41.1	35.3	21	12.8	10.8	8.56	36.3
0.441	43.3	36.7	21.3	12.9	10.7	8.65	37.8
0.257	45.2	37.6	22.2	13.2	11.1	8.75	38.7
0.15	46.1	38.3	22.2	13.2	10.9	8.95	39.1
0.0871	48.3	39.9	24.1	14.1	11.5	9.69	40.6
0.0507	49.3	41.8	27.3	16.5	11.4	11.4	42.5
0.0295	52.1	45.4	34.5	18.5	12.1	13.1	45.9
0.0172	58	50.9	42.4	25.5	13.4	18.1	48.3
0.01	67	63.5	59.9	33	15.7	24.2	56.7

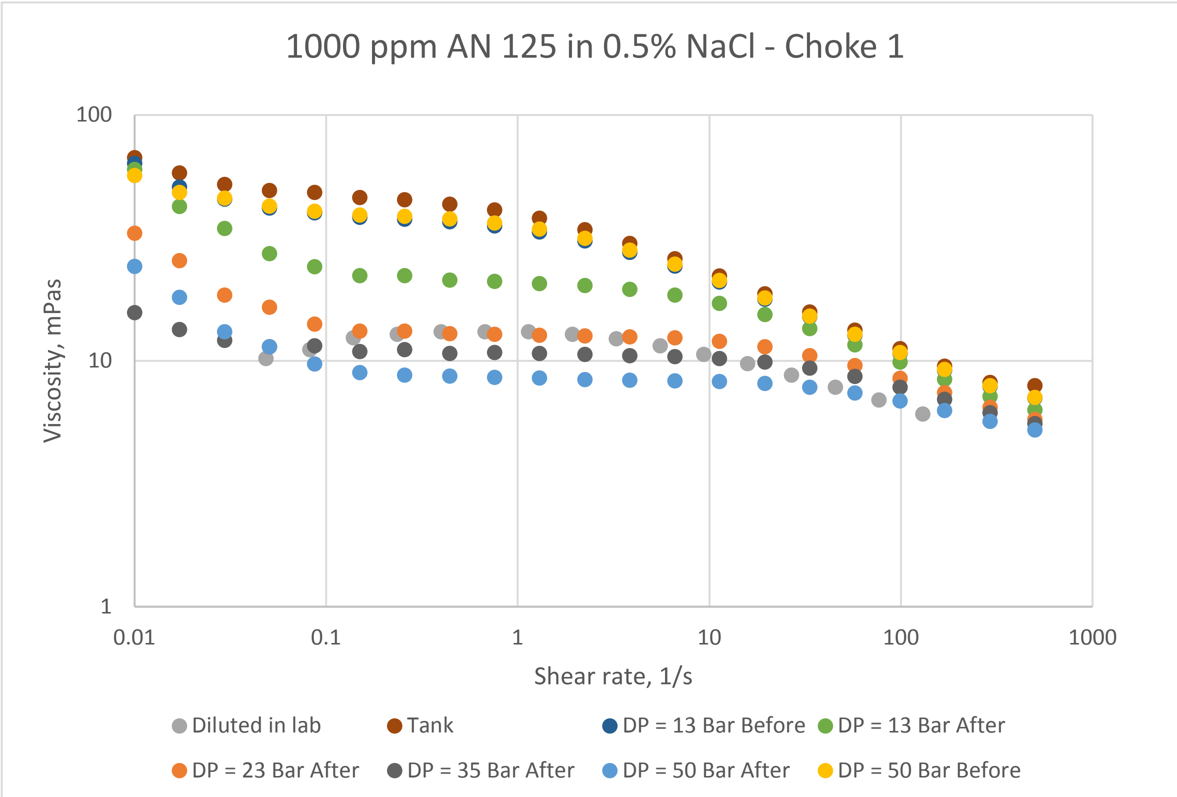


Figure 14 – Polymer viscosity – Test 4.

The deviation between lab-diluted and Tank sample viscosity was most likely due to the problem of proper cleaning of the tanks and flow lines after the previous polymer test – 10000 ppm 3630 polymer. The high concentration polymer was difficult to wash out with brine and traces of 3630 polymer was then mixed into the AN 125 polymer. At shear rate of 6.6 s^{-1}, the tank sample viscosity was 26 mPas while the results in Figure 4 reports viscosity of 11. 5 for the tank sample diluted to 1000 ppm in laboratory (which is close to the tank sample viscosity in Test 8).

For all other tests (at lower polymer viscosity), the clean up was regarded adequate.

Table 15 Polymer degradation – Test 4.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
4	1	AN125	1000	Tank	26	0.00	-
	1	AN125	1000	0	24.7	5.20	0.00
	1	AN125	1000	13	18.5	30.00	26.16
	1	AN125	1000	23	12.4	54.40	51.90
	1	AN125	1000	35	10.4	62.40	60.34
	1	AN125	1000	50	8.28	70.88	69.28

Table 16 Polymer filtration – Test 4.

Sample	ΔP, bar	Polymer	Conc, ppm	Choke 1 FR	Choke 1 Time, s	Choke 1 Shear rate	SF
Diluted lab		AN 125	1000	1.04	301	2.54E+04	
Brine lab		NaCl	5000	-	-	-	
Tank		AN 125	1000	1.20	689	1.11E+04	22.97
Brine Tank		NaCl	5000	1.00	30	2.55E+05	1.00
Before choke	13	AN 125	1000	1.13	444	1.72E+04	14.80
Before choke	23	AN 125	1000	-	-	-	-
Before choke	35	AN 125	1000	-	-	-	-
Before choke	50	AN 125	1000	1.17	456	1.68E+04	15.20
After choke	13	AN 125	1000	1.12	221	3.46E+04	7.37
After choke	23	AN 125	1000	1.09	130	5.89E+04	4.33
After choke	35	AN 125	1000	1.14	111	6.90E+04	3.70
After choke	50	AN 125	1000	1.10	88	8.70E+04	2.93

Table 17 Polymer viscosity after filtration – Test 4.

	Filtrate Tank	Filtrate ΔP = 13 Bar Before	Filtrate ΔP = 13 Bar After	Filtrate ΔP = 23 Bar After	Filtrate ΔP = 35 Bar After	Filtrate ΔP = 50 Bar After	Filtrate ΔP = 50 Bar Before
Polymer	AN125	AN125	AN125	AN125	AN125	AN125	AN125
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000
Choke type	1	1	1	1	1	1	1
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	7.47	8.17	6.27	5.7	5.53	5.16	
291	8.01	9.4	7.12	6.37	6.11	5.57	
169	9.33	11.1	8.34	7.3	6.9	6.16	
98.7	11	13.2	9.79	8.3	7.72	6.73	
57.4	13	15.8	11.5	9.33	8.52	7.24	
33.4	15.4	18.8	13.2	10.3	9.18	7.61	
19.5	18.2	22.2	15	11	9.68	7.87	
11.3	21.5	26	16.6	11.6	9.99	7.99	
6.6	25	30	17.9	11.9	10.2	8.08	
3.84	28.7	33.7	18.6	12	10.2	8.01	
2.24	32.3	37	19.1	12.1	10.3	7.93	
1.3	35.6	39.8	19.4	12.2	10.3	8.05	
0.758	38.1	41.6	19.6	12.2	10.3	7.99	
0.441	39.9	42.7	19.8	12.4	10.5	8.2	
0.257	41.1	43.6	20.3	12.5	10.6	8.23	
0.15	41.1	43.7	20.4	12.5	10.6	8.39	
0.0871	42.1	44.2	20.9	13.4	11	9.19	
0.0507	42.6	45.4	23.6	14.1	12	10.3	
0.0295	45.5	47.4	26	15.7	12.9	11.2	
0.0172	47.6	49.3	31.9	18.8	15.4	15.5	
0.01	52	56.4	43.6	26.8	19.8	20.7	

As discussed earlier, the filtration at shear rates of 1.1E+04 s^{-1} (Tank sample) and up to 8.7E+04 s^{-1} (Choke samples) had minor impact on the degradation.

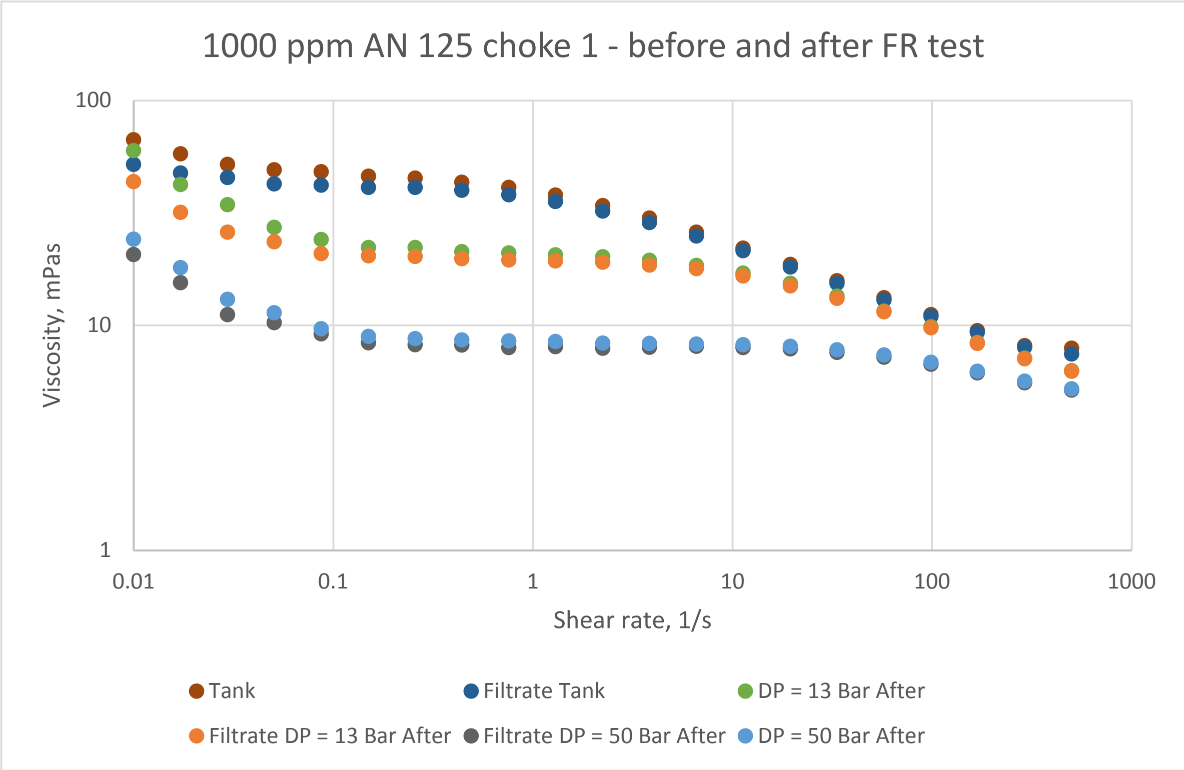


Figure 15 – Polymer viscosity, comparison of filtered and non-filtered – Test 4.

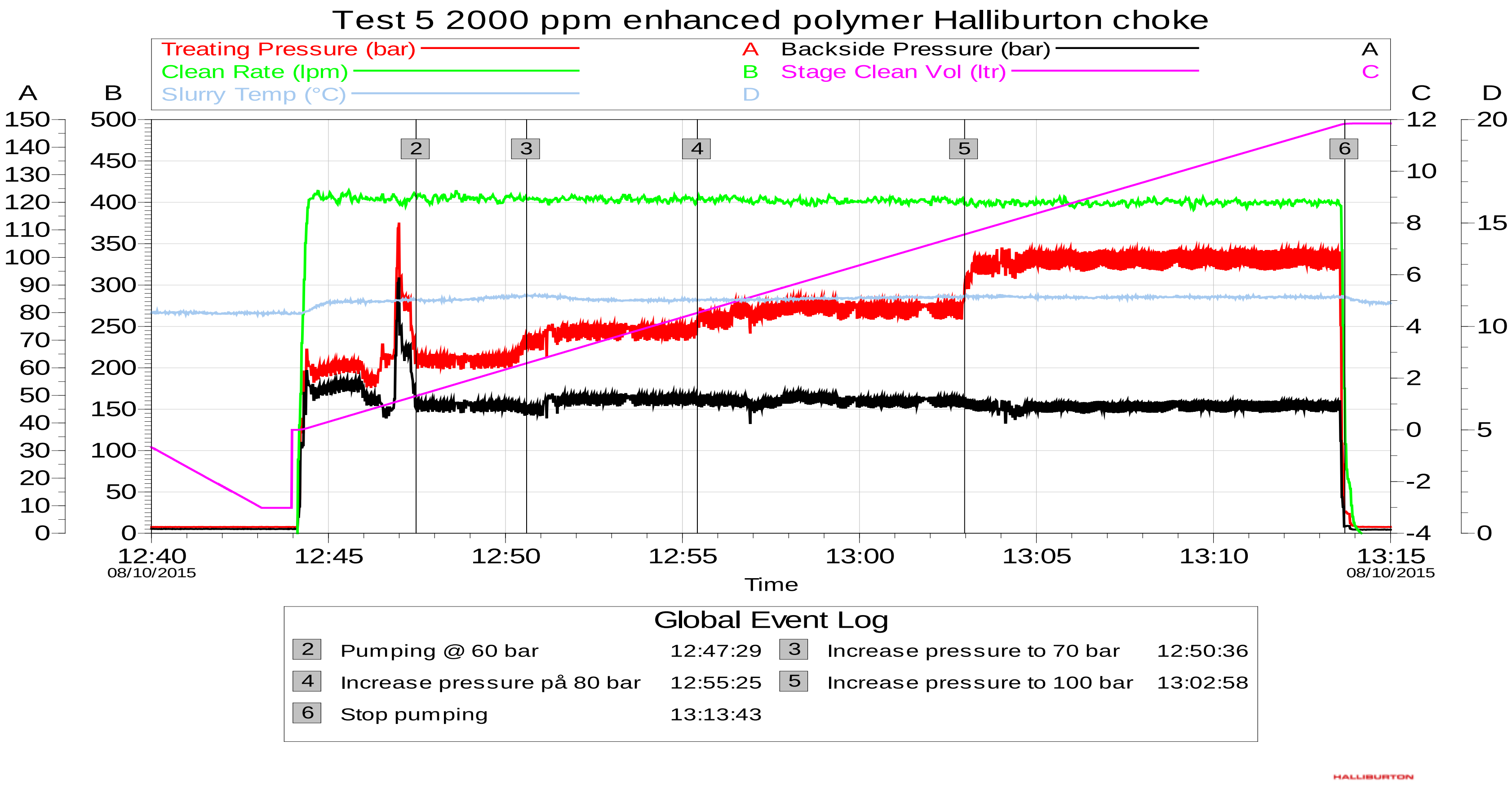
Test 5 – 2 000 ppm AN125 with Halliburton standard adjustable choke (Choke 1)

Job Event Log Test 5

Start Time	08-Oct-15 12:32:32	ucts
End Time	08-Oct-15 16:07:39	ucts
Volume	20.585	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	08-Oct-15 12:32:30	Start Job	Starting Job	0.0	0.0	0	
1		12:43:58	Stage 1	NEXT STAGE	2.3	1.6	-1	10.7
		12:43:59	Start Averaging	Start Avg Trt 1	2.3	1.5	-1	10.6
	2	12:47:28	Other	Pumping @ 60 bar	63.2	46.6	408	11.3
	3	12:50:35	Other	Increase pressure to 70 bar	69.7	45.0	405	11.5
	4	12:55:25	Other	Increase pressure to 80 bar	77.8	49.2	403	11.3
	5	13:02:58	Other	Increase pressure to 100 bar	88.4	47.9	398	11.5
	6	13:13:42	Other	Stop pumping	7.8	2.4	175	11.5
		16:07:39	End Averaging	End Avg Trt 1	2.6	1.4	-0	12.0
	7	16:07:42	End Job	Ending Job	2.6	1.4	-0	12.0

Pump chart – Test 5



Polymer sample analysis – Test 5

Table 18 Polymer viscosity – Test 5.

	Tank	ΔP = 16 Bar Before	ΔP = 16 Bar After	ΔP = 25 Bar After	ΔP = 34 Bar After	ΔP = 53 Bar After	ΔP = 53 Bar Before
Polymer	AN125	AN125	AN125	AN125	AN125	AN125	AN125
Concentration, ppm	2000	2000	2000	2000	2000	2000	2000
Choke type	1	1	1	1	1	1	1
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	9.87	9.44	8.23	7.93	7.78	7.39	9.44
291	11.4	11	9.7	9.31	9.07	8.46	11
169	13.6	13.1	11.6	11	10.6	9.71	13.1
98.7	16.4	15.7	13.9	12.9	12.3	11	15.7
57.4	19.7	18.9	16.5	15	14	12.1	18.9
33.4	23.6	22.7	19.4	17	15.5	13	22.7
19.5	28.2	27.1	22.2	18.7	16.8	13.7	27.1
11.3	33.5	32.2	24.8	20	17.7	14.1	32.2
6.6	39.4	37.7	26.9	20.9	18.2	14.3	37.7
3.84	45.5	43.2	28.4	21.4	18.4	14.3	43.1
2.24	51.6	48.5	29.3	21.6	18.6	14.4	48.4
1.3	57.4	53.2	29.9	21.9	18.6	14.5	53
0.758	62.3	56.7	30.2	22	18.7	14.6	56.4
0.441	66.2	59.2	30.5	22.1	18.7	14.8	58.9
0.257	69.3	61	31	22.3	18.7	15.1	60.7
0.15	71.4	61.9	31	22.1	18.5	15.2	61.6
0.0871	73.3	62.1	32	22.6	19.2	16.1	63.1
0.0507	76.1	64	33.2	24.9	19.6	17.8	65.2
0.0295	79.2	67.8	35.6	26.6	20	16.1	68.8
0.0172	82.6	66.1	39.3	30.3	18.9	22.6	70.1
0.01	89.3	71.6	45.2	36.3	23.5	31.9	80

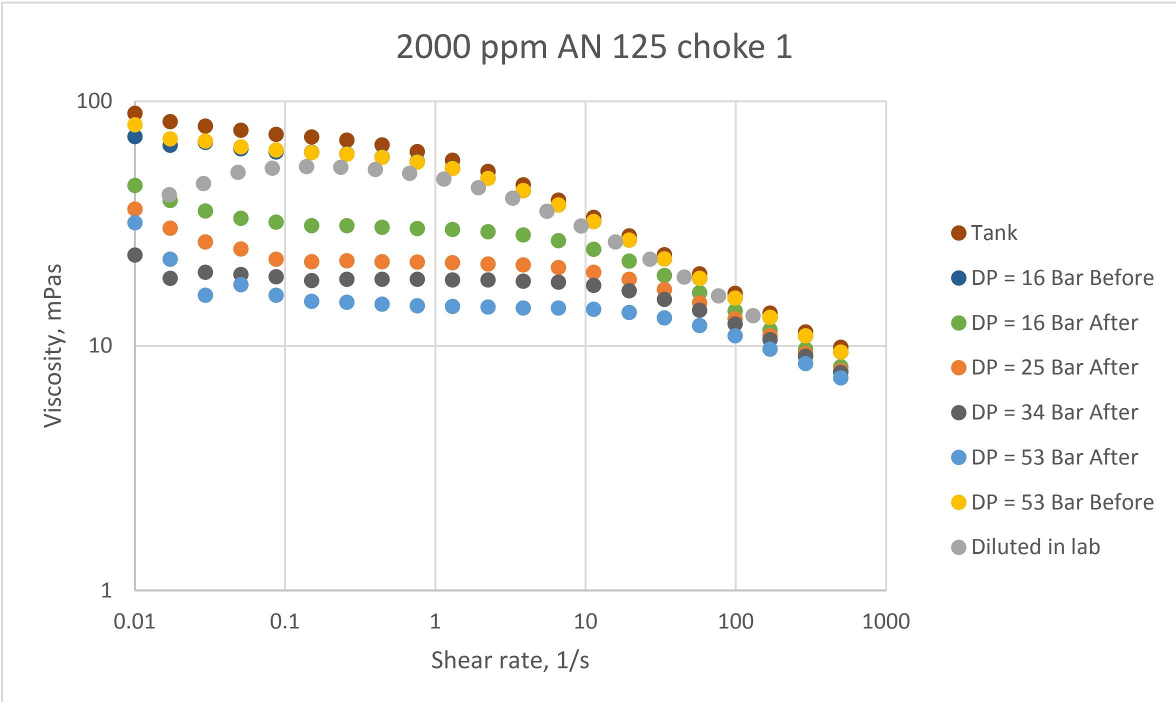


Figure 16 – Polymer viscosity – Test 5.

Table 19 Polymer degradation – Test 5.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
5	1	AN125	2000	Tank	39.4	0.00	-
	1	AN125	2000	0	37.7	4.43	0.00
	1	AN125	2000	16	26.9	32.55	29.43
	1	AN125	2000	25	20.9	48.18	45.78
	1	AN125	2000	34	18.2	55.21	53.13
	1	AN125	2000	53	14.3	65.36	63.76

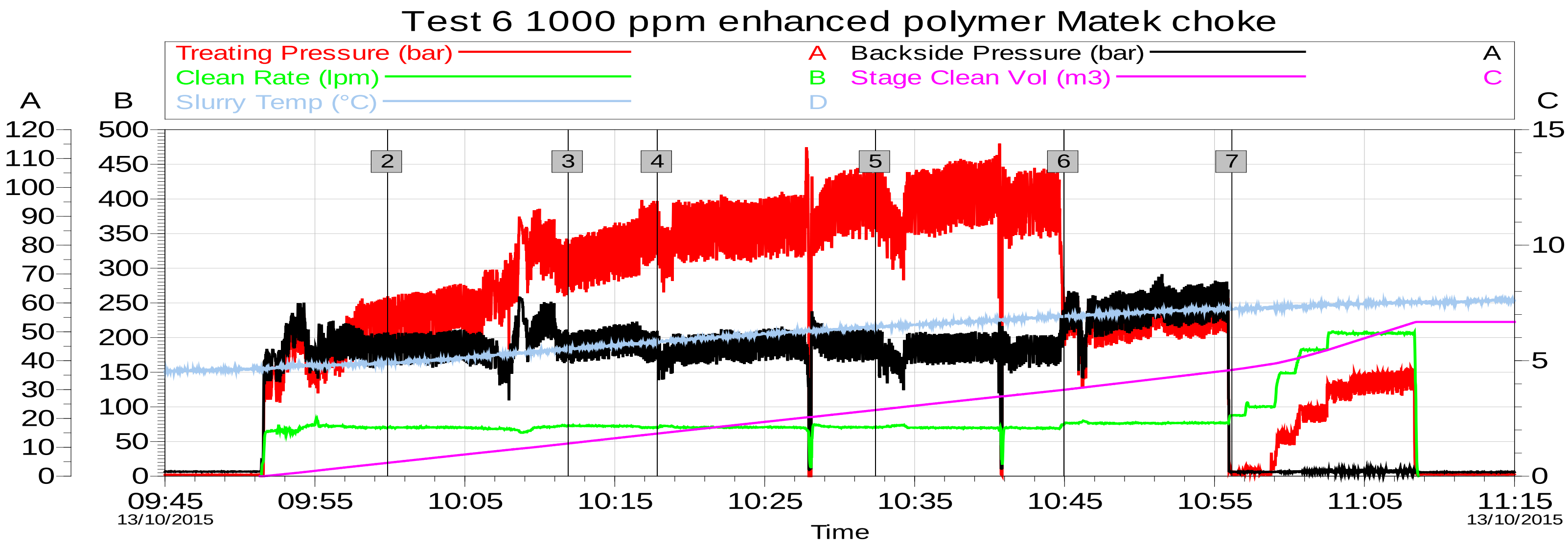
Test 6 – 1 000 ppm AN125 with Matek choke (Choke 2)

Job Event Log Test 6

Start Time	13-Oct-15 09:25:24	
End Time	13-Oct-15 12:26:03	
Clean Volume	6.676	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	13-Oct-15 09:25:22	Start Job	Starting Job	0.0	0.0	0	
1		09:51:20	Stage 1	NEXT STAGE	0.5	1.6		6.2
		09:51:21	Start Averaging	Start Avg Trt 1	0.5	1.5		6.2
	2	09:59:50	Other	Pumping 45% open on Matek choke first test 60 bar dif. pressure	56.9	46.1	70	6.6
	3	10:11:53	Other	Increase pressure to 70bar 39% opening on Matek choke	73.9	46.0	73	7.3
	4	10:17:50	Other	Increase pressure to 80 bar 37% opening on Matek choke	86.5	46.3	70	7.7
	5	10:32:23	Other	Increase pressure to 100 bar 33% opening on Matek choke	106.1	50.7	71	8.6
	6	10:44:56	Other	Open Matek choke 100%	61.9	54.9	75	9.2
	7	10:56:10	Other	Flushing	1.5	1.5	88	9.7
		12:26:03	End Averaging	End Avg Trt 1	0.8	1.5	-1	12.1
	8	12:26:05	End Job	Ending Job	0.8	1.5	-1	12.1

Pump chart – Test 6



Global Event Log

2	Pumping 45% open on Matek choke first test 60 bar dif. pressure	09:59:50
3	Increase pressure to 70bar 39% opning on Matek choke	10:11:54
4	Increase pressure to 80 bar 37% opning on Matek choke	10:17:50
5	Increase pressure to 100 bar 33% opning on Matek choke	10:32:23
6	Open Matek choke 100%	10:44:57
7	Flushing	10:56:10

Polymer sample analysis – Test 6

Table 20 Polymer viscosity – Test 6.

	Tank	ΔP = 13 Bar Before	ΔP = 13 Bar After	ΔP = 32 Bar After	ΔP = 43 Bar After	ΔP = 53 Bar After	ΔP = 53 Bar Before	100% Open After	100% Open Before
Polymer	AN125	AN125	AN125	AN125	AN125	AN125	AN125	AN125	AN125
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000	1000	1000
Choke type	2	2	2	2	2	2	2	2	2
Shear rate	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity
1/s	mPas	mPas	mPas	mPas	mPas	mPas	mPas	mPas	mPas
500	5.87	5.11	4.56	4.01	3.83	3.74	5.06	5.03	5.03
291	6.14	5.54	4.84	4.05	3.79	3.66	5.48	5.45	5.44
169	6.93	6.28	5.36	4.28	3.94	3.78	6.21	6.19	6.17
98.7	7.91	7.17	5.92	4.5	4.08	3.88	7.09	7.07	7.04
57.4	9.05	8.2	6.47	4.68	4.19	3.96	8.09	8.06	8.04
33.4	10.3	9.29	6.93	4.78	4.24	3.99	9.13	9.09	9.1
19.5	11.7	10.4	7.28	4.84	4.27	4.02	10.2	10.1	10.2
11.3	13.1	11.4	7.5	4.86	4.28	4.01	11.1	11	11.1
6.6	14.5	12.2	7.6	4.87	4.27	4.03	11.9	11.7	11.9
3.84	15.8	12.8	7.66	4.81	4.25	3.95	12.4	12.2	12.5
2.24	16.9	13.2	7.74	4.81	4.28	3.92	12.8	12.5	12.9
1.3	17.9	13.6	7.82	4.92	4.36	3.98	13.1	12.8	13.2
0.758	18.5	13.7	7.89	4.99	4.39	4.02	13.2	12.9	13.2
0.441	19	13.9	7.99	5.18	4.55	4.2	13.5	13.1	13.6
0.257	19.5	14.1	8.46	5.54	4.67	4.22	13.8	13.6	13.9
0.15	19.7	14	8.73	5.88	4.75	4.19	14	13.7	14.1
0.0871	20.6	14.9	9.73	6.34	5.52	4.74	14.6	14.6	14.6
0.0507	22.3	15.9	11.9	8.55	5.89	6.21	16.7	16.6	17
0.0295	24.3	16.2	12.7	12.4	8.36	7.91	17.1	18.4	18.2
0.0172	27.3	23	19.5	19.1	14.6	12.4	24.5	24.5	22
0.01	34.6	23.9	30.2	30.9	20.1	19.1	30.5	28	27.6

Note that for this choke valve, samples were taken before and after full opened choke and as can be seen minor viscosity reduction was observed. At 1000 ppm AN125 the reduction was 2%.

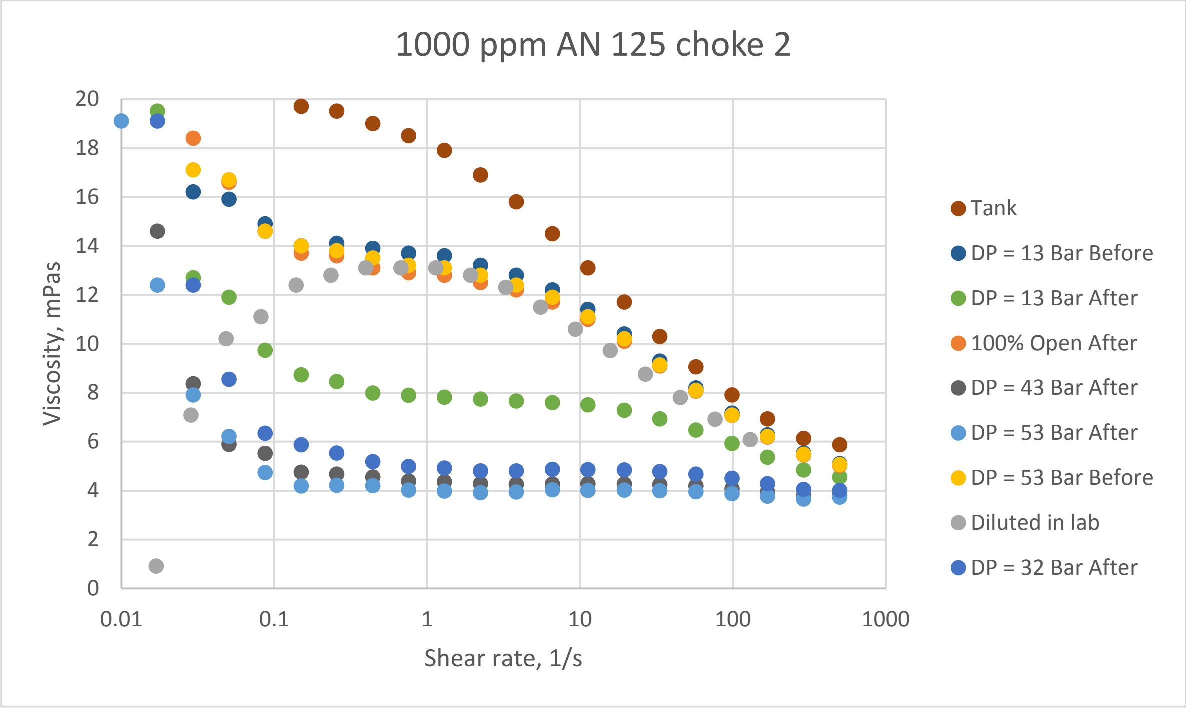


Figure 17 – Polymer viscosity – Test 6.

Table 21 Polymer degradation –Test 6.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
6	2	AN125	1000	Tank	14.5	0.00	-
	2	AN125	1000	0	12.2	17.04	0.00
	2	AN125	1000	13	7.6	51.11	41.07
	2	AN125	1000	32	4.87	71.33	65.45
	2	AN125	1000	43	4.27	75.78	70.80
	2	AN125	1000	53	4.03	77.56	72.95

Test 7 – 2 000 ppm AN125 with Matek choke (Choke 2)

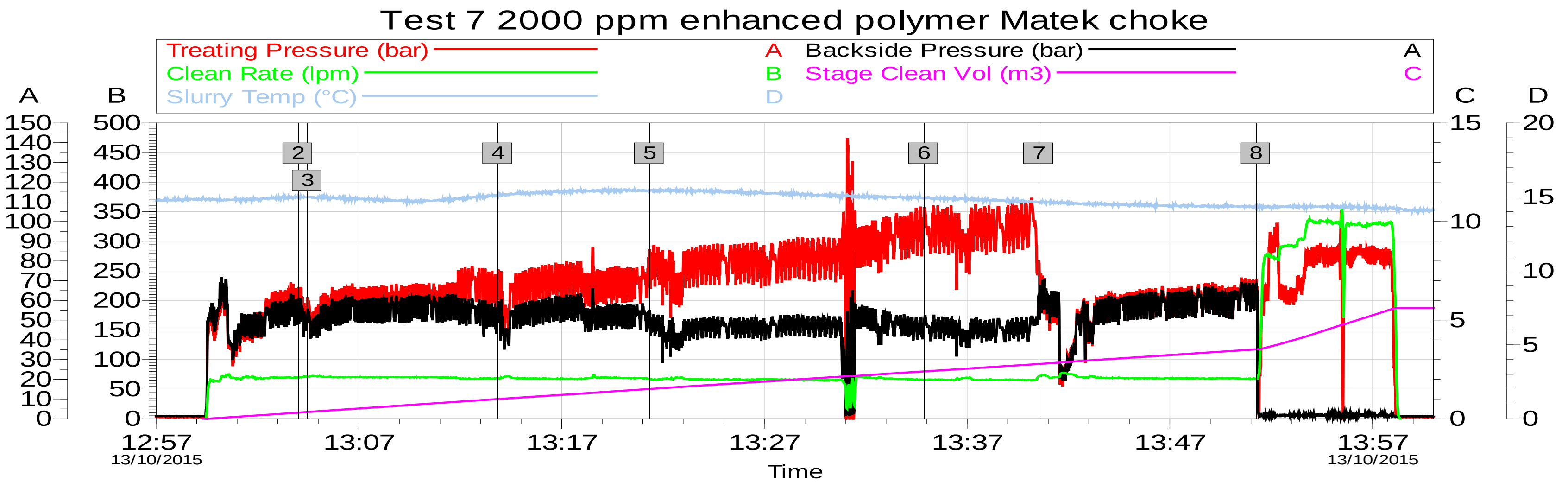
Job Event Log Test 7

Start Time	13-Oct-15 12:56:32	ucts
End Time	13-Oct-15 14:21:03	ucts
Volume	5.617	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	13-Oct-15 12:56:30	Start Job	Starting Job	0.0	0.0	0	
1		12:58:19	Stage 1	NEXT STAGE	0.8	1.2	-1	14.8
		12:58:20	Start Averaging	Start Avg Trt 1	0.8	1.3	-1	14.7
2		12:59:19	Stage 2	NEXT STAGE	0.7	1.3	-1	14.9
	2	13:04:00	Other	Pumping @ 60 bar 49.8% opening on Matek choke	60.7	55.9	70	15.0
	3	13:04:28	Other	Take sample	61.2	55.4	71	15.0
	4	13:13:51	Other	Increase pressure 70bar 42.6% open on Matek choke	69.0	54.0	69	15.1
	5	13:21:21	Other	Increase pressure to80 bar 37.3% open on Matek choke	77.9	50.7	67	15.4
	6	13:34:52	Other	Increase pressure to 100 bar 33% open on Matek choke	105.4	49.6	66	14.9
	7	13:40:32	Other	Open Matek choke to 100%	78.7	63.3	72	14.6
	8	13:51:15	Other	Flushing	68.3	66.3	68	14.4
		14:21:03	End Averaging	End Avg Trt 1	0.7	1.2	-1	13.8

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	9	14:21:05	End Job	Ending Job	0.7	1.2	-1	13.8

Pump chart – Test 7



Global Event Log

2	Pumping @ 60 bar 49.8% opning on Matek choke	13:04:01
3	Take sample	13:04:29
4	Increase pressure 70bar 42.6% open on Matek choke	13:13:52
5	Increase pressure to80 bar 37.3% open on Matek choke	13:21:21
6	Increase pressure to 100 bar 33% opnen on Matek choke	13:34:53
7	Open Matek choke to 100%	13:40:33
8	Flushing	13:51:15

Polymer sample analysis – Test 7

Table 22 Polymer viscosity – Test 7.

	Tank	ΔP = 5 Bar Before	ΔP = 5 Bar After	ΔP = 15 Bar After	ΔP = 35 Bar After	ΔP = 51 Bar After	ΔP = 51 Bar Before	100% Open After	100% Open Before
Polymer	AN125	AN125	AN125	AN125	AN125	AN125	AN125	AN125	AN125
Concentration, ppm	2000	2000	2000	2000	2000	2000	2000	2000	2000
Choke type	2	2	2	2	2	2	2	2	2
Shear rate	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity
1/s	mPas	mPas	mPas	mPas	mPas	mPas	mPas	mPas	mPas
500	9.69	8.64	7.98	7.62	7.02	6.39	8.54	8.11	8.6
291	11	10	9.31	8.9	8	7.06	9.91	9.46	9.97
169	13.1	11.9	11.1	10.6	9.18	7.82	11.8	11.2	11.8
98.7	15.7	14.2	13.2	12.5	10.4	8.5	14.1	13.4	14.1
57.4	18.8	17	15.6	14.6	11.6	9.04	16.8	16.1	16.9
33.4	22.5	20.4	18.4	16.8	12.6	9.4	20.2	19.1	20.2
19.5	26.8	24.3	21.3	19	13.3	9.62	24	22.4	24
11.3	31.7	28.5	24	20.8	13.8	9.72	28.1	25.7	28.2
6.6	37.2	32.9	26.5	22.1	14.1	9.75	32.3	28.7	32.4
3.84	42.9	37	28.3	23	14.2	9.73	36.2	31.2	36.3
2.24	48.7	40.6	29.6	23.6	14.3	9.76	39.6	33	39.7
1.3	54	43.5	30.5	23.9	14.5	9.9	42.2	34.3	42.3
0.758	58.3	45.2	30.9	24	14.6	10	43.8	34.9	43.9
0.441	61.9	46.4	31.3	24.3	14.8	10.3	45	35.5	44.8
0.257	64.4	47.2	31.7	24.7	15.3	10.7	46	36	45.8
0.15	65.9	47.8	31.9	24.8	15.4	11	46.5	36.1	46.3
0.0871	68.8	49.3	33.4	25.8	16.9	11.8	47.6	37.5	47.1
0.0507	70.9	50.2	35.1	27.4	18.6	13.6	49.2	39.3	49.2
0.0295	75	52.1	38.1	29.4	20.2	16.6	52.7	43.2	52.1
0.0172	80.1	53.5	44.1	34.3	24.9	21.1	56.4	46.6	56.9
0.01	95.3	66.6	53.8	42.6	33.7	30.8	62.8	55	66.4

Compared with the 1000 ppm AN125 where the viscosity degradation in open choke was 2% the 2000 ppm AN125 test resulted in 12%. This deviation in degradation through open choke cannot be explained by flow behaviour though the choke. Most likely it is due to combinations of sampling and accuracy in viscosity measurements. However, parallel viscosity measurements reproduced the viscosity reported in Table 22.

Table 23 Polymer degradation – Test 7.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
7	2	AN125	2000	Tank	37.2	0.00	-
	2	AN125	2000	0	32.9	11.88	0.00
	2	AN125	2000	5	26.5	29.56	20.06
	2	AN125	2000	15	22.1	41.71	33.86
	2	AN125	2000	35	14.1	63.81	58.93
	2	AN125	2000	51	9.75	75.83	72.57

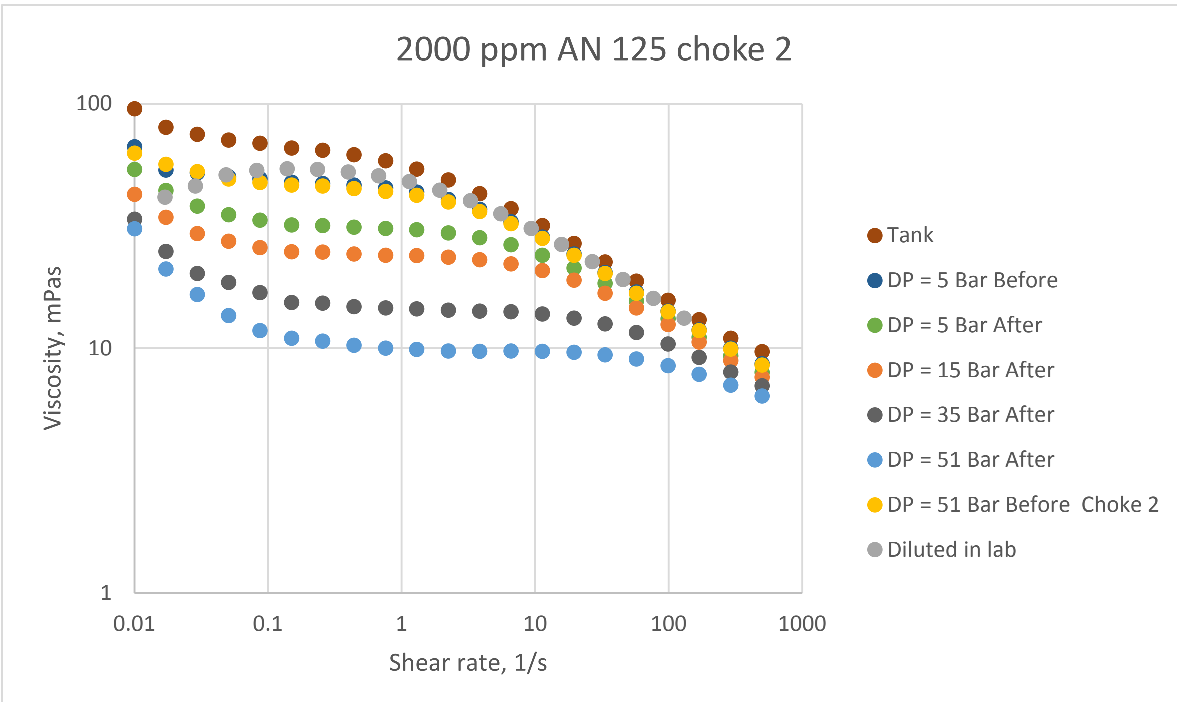


Figure 18 – Polymer viscosity – Test 7.

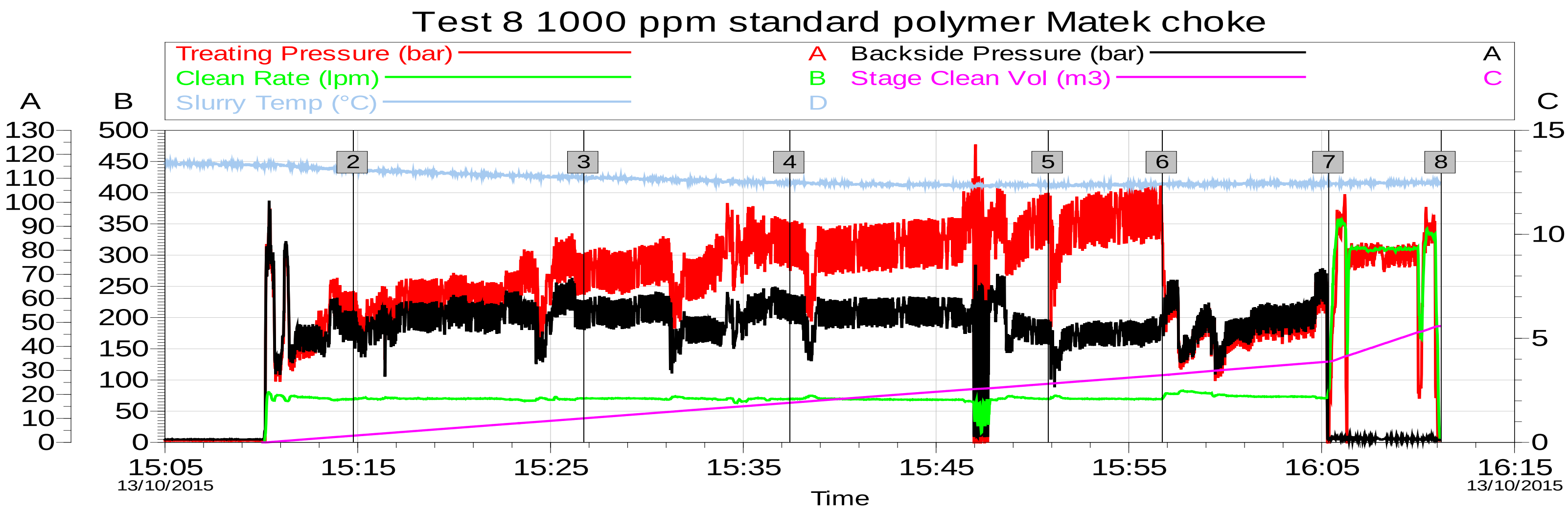
Test 8 – 1 000 ppm 3630 with Matek choke (Choke 2)

Job Event Log Test 8

Start Time	13-Oct-15 14:31:20	
End Time	13-Oct-15 16:11:08	
Volume	5.587	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	13-Oct-15 14:31:18	Start Job	Starting Job	0.8	1.2		13.8
1		15:10:04	Stage 1	NEXT STAGE	0.7	1.2		13.3
		15:10:05	Start Averaging	Start Avg Trt 1	0.7	1.2		13.3
	2	15:14:45	Other	Start pumping @ 60 bar 50% open Matek choke	58.7	51.6	69	13.1
	3	15:26:43	Other	Increase pressure 70 bar 43.9% open on Matek choke	70.9	54.0	70	12.7
	4	15:37:24	Other	Increase pressure to 80 bar 40.2 % open on Matek choke	85.1	57.8	69	12.5
	5	15:50:48	Other	Increase pressure to 100 bar 33.2% open on Matek choke	100.4	49.6	70	12.4
	6	15:56:44	Other	Open Matek choke to 100%	86.7	50.6	70	12.4
	7	16:05:22	Other	Flushing	-0.9	1.2	84	12.4
		16:11:08	End Averaging	End Avg Trt 1	0.8	1.0	12	12.5
	8	16:11:11	End Job	Ending Job	0.8	1.0	8	12.5

Pump chart – Test 8



Global Event Log

2	Start pumping @ 60 bar 50% open Matek choke	15:14:46
3	Increase pressure 70 bar 43.9% open on Matek choke	15:26:44
4	Increase pressure to 80 bar 40.2 % open on Matek choke	15:37:25
5	Increase pressure to 100 bar 33.2% open on Matek choke	15:50:49
6	Open Matek choke to 100%	15:56:44
7	Flushing	16:05:23
8	Ending Job	16:11:12

HALLIBURTON

Polymer sample analysis – Test 8

Table 24 Polymer viscosity – Test 8.

	Tank	ΔP = 13 Bar Before	ΔP = 13 Bar After	ΔP = 32 Bar After	ΔP = 43 Bar After	ΔP = 53 Bar After	ΔP = 53 Bar Before	100% Open Choke After	100% Open Before
Polymer	3630	3630	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000	1000	1000
Choke type	2	2	2	2	2	2	2	2	2
Shear rate	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	Viscosity	
1/s	mPas	mPas	mPas	mPas	mPas	mPas	mPas	mPas	
500	8.81	6.02	5.26	5.01	4.29	3.84	6.02	5.71	6.14
291	9.22	6.46	5.76	5.47	4.45	3.81	6.39	6.25	6.46
169	8.41	7.45	6.63	6.2	4.84	3.99	7.35	7.2	7.44
98.7	9.73	8.73	7.69	7.03	5.23	4.15	8.62	8.44	8.73
57.4	11.7	10.4	8.94	7.62	5.6	4.28	10.2	9.99	10.4
33.4	14	12.3	10.3	8.22	5.86	4.35	12.2	11.9	12.3
19.5	16.9	14.7	11.7	8.88	6.05	4.39	14.5	14.1	14.8
11.3	20.5	17.4	12.9	9.38	6.14	4.41	17.2	16.5	17.5
6.6	24.8	20.3	14	9.67	6.2	4.41	20	19	20.5
3.84	29.8	23.1	14.8	9.83	6.13	4.37	22.8	21.2	23.6
2.24	35.6	25.6	15.2	9.96	6.11	4.4	25.3	23.1	26.3
1.3	41.7	27.6	15.5	10.1	6.24	4.49	27.4	24.6	28.6
0.758	47.5	28.9	15.7	10.2	6.36	4.6	28.7	25.4	30.1
0.441	52.8	30	15.7	10.5	6.52	4.67	29.8	25.9	31.2
0.257	57.4	30.6	16.2	10.8	6.97	4.88	30.4	26.4	31.8
0.15	61.1	30.8	16.2	10.9	7.05	4.82	30.6	26.4	32.4
0.0871	63.5	31.7	16.3	12.1	7.92	5.85	32.1	27.5	33.4
0.0507	67	32.8	17.1	13.4	9.36	6.94	31.3	28.5	35.6
0.0295	71.2	34.4	16.1	15.3	14	8.59	36.5	30.4	37.7
0.0172	74.6	38	18.9	23.1	16.9	11.8	41	33.9	40
0.01	84.6	44.2	22.4	30	23.5	19.3	48.6	37.8	48.3

Viscosity degradation through open choke was for 1000 ppm 3630 was 8%.

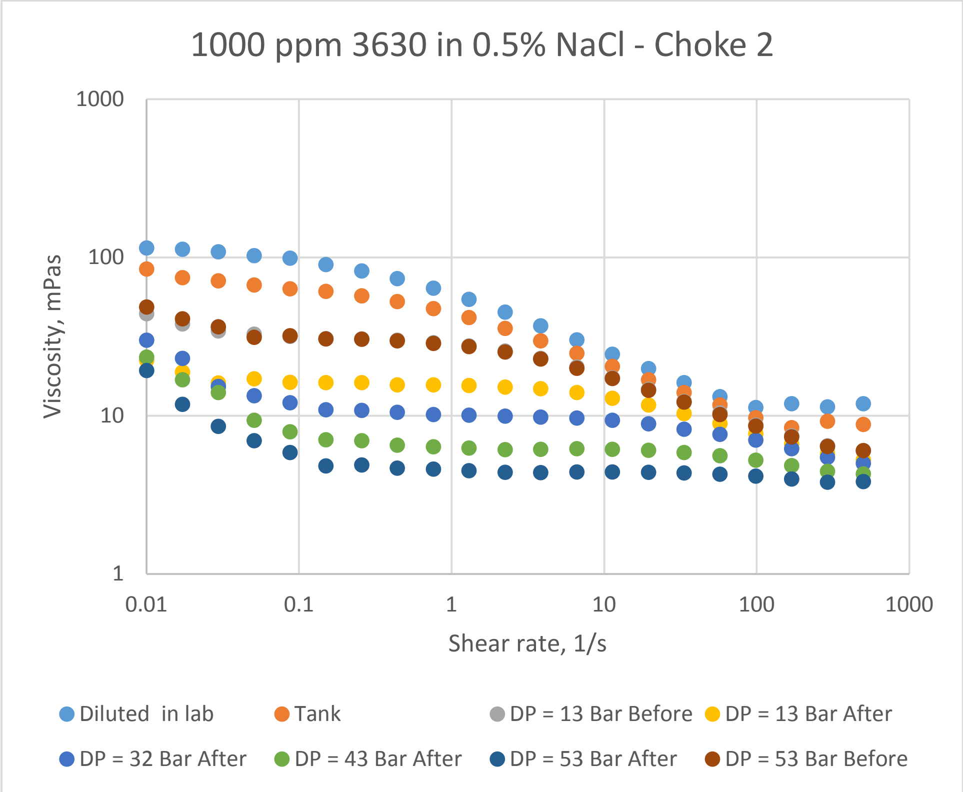


Figure 19 – Polymer viscosity – Test8.

Table 25 Polymer degradation – Test 8.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
8	2	3630	1000	Tank	24.8	0	-
	2	3630	1000	0	20.3	18.9	0.0
	2	3630	1000	13	14	45.4	32.6
	2	3630	1000	32	9.67	63.6	55.1
	2	3630	1000	43	6.2	78.2	73.1
	2	3630	1000	53	4.39	85.8	82.4

Table 26 polymer filtration – Test 8.

Sample	ΔP, bar	Polymer	Conc, ppm	Choke 2 FR	Choke 2 Time, s	Choke 2 Shear rate	SF
Diluted lab		3630	1000	-			
Brine lab		NaCl	5000	-			
Tank		3630	1000	1.098	920	8.32E+03	30.67
Brine Tank		NaCl	5000	1	30	2.55E+05	1.00
Before choke	13	3630	1000	1.065	326	2.35E+04	10.87
Before choke	32	3630	1000	-	-	-	
Before choke	43	3630	1000	-	-	-	
Before choke	53	3630	1000	-	-	-	
After choke	13	3630	1000	1.047	192	3.99E+04	6.40
After choke	32	3630	1000	1.049	125	6.12E+04	4.17
After choke	43	3630	1000	1.038	79	9.69E+04	2.63
After choke	53	3630	1000	1	54	1.42E+05	1.80

Test 9 – 1 000 ppm 3630 with fixed Halliburton chokes 20/64 "and 24/64 "

Job Event Log – Test 9

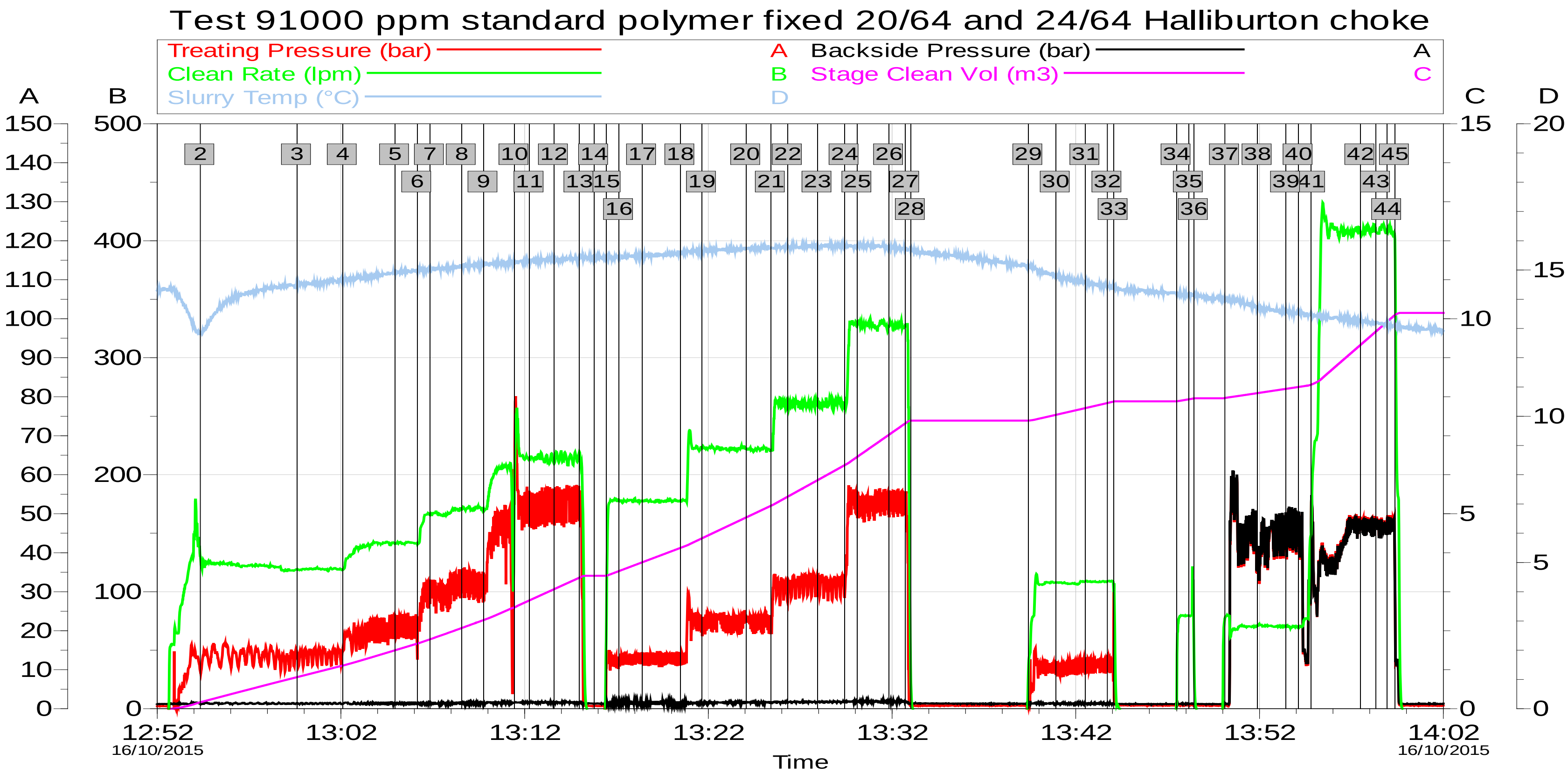
Start Time	16-Oct-15 11:01:35	
End Time	16-Oct-15 14:17:33	
Volume	10.151	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	16-Oct-15 11:01:32	Start Job	Starting Job	0.0	0.0	0	
1		12:52:47	Stage 1	NEXT STAGE	-1.2	1.3	55	14.3
		12:52:48	Start Averaging	Start Avg Trt 1	-1.4	1.3	55	14.4
	2	12:54:20	Other	Flushing sample point	9.6	1.3	130	12.9
	3	12:59:36	Other	Start sampling on 10 bar diff.pressure	14.4	1.5	119	14.4
	4	13:02:06	Other	Finish sampling	15.0	1.2	118	14.7
	5	13:04:56	Other	Start sampling 20 bar dif. pressure	23.9	1.4	141	14.9
	6	13:06:09	Other	Finish sampling	13.8	1.1	141	15.0
	7	13:06:50	Other	Flushing sample point	27.8	1.3	165	15.1
	8	13:08:34	Other	Start sampling 30 bar dif. pressure	34.4	1.5	170	15.1
	9	13:09:45	Other	Finish sampling	34.6	1.6	172	15.1
	10	13:11:26	Other	Changing gear on pump	55.8	1.6	179	15.3
	11	13:12:15	Other	Start flushing sample point	47.6	1.5	213	15.3
	12	13:13:35	Other	Start sampling 50 bar dif. pressure	55.0	1.7	211	15.4

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	13	13:14:58	Other	Finish sampling	54.3	1.7	219	15.5
	14	13:15:46	Other	Stop pumping changing choke to 24/64	0.8	1.3	-1	15.4
	15	13:16:27	Other	Start pumping on 24/64 choke	10.3	1.4	58	15.4
	16	13:17:08	Other	Start flushing	12.3	1.4	179	15.4
	17	13:18:23	Other	Start sampling 10 bar dif. pressure	13.9	1.6	178	15.5
	18	13:20:28	Other	Finish sampling	12.3	1.4	177	15.6
	19	13:21:39	Other	Start flushing sample point	22.0	1.4	223	15.6
	20	13:24:03	Other	Start sampling 20 bar dif. pressure	23.0	1.6	222	15.7
	21	13:25:24	Other	Finish sampling	23.8	1.6	221	15.8
	22	13:26:19	Other	Start flushing	27.9	1.5	263	15.8
	23	13:27:56	Other	Start sampling 30 bar dif. pressure	33.7	1.8	266	15.9
	24	13:29:24	Other	Finish sampling	28.4	1.6	256	15.8
	25	13:30:06	Other	Start flushing sample point	49.2	1.8	328	15.8
	26	13:31:50	Other	Start sampling 50 bar dif. pressure	53.5	1.9	326	15.8
	27	13:32:42	Other	Finish sampling	54.3	1.7	327	15.7
	28	13:33:01	Other	Stop pumping	0.8	1.4	38	15.6
	29	13:39:25	Other	New test 20/64 choke	0.5	1.3	21	15.1
	30	13:40:54	Other	Start flushing	9.1	1.3	108	14.8

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	31	13:42:31	Other	Start sampling 10 bar dif. pressure 20/64 choke	10.4	1.3	109	14.6
	32	13:43:43	Other	Finish sampling	12.3	1.5	109	14.4
	33	13:44:03	Other	Stop pumping	23.1	1.2	105	14.4
	34	13:47:29	Other	Start pumping without screw pump	1.4	1.5	3	14.2
	35	13:48:09	Other	Start flushing	0.9	1.3	79	14.2
	36	13:48:25	Other	Stop pumping	0.8	1.2	76	14.1
	37	13:50:07	Other	Start pumping	1.0	1.2	77	14.0
	38	13:51:53	Other	Start flushing	38.1	38.7	71	13.7
	39	13:53:26	Other	Start sampling without screw pump	41.6	42.1	71	13.5
	40	13:54:07	Other	Finish sampling	48.6	49.3	70	13.5
	41	13:54:48	Other	Increase rate to 400 lpm	48.6	48.9	149	13.4
	42	13:57:29	Other	Start flushing	46.5	46.0	408	13.3
	43	13:58:20	Other	Start sampling without 400 lpm	46.9	46.6	408	13.2
	44	13:58:56	Other	Finish sampling	47.5	47.0	408	13.1
	45	13:59:22	Other	Stop pumping	31.6	31.5	401	13.1
		14:17:33	End Averaging	End Avg Trt 1	0.8	1.3	-1	12.2
	46	14:17:36	End Job	Ending Job	0.8	1.3	-1	12.2

Pump chart – Test 9



Polymer sample analysis – Test 9

Table 27 Viscosity reduction – Fixed chokes, ID = 20/64" and 24/64", Test 9.

Test	Choke	Polymer	Conc ppm	Flow rate lpm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
9	4	3630	1000		Tank	27.6	0.00	-
	4	3630	1000		0	25.4	8.27	0.00
20/64"	4	3630	1000	108	10	14.3	50.00	45.49
	4	3630	1000	141	20	11.8	59.40	55.74
	4	3630	1000	171	31	10	66.17	63.11
	4	3630	1000	214	51	7.8	74.44	72.13
	5	3630	1000		Tank	27.6	0.00	-
	5	3630	1000		0	25.1	9.40	0.00
24/64"	5	3630	1000	177	12	14.1	50.75	45.64
	5	3630	1000	221	21	11.9	59.02	54.77
	5	3630	1000	261	31	10.5	64.29	60.58
	5	3630	1000	328	52	7.9	74.06	71.37

Test 10 – 1 000ppm 3630 with SNF choke system

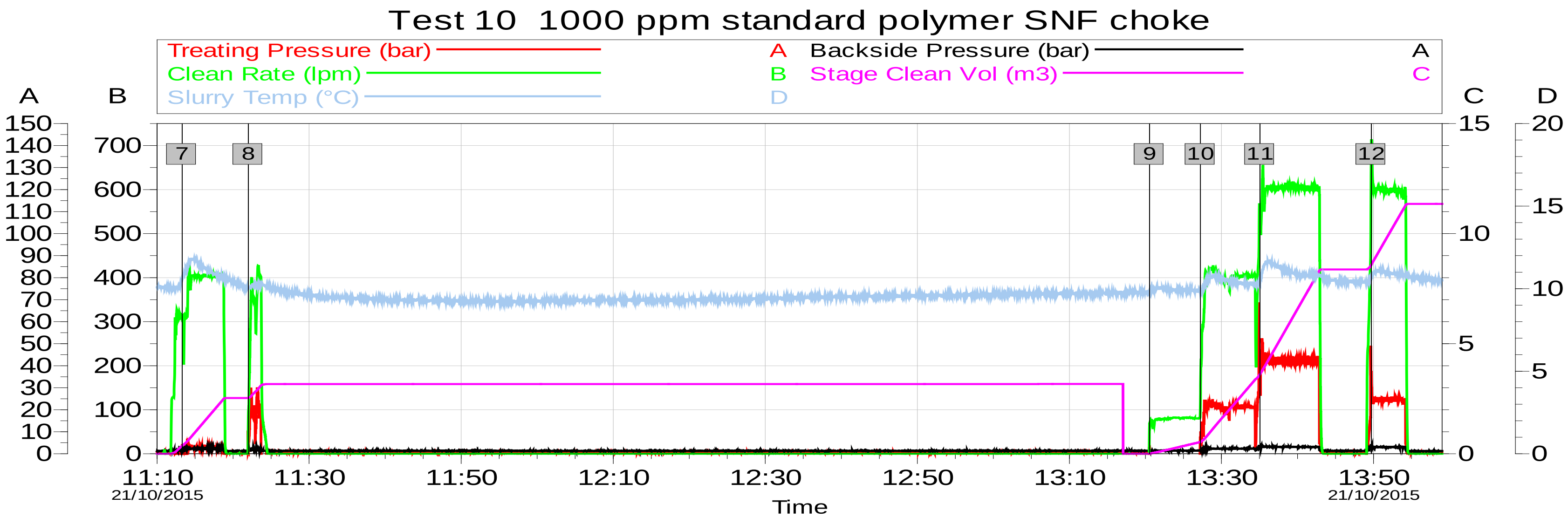
Job Event Log Test 10

Start Time	21-Oct-15 09:02:59	ucts
End Time	21-Oct-15 13:59:42	ucts
Volume	19.872	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	1	21-Oct-15 09:02:57	Start Job	Starting Job	0.2	1.2	-0	
	2	09:49:59	Other	start leak test SNF choke	118.2	119.3	0	
	3	10:00:00	Other	SNF choke test OK	116.9	118.1	0	
1		10:40:05	Stage 1	Reference tester SNF Vann	3.0	1.4	74	9.3
		10:40:06	Start Averaging	Start Avg Trt 1	3.0	1.5	74	9.3
	4	10:50:13	Other	Reference SNF 400m water	49.3	2.1	399	10.7
	5	10:55:14	Other	Reference SNF 200m Vann	28.0	2.0	405	10.7
	6	10:58:27	Other	Reference SNF 50m Vann	7.3	1.9	401	10.6
2		11:07:08	Stage 2	NEXT STAGE	0.5	1.3	0	10.1
	7	11:13:17	Other	Reference test 1000ppm std pol. 50m	-0.5	1.9	316	10.5
	8	11:22:00	Other	Reference SNF 1000ppm std. pol. 200m	0.4	1.5	58	10.0
3		13:17:03	Stage 3	NEXT STAGE	0.5	1.4	0	9.7
	9	13:20:33	Other	Choke test SNF 400m 80L/min w. screw pump 1000ppm std polymer	-1.3	1.5	70	9.7

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
	10	13:27:15	Other	Choke Test SNF 400m 400l/min w. screw pump 1000ppm std polymer	7.3	1.6	157	9.9
	11	13:35:04	Other	Choke test SNF 400m 600l/min w. screw pump 1000 ppm std polymer	36.0	3.0	522	10.6
	12	13:49:43	Other	Choke test SNF 200m 600l/min w. screw pump 1000ppm std polymer	35.6	3.9	698	10.6
		13:59:42	End Averaging	End Avg Trt 1	0.6	1.3	0	10.6
	13	13:59:45	End Job	Ending Job	0.6	1.3	0	10.5

Pump chart – Test 10



Global Event Log		
7	Referanse teest 1000ppm std pol. 50m	11:13:17
8	Referanse S&F 1000ppm std. pol. 200m	11:22:00
9	Choke test S&F 400m 80L/min w. screw pump 1000ppm std polymer	13:20:33
10	Choke Test S&F 400m 400l/min w. screw pump 1000ppm std polymer	13:27:16
11	Choke test S&F 400m 600l/min w. screw pump 1000 ppm std polymer	13:35:05
12	Choke test S&F 200m 600l/min w. screw pump 1000ppm std polymer	13:49:43

Polymer sample analysis – Test 10

Table 28 Polymer viscosity – Test 10.

	Tank	400 lpm ΔP = 20 Bar Before	400 lpm ΔP = 20 Bar After	600 lpm ΔP = 23 Bar Before	600 lpm ΔP = 23 Bar After	600 lpm ΔP = 40 Bar Before	600 lpm ΔP = 40 Bar After	70 lpm Before
Polymer	3630	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000	1000
Choke type	3	3	3	3	3	3	3	3
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	9.47	8.78	8.15	7.7	6.61	7.81	6.55	7.88
291	10.2	8.84	7.78	7.35	7.12	7.3	7.05	7.4
169	9.31	8.67	8.81	8.53	8.3	8.52	8.23	8.48
98.7	10.7	10.5	10.5	10.2	9.85	10.1	9.77	10.1
57.4	13	12.7	12.7	12.2	11.8	12.2	11.7	12.1
33.4	15.8	15.4	15.4	14.8	14.3	14.8	14.2	14.7
19.5	19.4	18.8	18.9	18	17.4	18	17.2	17.8
11.3	23.8	23.1	23.1	22	21.1	21.9	20.9	21.7
6.6	29.4	28.5	28.4	26.8	25.6	26.7	25.2	26.5
3.84	36.1	34.7	34.6	32.1	30.2	31.9	29.6	31.8
2.24	43.8	41.9	41.3	37.7	34.8	37.5	33.9	37.5
1.3	52.4	49.7	48.2	43.2	38.8	42.9	37.7	43.1
0.758	61	57.2	54.6	47.8	42	47.6	40.5	47.8
0.441	68.7	63.8	59.6	51	43.7	50.9	42	51.1
0.257	75.3	69	63.5	53.1	44.5	53	42.8	53
0.15	81	73.8	66.4	54.3	44.9	54.9	43.2	54.6
0.0871	84.3	77.2	68	54.1	43.7	54.7	42.7	54.3
0.0507	86.3	80.6	69.9	56.2	43.7	55.5	43	54.4
0.0295	87.1	87.1	70.3	53.4	42.2	57.9	43.8	51.5
0.0172	87.2	94.1	72.2	49.1	42.3	56.2	43.4	48.9
0.01	81.3	99.2	68.3	50.2	35.5	60.6	48.5	46.9

There was through the tests with Chokes 1 and 2 a general observation that viscosity was degraded from Tank to sampling point before choke. The Choke 2 tests, which was performed at 70 lpm, indicated larger viscosity reduction than for Choke 1 (at 400 lpm). To verify the hypothesis that the viscosity reduction through the pump was rate dependent, samples from choke 3 was taken at flow rate of 70, 400 and 600 lpm. As can be seen from the viscosity data, the degradation at 70 and 600 lpm was approximately the same, while the viscosity reduction at 400 lpm was slightly less. Rate dependent viscosity reduction through the pumps may therefore be ruled out.

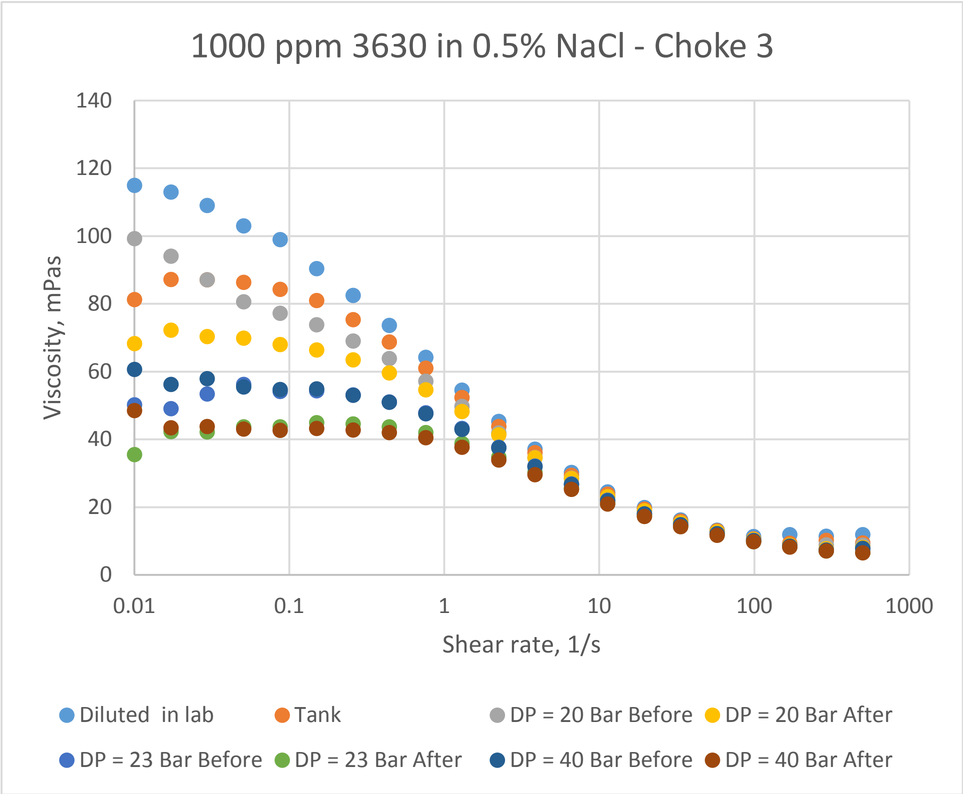


Figure 20 – Polymer viscosity – Test 10.

Table 29 Polymer degradation – Test 10.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
10	3	3630	1000	Tank	29.4	0.00	-
	3	3630	1000	0	28.5	3.17	0.00
	3	3630	1000	20	28.4	3.52	0.36
	3	3630	1000	23	26.8	9.15	6.18
	3	3630	1000	40	26.7	9.51	6.55

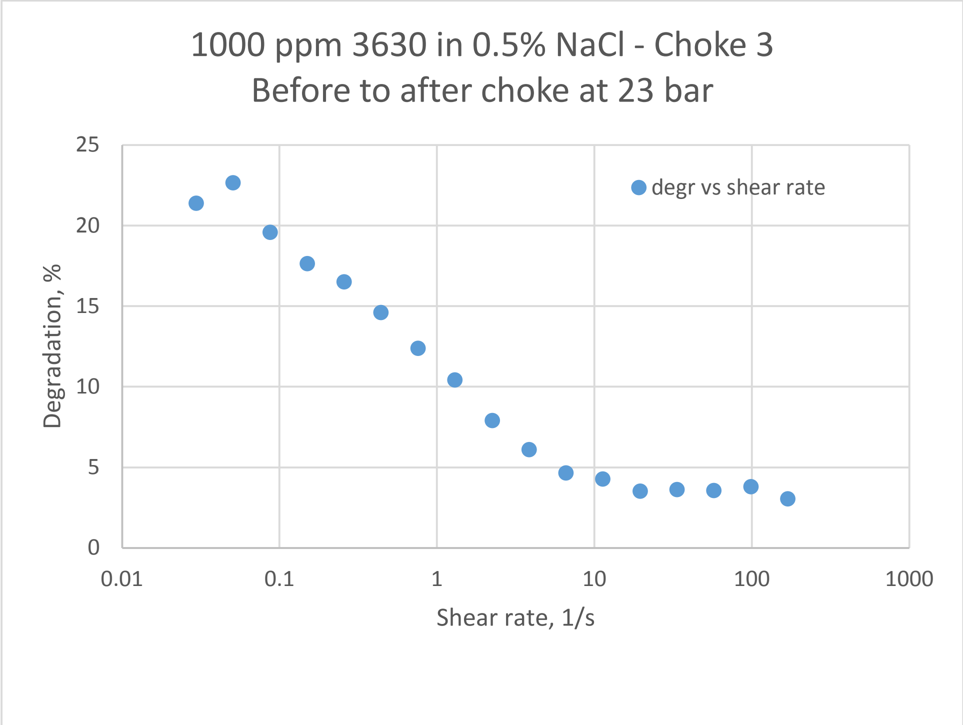


Figure 21 – Viscosity degradation, showing the effect of at which shear rate the degradation is derived – Test 10.

Table J2 above shows that the polymer degradation in this test is significantly lower during the Choke 1 and 2 tests. At the shear rate of 6.6 s^{-1}, the degradtion is less than 10%. However, as shown in Fig. J2, the degradtion depends strongly on at which shear rate the degradation is calculated. This is however a common observation for all degradation experiments.

Table 30 Polymer filtration – Test 10.

Sample	ΔP, bar	Polymer	Conc, ppm	Choke 3 FR	Choke 3 Time, s	Choke 3 Shear rate	SF
Diluted lab		3630	1000	-	-	-	
Brine lab		NaCl	5000	-	-	-	
Tank		3630	1000	1.06	806	9.50E+03	26.87
Brine Tank		NaCl	5000	1.00	30	2.55E+05	1.00
Before choke	20	3630	1000	1.04	466	1.64E+04	15.53
Before choke	23	3630	1000	-	-	-	
Before choke	40	3630	1000	-	-	-	
After choke	20	3630	1000	1.04	556	1.38E+04	18.53
After choke	23	3630	1000	1.02	333	2.30E+04	11.10
After choke	40	3630	1000	1.02	329	2.33E+04	10.97

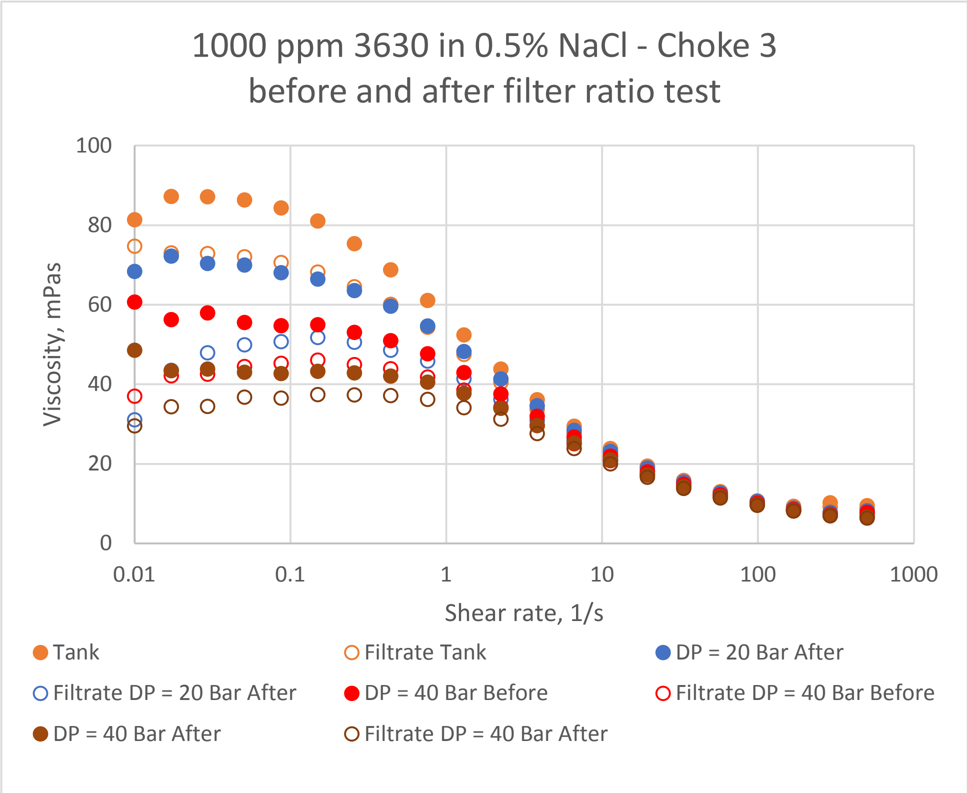


Figure 22 – Viscosity degradation, effect of filtration – Test 10.

From the Choke 1 and Choke 2 tests, the degradation through the filter was marginal. Figure 22 shows that this is not valid for choke 3; at all four test combinations, the filtrate was significantly degraded. For the test samples at 20 to 40 bar, this is explained by the high shear rate through the filter (1-2E+04 s-1) which will degrade the polymer. For comparison, the same or even high shear rates did not further degrade the polymer in choke 1 and 2. This is because in these tests the polymer was already severely degraded through the choke.

Compared with test 1, shear rate of 1.4E+03 s^{-1} did not degrade the polymer while shear rate of 9.5E+03 s^{-1} in test 10 did.

Table 31 Polymer viscosity after filtration – Test 10.

	Filtrate Tank	Filtrate 400 lpm ΔP = 20 Bar Before	Filtrate 400 lpm ΔP = 20 Bar After	Filtrate 600 lpm ΔP = 23 Bar Before	Filtrate 600 lpm ΔP = 23 Bar After	Filtrate 600 lpm ΔP = 40 Bar Before	Filtrate 600 lpm ΔP = 40 Bar After
Polymer	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000
Choke type	3	3	3	3	3	3	3
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	8.7		7.5		6.4	6.95	6.3
291	9.16		7.23		6.96	7.12	6.93
169	8.59		8.4		8.11	8.28	8.07
98.7	10.4		9.99		9.61	9.82	9.55
57.4	12.5		12		11.5	11.8	11.4
33.4	15.2		14.5		13.9	14.2	13.8
19.5	18.5		17.5		16.8	17.2	16.6
11.3	22.6		21.3		20.2	20.8	20
6.6	27.7		25.8		24.1	25	23.8
3.84	33.7		30.9		28.1	29.6	27.6
2.24	40.4		36.2		31.8	34.2	31.2
1.3	47.5		41.4		35	38.5	34.1
0.758	54.3		45.8		37.3	41.8	36.2
0.441	60.1		48.5		38.1	43.9	37.1
0.257	64.5		50.5		38.4	44.9	37.3
0.15	68.2		51.7		38.6	46	37.4
0.0871	70.6		50.7		37.4	45.2	36.5
0.0507	72		49.9		36.1	44.4	36.7
0.0295	72.8		47.9		34.5	42.5	34.4
0.0172	73		43.5		30.4	42.1	34.3
0.01	74.7		31		26.2	37	29.5

Test 11 – 2 000 ppm 3630 and 1 000 ppm AN125 with SNF choke system (Choke 3)

Job Event Log Test 11

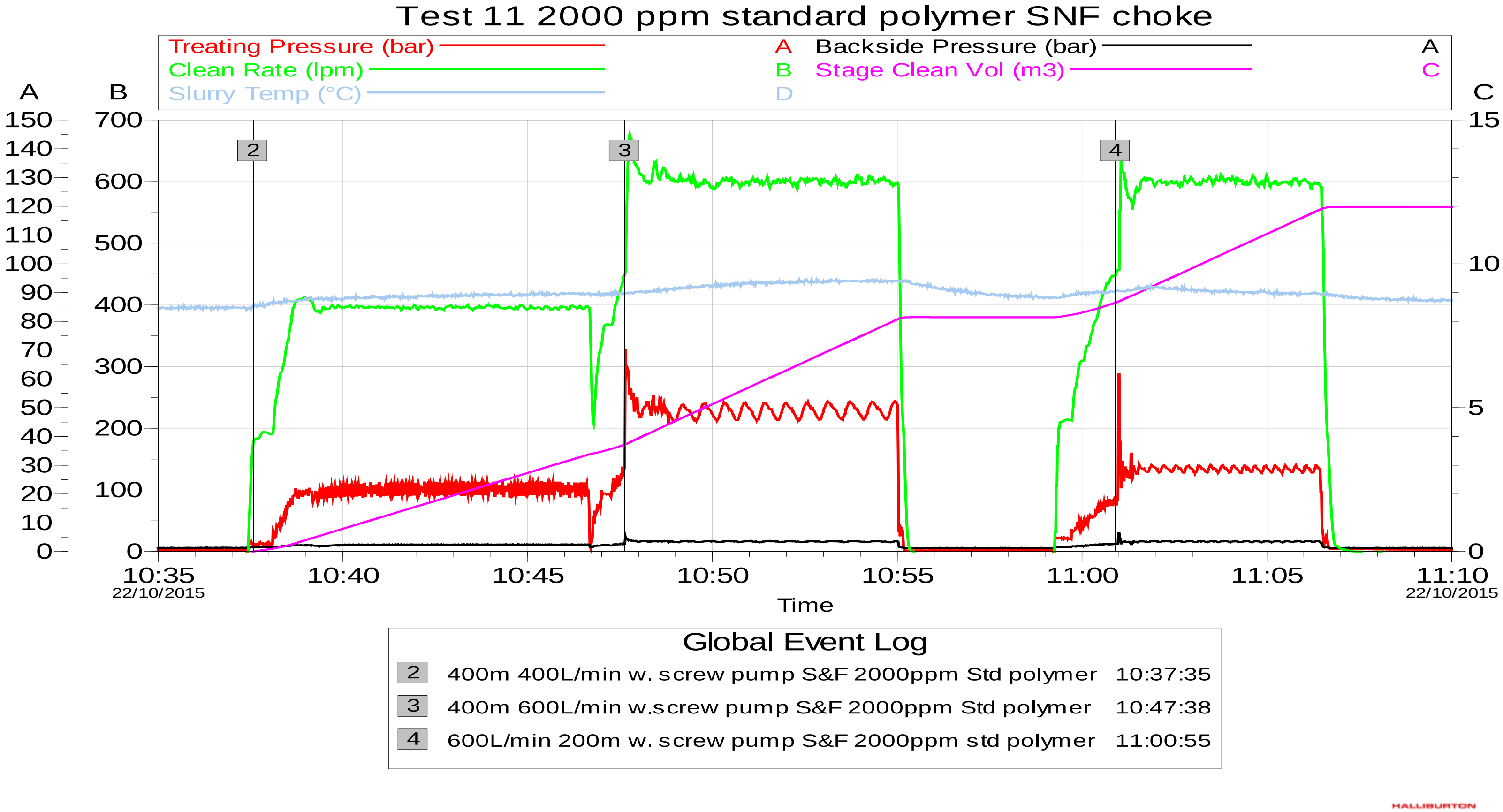
Start Time	22-Oct-15 08:34:26	
End Time	22-Oct-15 14:02:04	
Clean Volume	24.335	m³

Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Stage Clean Vol m³	Slurry Temp °C
	1	22-Oct-15 08:34:24	Start Job	Starting Job	0.5	1.2	-0	14.165	11.5
1		10:36:28	Stage 1	NEXT STAGE	0.5	1.3	-0	-0.014	11.3
		10:36:29	Start Averaging	Start Avg Trt 1	0.5	1.3	-0	-0.014	11.3
2		10:36:44	Stage 2	S&F 2000ppm Std polymer	0.5	1.4	-0	-0.014	11.3
	2	10:37:34	Other	400m 400L/min w. screw pump S&F 2000ppm Std polymer	2.7	1.5	175	0.001	11.3
	3	10:47:37	Other	400m 600L/min w.screw pump S&F 2000ppm Std polymer	29.4	2.7	447	3.709	11.9
	4	11:00:54	Other	600L/min 200m w. screw pump S&F 2000ppm std polymer	18.1	2.6	448	8.646	12.1
3		13:33:33	Stage 3	NEXT STAGE	0.6	1.3	-0	11.970	11.8
	5	13:34:02	Other	Choke test S&F 400m 400L/min 1000ppm Enh. Polymer	12.0	1.9	211	11.980	11.8

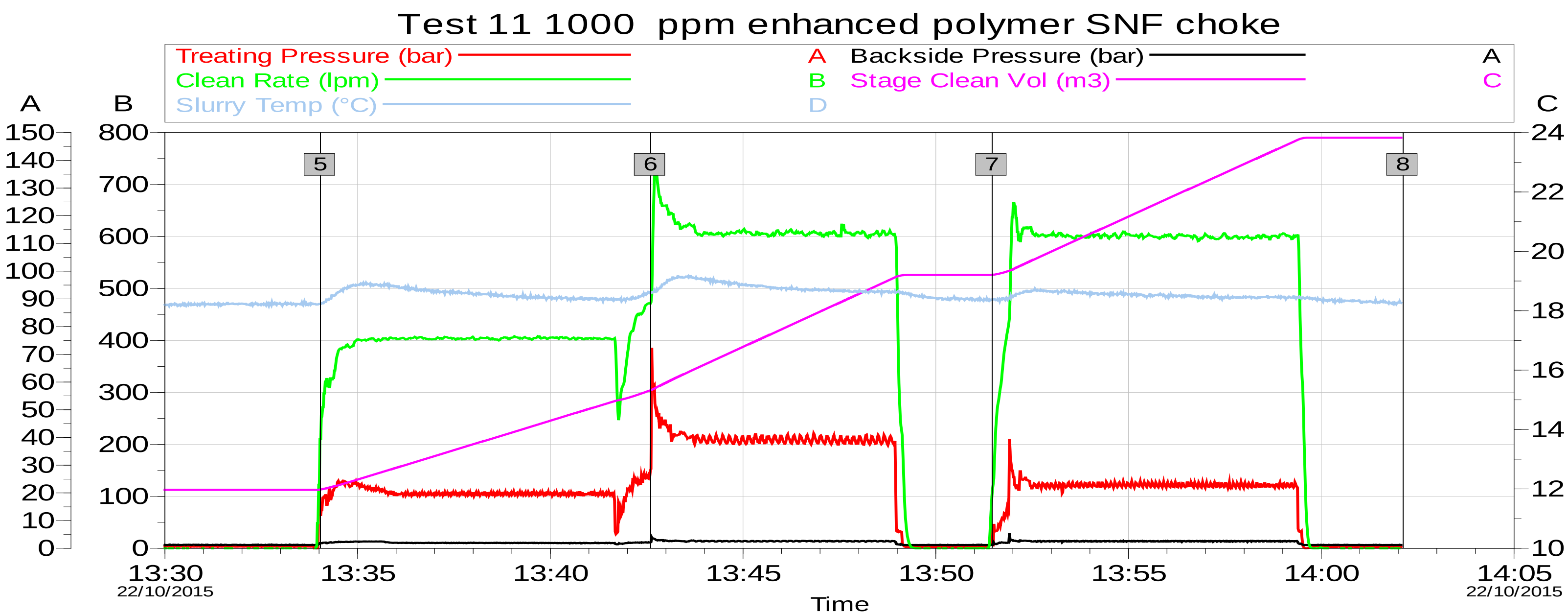
Stage Number	Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Stage Clean Vol m³	Slurry Temp °C
	6	13:42:36	Other	Choke test S&F 400m 600L/min 1000ppm enh. Polymer	28.3	2.2	471	15.322	12.3
	7	13:51:27	Other	Choke test S&F 200m & 600L/min 1000ppm enh. Polymer	4.6	1.3	100	19.211	12.0
		14:02:04	End Averaging	End Avg Trt 1	0.5	1.2	-0	23.828	11.8
	8	14:02:07	End Job	Ending Job	0.5	1.2	-0	23.828	11.8

Pump chart – Test 11a

Test 11 2000 ppm standard polymer SNF choke



Pump chart – Test 11b



Global Event Log

5	Choke test S&F 400m 400L/min 1000ppm Enh. Polymer	13:34:02
6	Choke teest S&F 400m 600L/min 1000ppm enh. Polymer	13:42:36
7	Choke test S&F 200m & 600L/min 1000ppm enh. Polymer	13:51:28
8	Ending Job	14:02:07

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Polymer sample analysis – Test 11

Table 32 Polymer viscosity – Test 11a.

	Tank	400 lpm ΔP = 18 Bar Before	400 lpm ΔP = 18 Bar After	600 lpm ΔP = 25 Bar Before	600 lpm ΔP = 25 Bar After	600 lpm ΔP = 44 Bar Before	600 lpm ΔP = 44 Bar After
Polymer	3630	3630	3630	3630	3630	3630	3630
Concentration, ppm	2000	2000	2000	2000	2000	2000	2000
Choke type	3	3	3	3	3	3	3
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	16.8	14.3	14.1	13.9	14.1	14.8	12.8
291	19.4	14.3	14.1	14.2	14.2	14.7	14.1
169	19	17.7	17.7	17.8	17.8	17.9	17.6
98.7	23.7	22.5	22.5	22.6	22.7	22.9	22.3
57.4	30.9	28.9	28.9	29.1	29.2	29.5	28.7
33.4	40.4	37.5	37.5	37.8	37.9	38.4	37.3
19.5	53.2	49.2	49.3	49.7	49.9	50.4	49
11.3	70.7	65.1	65.3	65.9	66.1	66.9	64.9
6.6	94.6	86.6	86.9	87.8	88.2	89.2	86.6
3.84	127	115	115	117	117	119	115
2.24	170	151	152	154	155	158	152
1.3	225	196	197	200	202	206	197
0.758	293	246	247	252	256	262	247
0.441	371	298	300	307	312	323	300
0.257	458	350	351	360	369	386	351
0.15	555	401	401	411	425	450	399
0.0871	657	446	445	457	475	510	439
0.0507	763	484	481	495	520	566	474
0.0295	875	519	516	532	555	617	502
0.0172	989	547	544	555	589	663	524
0.01	1110	569	568	586	621	703	540

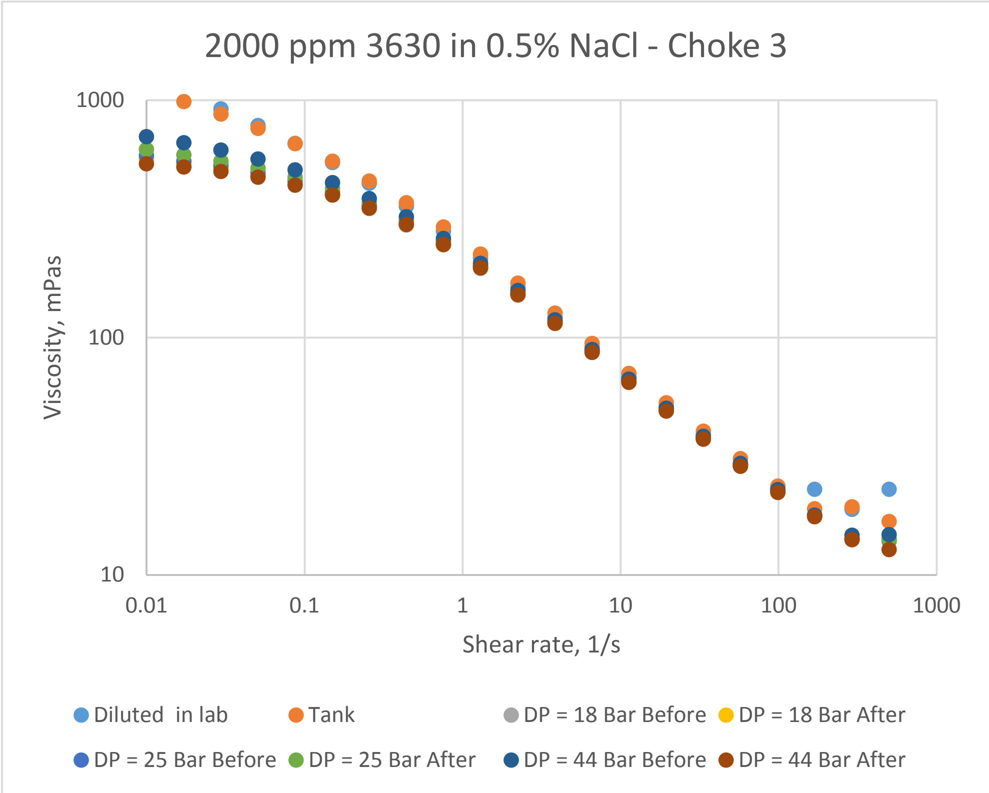


Figure 23 – Viscosity degradation – Test 11a.

Table 33 Polymer degradation – Test 11a.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
11	3	3630	2000	Tank	94.6	0.00	-
	3	3630	2000	0	86.6	8.55	0.00
	3	3630	2000	18	86.9	8.23	-0.35
	3	3630	2000	25	88.2	6.84	-1.87
	3	3630	2000	44	86.6	8.55	0.00

Table 34 Polymer viscosity –Test 11b.

	Tank	400 lpm ΔP = 17 Bar Before	400 lpm ΔP = 17 Bar After	600 lpm ΔP = 20 Bar Before	600 lpm ΔP = 20 Bar After	600 lpm ΔP = 38 Bar Before	600 lpm ΔP = 38 Bar After
Polymer	AN125	AN125	AN125	AN125	AN125	AN125	AN125
Concentration, ppm	1000	1000	1000	1000	1000	1000	1000
Choke type	3	3	3	3	3	3	3
Shear rate 1/s	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas	Viscosity mPas
500	5.94	5.28	5.6	5.2	5.11	5.22	5.11
291	6.14	5.71	6.09	5.61	5.52	5.63	5.52
169	6.91	6.47	6.93	6.34	6.25	6.36	6.26
98.7	7.88	7.4	7.97	7.23	7.14	7.25	7.15
57.4	8.99	8.48	9.19	8.26	8.16	8.29	8.18
33.4	10.2	9.64	10.5	9.36	9.23	9.4	9.25
19.5	11.6	10.8	12	10.5	10.3	10.6	10.4
11.3	13	12	13.3	11.6	11.3	11.6	11.3
6.6	14.5	13	14.8	12.6	12.2	12.6	12.3
3.84	15.7	13.7	15.8	13.3	12.8	13.4	12.8
2.24	16.7	14.2	16.5	13.8	13.1	13.8	13.1
1.3	17.5	14.5	17.1	14.3	13.4	14	13.3
0.758	18	14.7	17.5	14.6	13.5	14.2	13.5
0.441	18.1	14.7	17.8	15.2	13.5	14.2	13.7
0.257	17.7	14.6	18.2	15.9	13.5	14.4	14.2
0.15	17.6	15.4	19.2	19.3	14.1	14.5	14.7
0.0871	16.7	15.2	19.6	22	14	14.2	15.5
0.0507	15.1	17.2	21.6	28.2	15.5	15.4	18.2
0.0295	14.2	17.2	24.8	41	17.9	16.9	23.8
0.0172	8.44	18.4	37.4	58.2	21.7	19.1	28.3
0.01	7.63	22.2	53.1	88.2	28.2	31.8	40.7

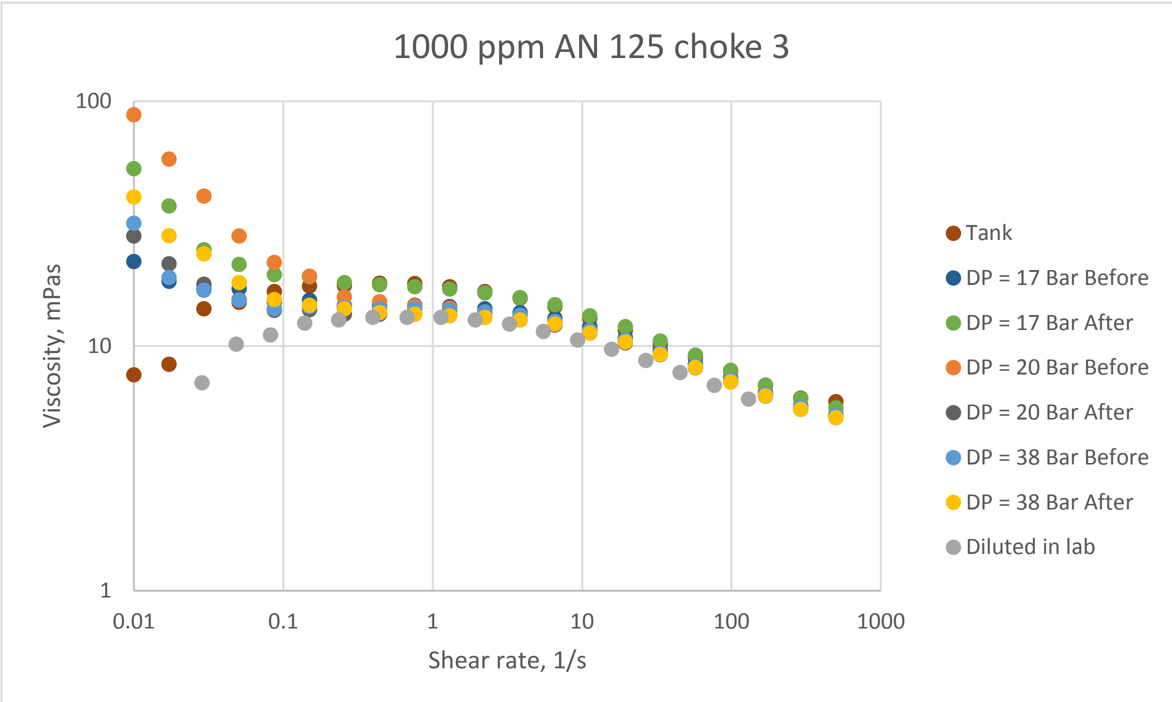


Figure 24 – Viscosity degradation – Test 11b.

Table 35 Polymer degradation – Test 11b.

Test	Choke	Polymer	Conc ppm	ΔP Bar	Viscosity at 6.6 s^-1 mPas	Degradation Relative to Tank %	Degradation before -after choke %
11b	3	AN125	1000	Tank	14.5	0.00	-
	3	AN125	1000	0	13	11.11	0.00
	3	AN125	1000	17	14.8	-2.22	-15.00
	3	AN125	1000	20	12.2	17.04	6.67
	3	AN125	1000	38	12.3	16.30	5.83

Table 36 Polymer filtration – Test 11b.

Sample	ΔP, bar	Polymer	Conc, ppm	Choke 3 FR	Choke 3 Time, s	Choke 3 Shear rate	SF
Diluted lab		AN125	1000	-	-	-	
Brine lab		NaCl	5000	-	-	-	
Tank		AN125	1000	1.06	258	2.97E+04	8.60
Brine Tank		NaCl	5000	1.00	30	2.55E+05	1.00
Before choke	17	AN125	1000	1.02	159	4.81E+04	5.30
Before choke	20	AN125	1000	-	-	-	
Before choke	38	AN125	1000	-	-	-	
After choke	17	AN125	1000	1.05	181	5.32E+04	6.03
After choke	20	AN125	1000	1.02	144	5.63E+04	4.80
After choke	38	AN125	1000	1.02	136	5.63E+04	4.53

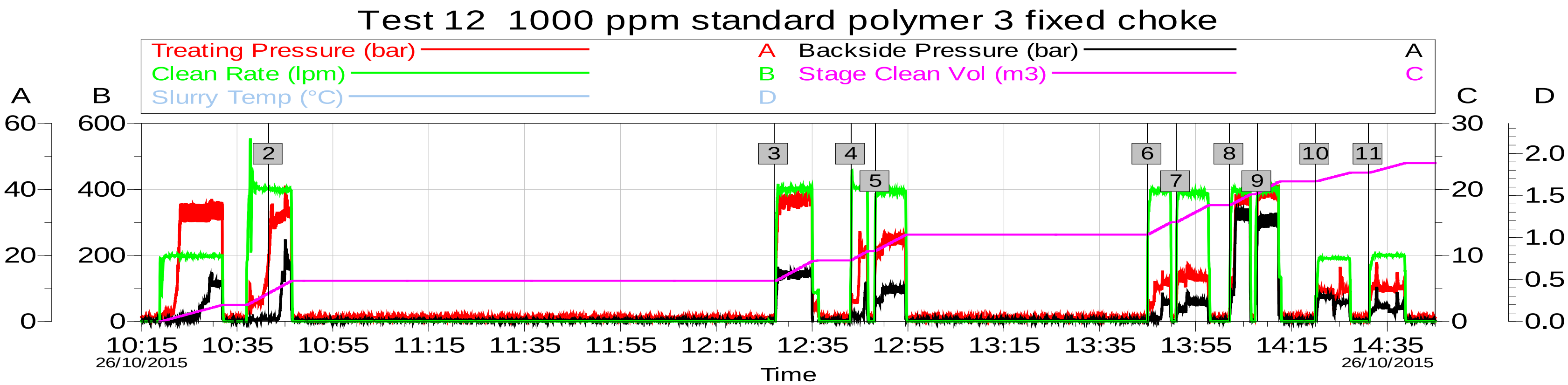
Test 12 – 1 000 ppm standard polymer through 3 fixed chokes (1st round)

Job Event Log – Test 12

Start Time	26-Oct-15 09:34:52	
End Time	27-Oct-15 08:38:04	
Clean Volume	23.970	m³

Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Slurry Temp °C
1	26-Oct-15 09:34:52	Start Job	Starting Job	1.4	0.2	-0	8.3
2	10:41:36	Other	establishing choke levels	20.0	0.9	402	10.0
3	12:27:03	Other	1000ppm std polymer, 3 chokes 50-32-16-0 bar	1.2	0.3	0	12.7
4	12:43:07	Other	adjusting chokes	6.4	1.4	179	13.1
5	12:48:14	Other	1000ppm standard, 3 chokes 30-20-10-0 bar	17.9	5.2	363	12.6
6	13:44:58	Other	establishing choke positions before test	4.6	0.7	50	11.8
7	13:50:57	Other	trying to achieve 15-10-5-0 bar drop	4.1	-0.5	90	11.9
8	14:02:03	Other	establishing rate for 5 bar drop	1.2	0.3	-0	11.7
9	14:07:53	Other	1000ppm std polymer5-10 bar drop pr. choke	35.7	26.9	373	11.9
10	14:19:59	Other	establishing choke opening	4.2	2.7	0	11.6
11	14:31:05	Other	1000ppm std. polymer, 15-10-5-0 bar drop	1.3	0.3	-0	11.5
12	27-Oct-15 08:38:04	End Job	Ending Job	1.3	0.1	-0	8.2

Pump chart – Test 12



Global Event Log

2	establishing choke levels	10:41:37
3	1000ppm std polymer, 3 chokes 50-32-16-0 bar	12:27:03
4	adjusting chokes	12:43:08
5	1000ppm standard, 3 chokes 30-20-10-0 bar	12:48:14
6	establishing choke positions before test	13:44:58
7	trying to achive 15-10-5-0 bar drop	13:50:58
8	establishing rate for 5 bar drop	14:02:04
9	1000ppm std polymer5-10 bar drop pr. choke	14:07:53
10	establishing choke opening	14:20:00
11	1000ppm std. polymer, 15-10-5-0 bar drop	14:31:06

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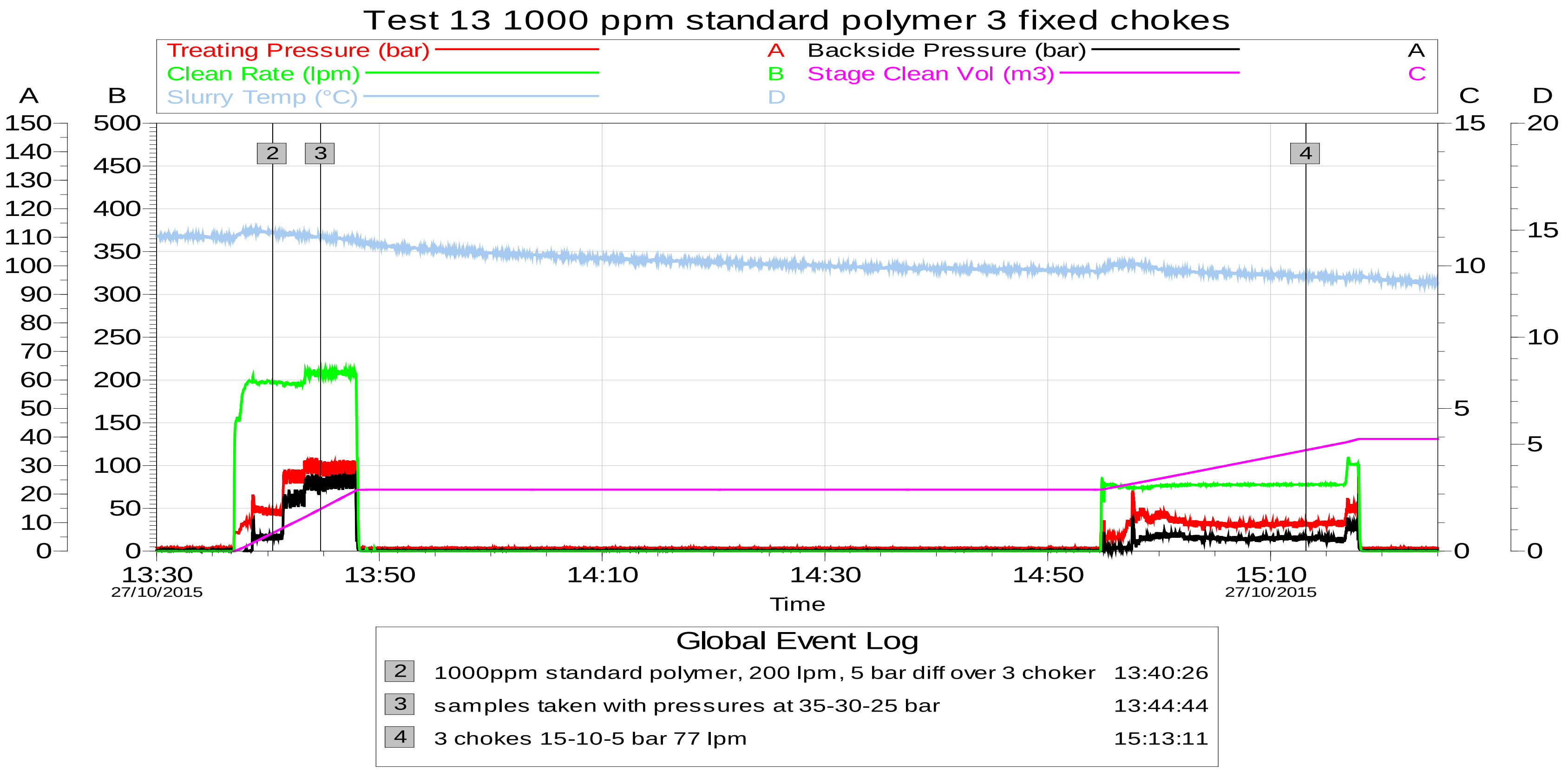
Note. The pressure readings on the chart are logged after the first choke valve and after the second choke valve. The pressure before the first choke was recorded manually

Test 13 – 1 000 ppm standard polymer through 3 fixed choke (2^{nd} round control test)

Job Event Log Test 13

Event Number	Time ucts	Description	Comment	Treating Pressure bar	Backside Pressure bar	Clean Rate L/min	Stage Clean Vol m³	Slurry Temp °C
1	27-Oct-15 13:23:06	Start Job	Starting Job	1.1	0.4	-0	-0.000	14.7
2	13:40:25	Other	1000ppm standard polymer, 200 lpm, 5 bar diff over 3 choker	13.7	5.0	197	0.636	14.9
3	13:44:44	Other	samples taken with pressures at 35-30-25 bar	29.9	24.2	210	1.479	14.6
4	15:13:11	Other	3 chokes 15-10-5 bar 77 lpm	10.0	5.0	78	3.540	12.8
5	16:04:25	End Job	Ending Job	1.2	0.3	-0	3.935	12.6

Pump chart – Test 13



Note. The pressure readings on the chart are logged after the first choke valve and after the second choke valve. The pressure before the first choke was recorded manually

Polymer sample analysis – Tests 12 and 13

Three choke valves were put in series and SNF sampling devices were placed after choke valve 1 and after choke valve 2. Sampling after choke 3 at atmospheric pressure was performed by standard sampling. Pressure reading was performed before and after choke 2. Outlet pressure was atmospheric pressure, while choke valve 1 was adjusted to same opening and differential pressure as choke 2. The line pressure as well as differential choke valve pressure are tabulated in Table L1 below. To be able to produce stable differential pressure in the range of 5 to 20 bar, the flow rate was varied, e.g. in the first experiment, Test 12a, the flow rate was 400 lpm, and the differential pressures were 15, 15 and 25 bar, while in Test 13b, the flow rate was 78 lpm and the differential pressures were 5, 5 and 5 bar.

In Test 12 the tank viscosity was 27. 5 mPas, while in Test 13 the tank viscosity was 21.9 mPas. From previous tests some viscosity reduction was observed from the tank to the sampling point before choke. In these tests, no sampling was performed before the first choke. In the estimation of viscosity degradation it was assumed that viscosity degradation before first choke will be similar as those measured in the previous tests. Therefore the viscosity before choke 1 of 24.8 mPas (Test 12) and 19.2 in Test 13a) are estimated.

Table 37 Polymer degradation – Tests 12 and 13.

	Test	Tank	Before Choke 1	After Choke 1	After Choke 2	After Choke 3
12a	Q, lpm	400				
	Pressure, bar		55	40	25	0
	DP, bar			15	15	25
	Visc, mPas	27.5	24.8	11.6	8.69	8.26
	Degradation, %		0	55.4	67.7	69.5
12b	Q, lpm	363				
	Pressure, bar		29	21	13	0
	DP, bar			8	8	13
	Visc, mPas	27.5	24.8	16.4	12.5	12
	Degradation, %		0	35.2	51.6	53.7
12c	Q, lpm	373				
	Pressure, bar		22	16	10	0
	DP, bar			6	6	10
	Visc, mPas	27.5	24.8	20.5	20.3	19.5
	Degradation, %		0	18.0	18.8	22.2
13a	Q, lpm	200				
	Pressure, bar		36	31	26	0
	DP, bar			5	5	26
	Visc, mPas	21.9	19.2	15.1	15.3	10.2
	Degradation, %		0	22.6	21.5	49.5
13b	Q, lpm	78				
	Pressure, bar		15	10	5	0
	DP, bar			5	5	5
	Visc, mPas	21.9	21.9	19	19.1	16.3
	Degradation, %		0	13.9	13.4	26.8

Polymer samples pH measurements.

Table 38 pH in polymer samples, Choke 1 to 3.
SNF mother solutions at 15000 ppm diluted in 0.5% NaCl brine

Sample	ΔP, bar	Polymer	Conc, ppm	Choke 1 pH	Choke 2 pH	Choke 3 pH	Polymer	Conc, ppm	Choke 1 pH	Choke 2 pH	Choke 3 pH
Diluted lab		3630	1000	7.77	-	-	AN 125	1000	7.75	-	-
Diluted lab		3630	2000	7.79	-	-	AN 125	2000	7.73	-	-
Diluted lab		3630	10000	7.25	-	-	AN 125	10000	-	-	-
Brine lab		NaCl	5000	7.96	-	-	NaCl	5000	-	-	-
Tank		3630	1000	7.65	7.69	7.53	AN 125	1000	7.73	8.23	7.87
Tank		3630	2000	7.36	-	7.37	AN 125	2000	7.70	7.84	-
Brine Tank		NaCl	5000	8.07	8.92	8.15	NaCl	5000	8.87	8.92	8.16
Before choke	Full opening	3630	1000	-	7.80	-	AN125	1000	-	8.16	-
Before choke	10	3630	1000	7.58	7.76	-	AN 125	1000	7.69	8.22	-
Before choke	20	3630	1000	7.58	7.74	7.67	AN 125	1000	7.75	8.20	7.86
Before choke	30	3630	1000	7.59	7.75	7.68	AN 125	1000	7.74	8.28	7.84
Before choke	50	3630	1000	7.61	7.79	7.64	AN 125	1000	7.77	8.20	7.74
After choke	Full opening	3630	1000	-	7.77	-	AN 125	1000	-	7.95	-
After choke	10	3630	1000	7.56	7.62	-	AN 125	1000	7.80	8.18	-
After choke	20	3630	1000	7.55	7.69	7.66	AN 125	1000	7.78	7.97	7.63
After choke	30	3630	1000	7.58	7.66	7.68	AN 125	1000	7.79	8.01	7.77
After choke	50	3630	1000	7.59	7.74	7.60	AN 125	1000	7.81	8.15	7.70
Before choke	Full opening	3630	1000	-	-	-	AN 125	2000	-	7.94	-
Before choke	10	3630	2000	7.38	-	-	AN 125	2000	7.72	7.85	-
Before choke	20	3630	2000	7.32	-	7.38	AN 125	2000	7.74	7.87	-
Before choke	30	3630	2000	7.32	-	7.40	AN 125	2000	7.75	7.89	-
Before choke	50	3630	2000	7.39	-	7.44	AN 125	2000	7.74	7.81	-
After choke	Full opening	3630	2000	-	-	-	AN 125	2000	-	7.92	-
After choke	10	3630	2000	7.35	-	-	AN 125	2000	-	7.89	-
After choke	20	3630	2000	7.34	-	7.36	AN 125	2000	7.73	7.84	-
After choke	30	3630	2000	7.44	-	7.43	AN 125	2000	7.76	7.82	-
After choke	50	3630	2000	7.44	-	7.39	AN 125	2000	7.75	7.91	-
Before choke	10	3630	10000	6.99	-	-	AN 125	10000	-	-	-
Before choke	20	3630	10000	7.04	-	-	AN 125	10000	-	-	-
Before choke	30	3630	10000	7.02	-	-	AN 125	10000	-	-	-
Before choke	50	3630	10000	7.01	-	-	AN 125	10000	-	-	-
After choke	10	3630	10000	6.95	-	-	AN 125	10000	-	-	-
After choke	20	3630	10000	7.06	-	-	AN 125	10000	-	-	-
After choke	30	3630	10000	6.94	-	-	AN 125	10000	-	-	-
After choke	50	3630	10000	7.10	-	-	AN 125	10000	-	-	-

Table 39 pH in polymer samples, Fixed chokes 4 and 5.

SNF mother solutions at 15000 ppm diluted in 0.5% NaCl brine - Fixed chokes

Sample	Choke	ΔP, bar	Polymer	Conc, ppm	pH	Choke	ΔP, bar	Polymer	Conc, ppm	pH
Brine			NaCl	5000	7.51	Brine		NaCl	5000	7.51
Tank			3630	1000	7.61	Tank		3630	1000	7.61
Before choke	20/64	10	3630	1000	7.73	24/64	12	3630	1000	7.73
Before choke	20/64	20	3630	1000	7.70	24/64	21	3630	1000	7.74
Before choke	20/64	31	3630	1000	7.70	24/64	31	3630	1000	7.71
Before choke	20/64	51	3630	1000	7.69	24/64	52	3630	1000	7.71
After choke	20/64	10	3630	1000	7.68	24/64	12	3630	1000	7.74
After choke	20/64	20	3630	1000	7.73	24/64	21	3630	1000	7.70
After choke	20/64	31	3630	1000	7.68	24/64	31	3630	1000	7.71
After choke	20/64	51	3630	1000	7.70	24/64	52	3630	1000	7.70

Table 40 pH in polymer samples, Multiple chokes.

SNF mother solutions at 15000 ppm diluted in 0.5% NaCl brine - Multiple chokes

Sample	ΔP, bar	Polymer	Conc, ppm	pH	ΔP, bar	Polymer	Conc, ppm	pH
Brine		NaCl	5000	7.51		NaCl	5000	7.49
Tank		3630	1000	7.61		3630	1000	7.94
After choke 1	15	3630	1000	7.66	5	3630	1000	7.70
After choke 2	15	3630	1000	7.69	5	3630	1000	7.79
After choke 3	25	3630	1000	7.64	25	3630	1000	7.68
After choke 1	8	3630	1000	7.59	5	3630	1000	7.77
After choke 2	8	3630	1000	7.66	5	3630	1000	7.87
After choke 3	13	3630	1000	7.62	5	3630	1000	7.82
After choke 1	6	3630	1000	7.62				
After choke 2	6	3630	1000	7.73				
After choke 3	10	3630	1000	7.74				

Polymer degradation – Summary

Figure 25 summarizes the single choke valve polymer shear degradation tests. Note that Choke 1 is the standard Halliburton choke, Choke 2 is the Matek choke, choke 3 is the SNF choke and chokes 4 and 5 are the fixed orifice chokes at ID = 20/64" and 24/64". Degradation is reported as the viscosity ratio before and after choke vs. differential pressure across the choke. Similar trends would have been seen if the viscosity degradation were derived relative to the tank viscosity. However the viscosity reduction at ΔP = 0 would not have been 0%.

The trend lines in Figure 25 are obtained by assuming that degradation depends on the actual pressure in a similar ways as previously has been shown to match degradation in capillary tubes with shear rate.

$$\eta_D = 1 - [1 + (A \cdot \Delta P)^2]^{-m/2}$$

The curves are matched with m = ½ and A is the tuning parameters. The results predicts that for practical purposes the maximum degradation through standard chokes reach a stable level of degradation, here in the range of 70-80%.

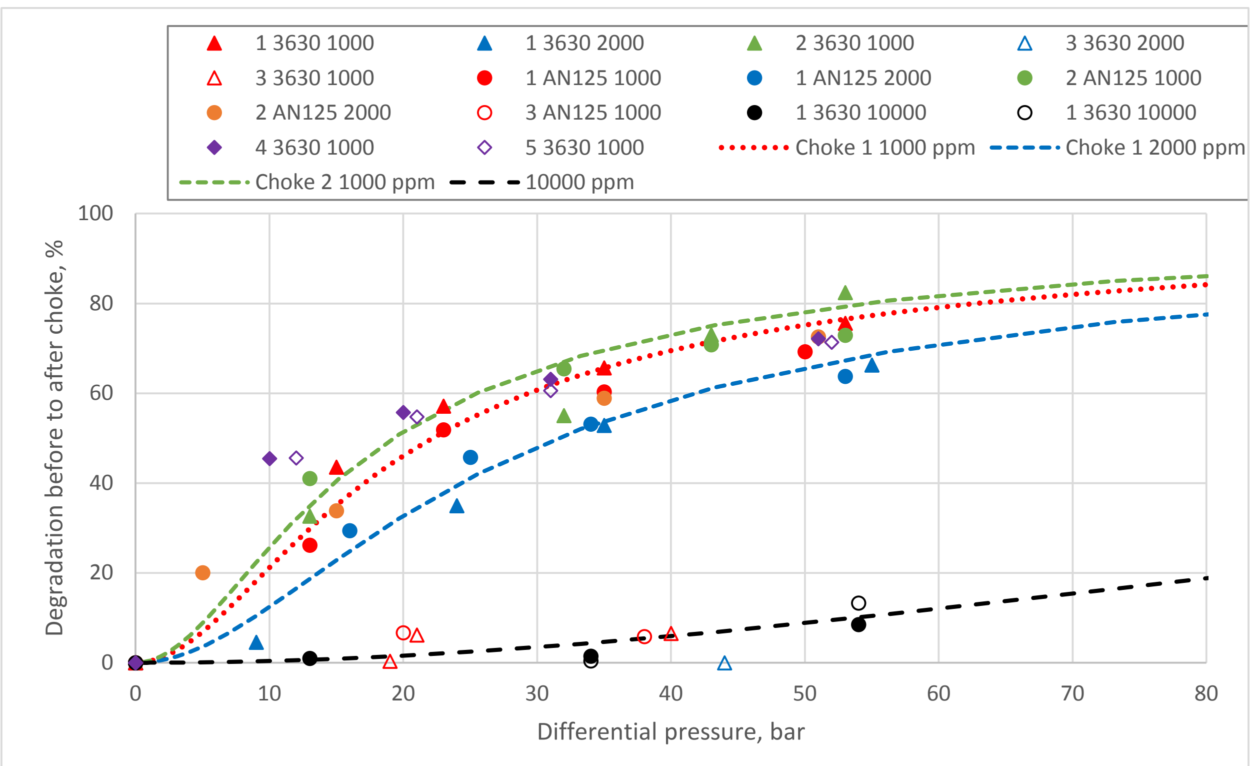


Figure 25 – Viscosity degradation chokes 1 to 3.

The results shown in Figure 25 are in Figures 26 to 28 shown separately for the thre different choke types.

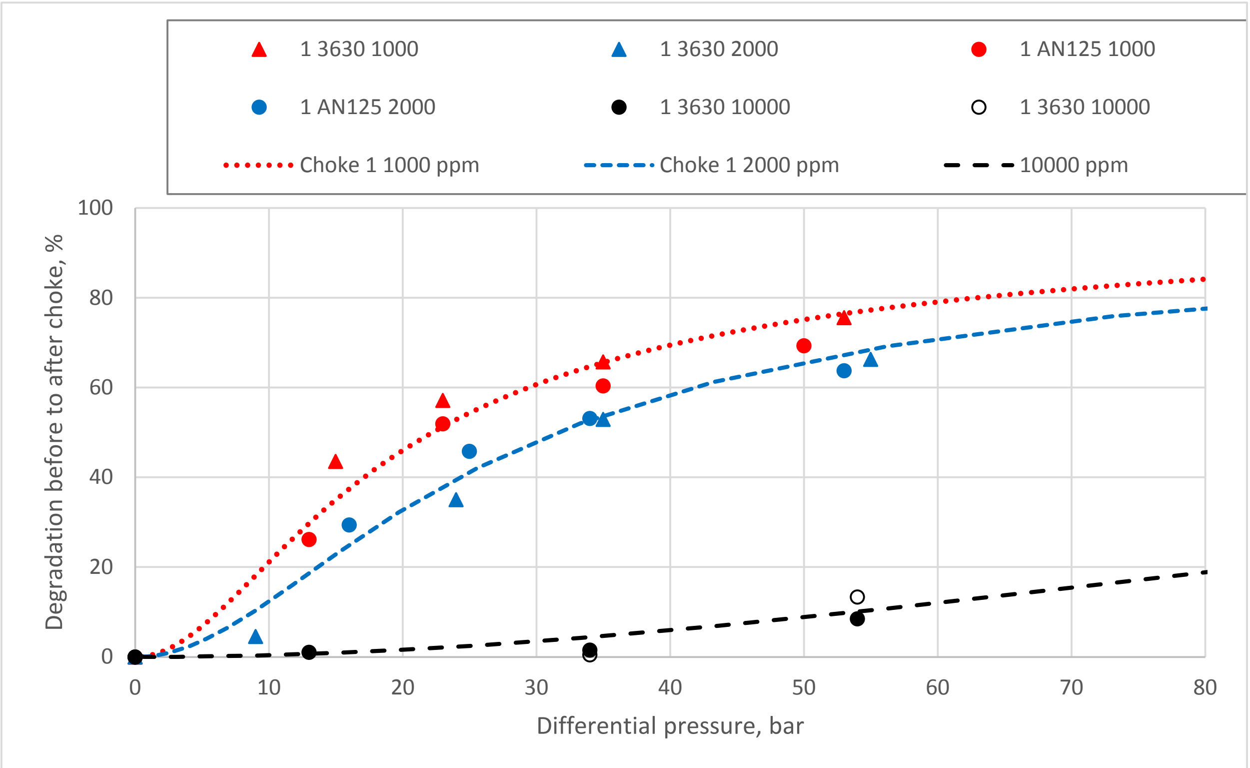


Figure 26 – Viscosity degradation choke 1.

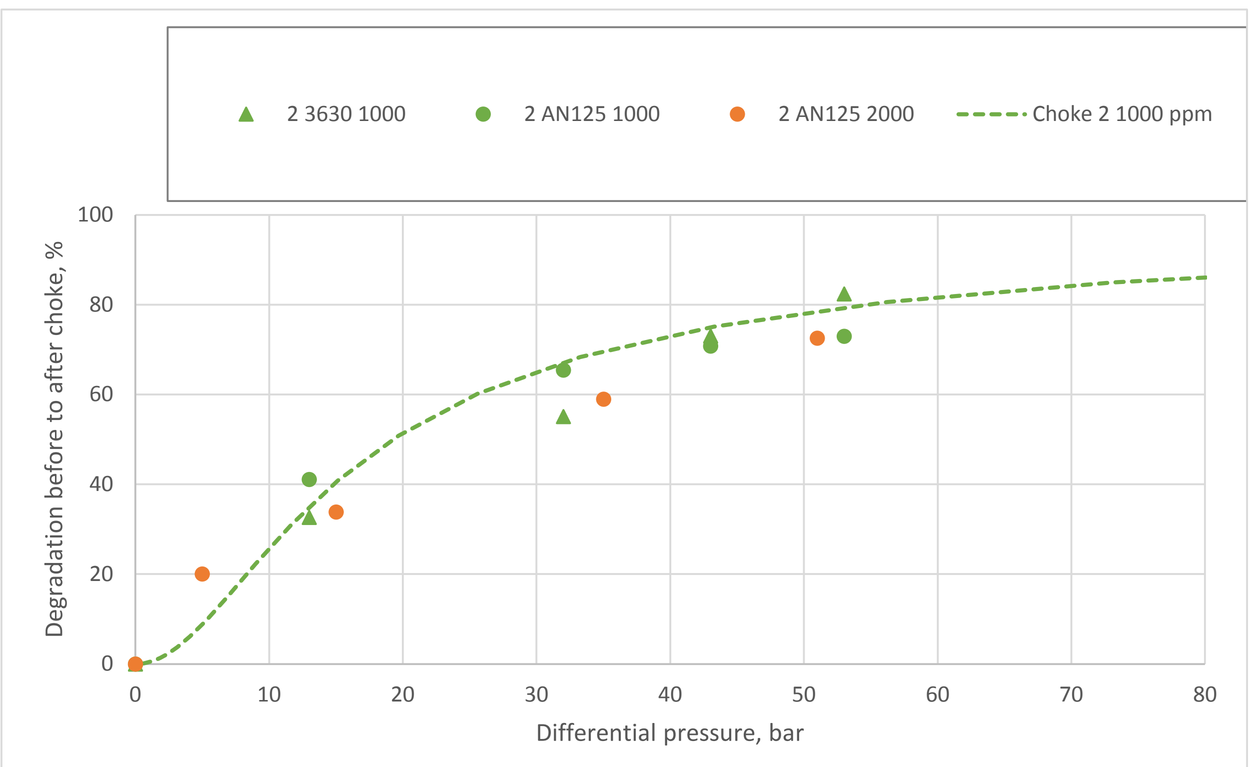


Figure 27 – Viscosity degradation choke 2.

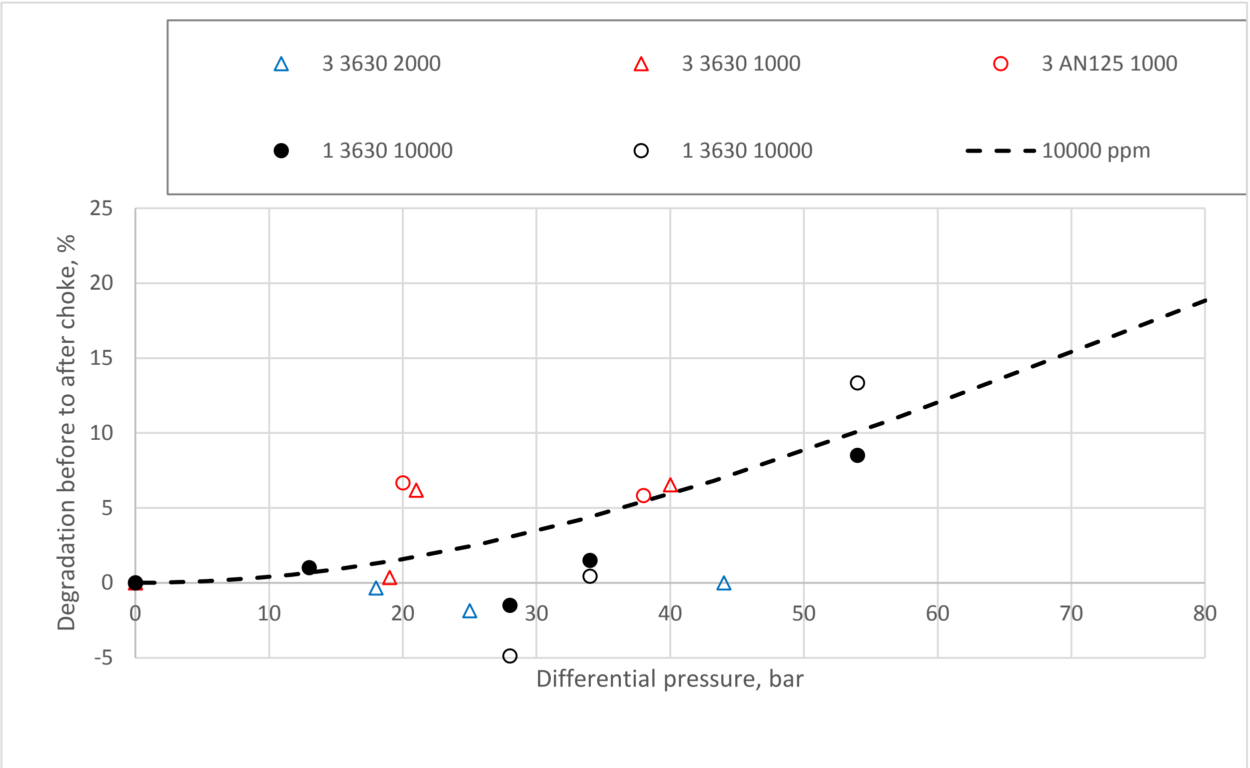


Figure 28 – Viscosity degradation choke 3.

Figure 29 shows degradtion in multiple chokes. As can be seen, at differential pressures of 15, 15 and 25 bar across the three chokes, the degradation is similar to single choke. At differential pressures of 8, 8 and 13 bar, the degradation is slightly reduced. When the differential pressure is decreased to 6 and 5 bar, all the degradation took place across the first choke and the net effect is improved.

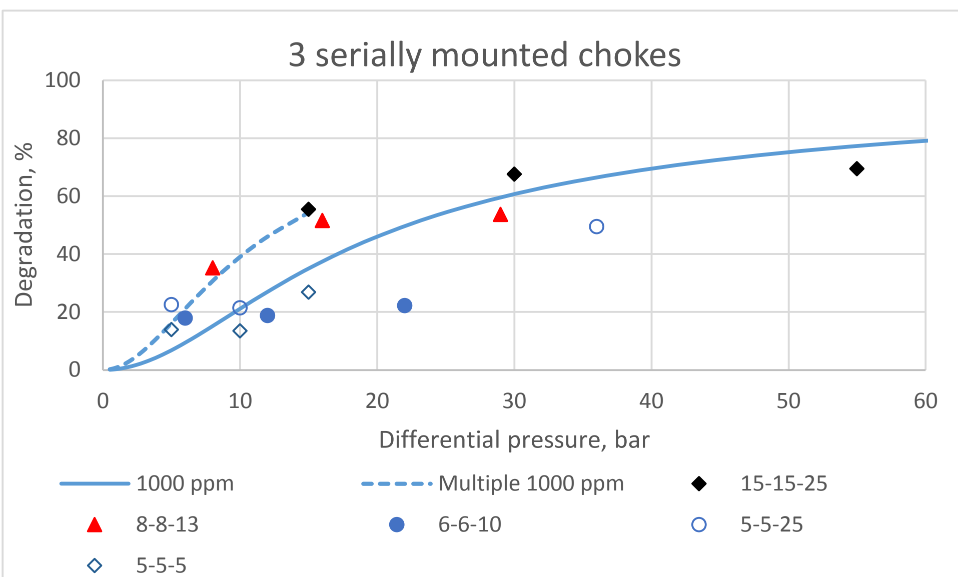


Figure 29 – Viscosity degradation multiple chokes.

Filter ratio tests revealed that the filtration rate or screen factor (defines as the ration between filtration rate of polymer and brine) depends strongly polymer rheology. Figure 30 compares screen factors for 1000 ppm 3630 in the multiple choke experiments as well as the choke 3 experiment. (Results from choke 1 and choke 2 were omitted due to poor water quality.). The blue dotted line represents a linear relationship between viscosity and screen factor, while the experiments is relatively well matched with the green curve. At low to moderate viscosity screen factor is less than predicted by Newtonian viscosity and can easily be explained by shear thinning behaviour of the polymer, i.e., the effective polymer viscosity at the actual shear rate is less than the Newtonian bulk viscosity. At higher viscosity, screen factor increases and this is due to elongation when the polymer passes the pores in the filters.

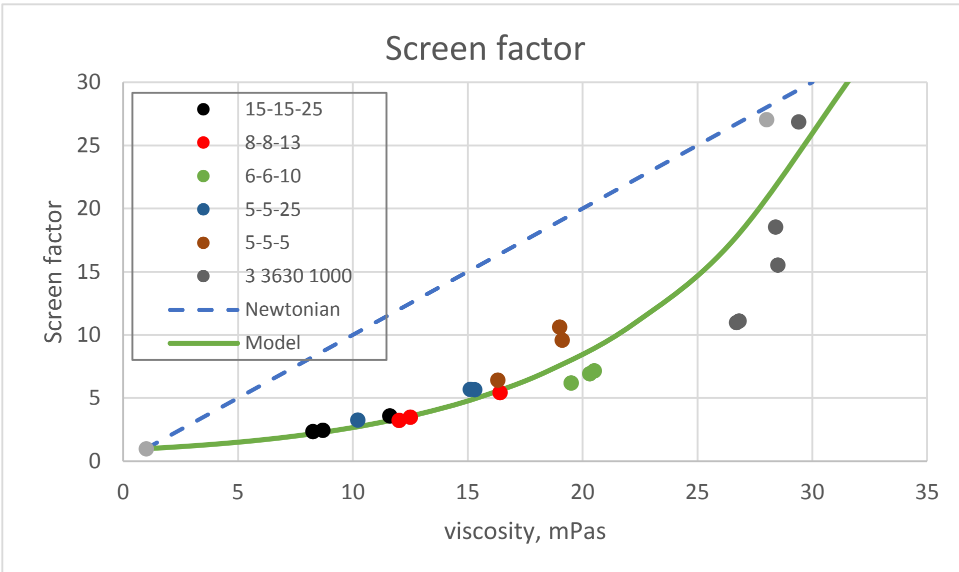


Figure 30 – Screen factor vs. effective bulk viscosity, experiments performed with 1000 ppm 3630.

Chemical waste handling

The project required a large amount of polymer solution . A total of 44 m3 15000 ppm polymer solution was received from the polymer supplier. All chemical waste was handled with care in order to avoid any spill. Waste was collected into dedicated tanks following each test stage. All polymer solution diluted down to 2000 ppm or lower were shipped to SAR for a controlled chemical distuction. Whereas, the high concentration solutions wer sent back to SNF.