

Master Thesis:

***“Primary well cementations in OMV-AUT  
from 2004 – 2009. Analysis and potential of  
improvement.”***

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# 1 Abstract

Unexpected complications occurred while producing several wells drilled by OMV AUT in the area north-east of Vienna from 2006 to 2009. On some wells the watercut increased much faster than predicted, on other wells cross flow was indicated. Zonal isolation of these wells, which should be provided by cement behind the annulus, could be compromised. The initial task of this thesis was to research how compromised zonal isolation can be identified in a reliable manner and if/how they can be related to the cementing practices. The current cementing practices as performed by the drilling department in Gänserndorf (SOB) were evaluated and compared to the best practices recommended by the oil industry.

The following objectives are covered by this thesis

- At the very beginning there is a short summary to gain a quick overview about this work and the results of the research. This section is followed by an introduction which previous work was done related to primary well cementations by OMV AUT
- An extensive theoretical overview is given about all the factors that may influence the quality of a cement job
- The cementing practices of OMV AUT are examined and described in detail
- The 9 5/8" cement job on the Husky 1 was witnessed on location in April 2010. The process of this cementation is documented very detailed, the monitored data is compared with simulated data
- Cement jobs on several other wells were examined in detail, casing rotation and different flow rates were simulated to evaluate if the OMV guidelines were applicable in theory
- A detailed conclusion and recommendations are given at the end

## 2 Extensive Abstract

A more detailed conclusion and summary are given at the end of the thesis.

### 2.1 Conclusion

The production and workover history of selected wells were surveyed with the goal to find a way to clearly identify zonal isolation problems. On some wells bad cement integrity was proven but on many wells no definite statement can be given because of various degrees of unknowns. Other wells were included because of different problems related to the cement job.

Out of the 58 wells drilled from 2004 – 2009 nine wells, marked red, with probable cement job problems were evaluated. Four wells marked in green without recognized cementation problems were selected and evaluated for reference. The Strasshof T 004 and 011, marked in orange, show symptoms of poor cement integrity but the cement job quality was not evaluated in this thesis because of the complexity of this task which would probably fill another thesis.

The majority of the wells drilled in that time frame showed no abnormalities which would qualify them for closer cement job evaluation and are therefore unmarked.

HOEFLEIN 010	STRASSHOF T 005	HUTSAUL 002
NIEDERSULZ 012a	ROSELDORF 021	STRASSHOF T 012
ERDPRESS 003a	STRASSHOF T 005a	SPANNBERG 023
TALLESBRUNN 040	SCHOENKIRCHEN 434a	HOCHLEITEN 075a
EBENTHAL 017a	STRASSHOF T 006a	OBERWEIDEN W 001
PLATTWALD NORD 001	SCHOENKIRCHEN 433	MATZEN 564
PROTTES T SUED 001a	SCHOENKIRCHEN 435	MATZEN 565
ZEISELBERG 001	AO Matzen 626 (App) - abgelenkt	MATZEN 566
STRASSHOF T 004	MATZEN 626b	STRASSHOF T 009b
STRASSHOF T 004a	SPANNBERG 021	MATZEN 567
ERDPRESS 006	HOCHLEITEN 074	MATZEN F 261
ERDPRESS 005	OBERSULZ 003	STOCKERAU OST 017
ERDPRESS 004	BOCKFLIESS 201	BOCKFLIESS 200
EBENTHAL TIEF 001	STRASSHOF T 011	MATZEN F 262
ZISTERSDORF 004	SCHOENKIRCHEN 436	SCHOENKIRCHEN T 091
MATZEN 624	SCHOENKIRCHEN 367	MUEHLBERG S 002a
HOHENRUPPERSDORF 043	BOCKFLIESS 203	STRASSHOF T WEST 001
HOHENRUPPERSDORF 044	BOCKFLIESS 202	MATZEN 501
HOCHLEITEN 008a	BOCKFLIESS 072A	PROTTES T WEST 001
PILLICHSDORF 004a	MUEHLBERG S 001	EBENTHAL F18
		EBENTHAL F19

Figure 1 - Overview of wells drilled between 2004-2009

### 2.1.1 Overview about the evaluated wells

Well Description	situation	conclusion
<p><b>Bockfließ 72a</b> 1650m MD 83deg deviated producer, no CBL available.</p>	<p>Initially very high water saturations, very little oil was produced.</p>	<p>High degree of uncertainties, no final judgment can be given about the cement quality on this well</p>
<p><b>Bockfließ 201</b> 1756m MD 16deg slightly deviated production well, poor CBL in reservoir section.</p>	<p>Initially very high watercut, formation water may rise in the annulus from highly water saturated layers 4-5m below the perforations.</p>	<p>The increase in watercut is very likely ordinary coning from the next water layer and not a sign of poor zonal isolation. Watercut was reduced after shutting the lowest perforation.</p>
<p><b>Bockfließ 202</b> 1774m MD 27deg slightly deviated producer, very good CBL in reservoir section.</p>	<p>After some production inflow was reduced, the oil level dropped below pump level, Probably very small compartment.</p>	<p>The problems on this well cannot be brought in context with poor cement integrity.</p>
<p><b>Bockfließ 203</b> 1853m MD 35deg deviated producer, good CBL in reservoir section.</p>	<p>Unexpected high increase in watercut, formation water may rise in the annulus from high water saturated layers 4-5m below the perforations</p>	<p>The increase in watercut is very likely ordinary coning from the next water layer and not a sign of poor zonal isolation. Watercut was reduced after shutting the lowest perforation.</p>
<p><b>Ebenthal F19</b> 2470m MD, 50 deg. deviated injector, CBL reads very good bonding in reservoir section.</p>	<p>Bad zonal isolation behind 7in casing</p>	<p>Very likely cement integrity problem at reservoir depth. Identified by setting packer between perforations and doing hydraulic communication tests.</p>
<p><b>Matzen 261F</b> 1840m MD vertical injector, good CBL in reservoir section.</p>	<p>Huge losses during drilling (&gt;800m<sup>3</sup>) and also big losses during cementing</p>	<p>Big losses while cementing Top of cement 1355m lower than planned in 7in casing.</p>

<p><b>Spannberg 23</b> 3602m MD 67deg deviated producer, no CBL available.</p>	<p>Very fast increase in watercut during production, the water is assumed to migrate through the annulus from a water bearing layer underneath.</p>	<p>The increase in watercut is probably ordinary coning from the next water layer and not a sign of poor zonal isolation. Watercut was reduced after shutting the lowest perforation.</p>
<p><b>Mühlberg S2a</b> 2047m MD 35deg deviated production, poor CBL in reservoir section.</p>	<p>Produces very high gas – oil ratios</p>	<p>It is possible that the gas comes from a layer underneath, migrates upwards behind the 7in casing and enters the wellbore through the perforations.</p>
<p><b>Prottes Tief West 1</b> 3400m MD deviated production well, very poor CBL's in the upper stage section.</p>	<p>While cementing the lower stage on the 9 5/8 intermediate casing the cement hardened out and prevented circulation on the upper stage.</p>	<p>After several remedial cementing operations the upper section could be isolated to surface.</p>

### 2.1.2 OMV Austria cementing practices

To reduce the chance that the cement job itself causes zonal isolation problems it is recommend revising the existing cementing practices.

The cement jobs performed by SOB in the recent years differ in some aspects from the best practices generally recommended by the industry<sup>1</sup>. See “good cementing practices” created by OMV Vienna in 2006 attached in Appendix B.

Major differences were:

- No casing rotation or reciprocation was done, however moving the casing is regarded as a very effective way to ensure good quality cementations.
- The displacement rates of the cement slurry were at 1200-600 l/min (about 1400-2500 l/min are recommended by OMV EP, basically the maximum rate possible)<sup>2</sup>

No obligatory standard exist within OMV AUT to regulate the parameters and minimum requirements for performing a cement job. The design of a primary well cementation is based on the job proposal by Schlumberger, best practices established locally and experience of the engineers involved.

Of course performing casing rotation will increase the costs of the cement job. When using standard API casing which is available in OMV stocks, torque rings have to be purchased to upgrade the couplings for withstanding higher rotation torque. Also a special rotating cement head is needed to enable rotation during pumping and displacement.

## **2.2 Recommendations**

### **2.2.1 Planning the cement job**

- When estimating costs for a new well it is also advisable to consider the possible costs of additional workover operations if zonal isolation in the pay zone is compromised.
- Try to reduce doglegs to a minimum, a crooked trajectory causes additional friction when running in and rotating the casing.
- Purchasing a drilling software suite is currently (mid. 2010) ongoing by OMV EP. It is strongly supported by this thesis to acquire such a tool which enables the drilling engineers to easily run OMV intern calculations and simulations on several parts of the cement job and the drilling program in general. Some examples are:
  - standoff calculations (use real caliper data)
  - expected loads while running in hole (use real LWD trajectory data)
  - expected torque necessary for rotating the casing (use real LWD trajectory data)
  - flow out simulation during cement job (avoid mistaking U tubing effects for losses)
  - fluids positions during the cement job (knowing exactly where fluids are during pumping)
  - max ECD simulation, see which parameters influence the ECD most (cement column height, pump rate, slurry mixture, annulus clearance, etc.) compare this simulations with results from Schlumberger
- For two stage cementations: the top of cement should be planned at or below the stage tool. If possible the tool should be installed at a depth where the zonal isolation immediately beneath the tool is not of great importance.

### **2.2.2 Executing the cement job**

- Reciprocation casing: (limited by friction and swab/surge pressures) Move the casing up and down during cement job, keep safety margin to the predicted hardening time of cement so you don't get stuck while the casing is pulled up. Also swab and surge effects have to be considered
- Rotating casing: (limited by couplings) Rotate the casing while pumping and displacing the cement. Torque rings can double the maximum allowed torque on standard API couplings. The less crooked a trajectory is drilled the less torque will be created when rotating the casing.
- Use the rig pumps for displacing the cement (calibrate prior to job), three advantages:
  - higher rates of displacement (Schlumberger's cementing is limited to 1200l/min with the 2" cementing line up to the rig floor they used on the evaluated jobs)

- flow in and flow out rate can be easily monitored and compared and used for real time decision making (identifying fluid loss, etc...)
- with a crossover sub the casing can be rotated via the topdrive system.
- (limited by fracture gradient) Pump with highest possible flow rates for better mud displacement. Reduce pump rate as hydrostatic pressure increases to keep the bottom ECD constant.

### **2.2.3 After the cement job**

- Ensure that the parameters of the cement job are well archived. It can be very helpful, when evaluating the data to have the records (caliper logs, time logs, etc...) also available in digital format and not only as PDF or as scanned sheet. The most important records of a cement job are:
  - end of job reports from Schlumberger
  - timelogs from Geoservices
  - caliper logs used for standoff and volume calculations
  - standoff calculations from Weatherford
  - rheology data of the slurries used for cementing
  - cement bond logs which evaluate the cement quality

# 3 History of cement job quality control within OMV AUT

This chapter gives an overview what was done within OMV AUT to evaluate and improve the cementing practices.

Master Thesis Mr. Doschek  
Cementing in deviated and horizontal wells

Guidelines for the use of Centralizer and scraper on production casing

Switch to Schlumberger as cementing contractor

Master thesis Mr. Csar  
"Primary well cementations, analysis and potential of improvement"

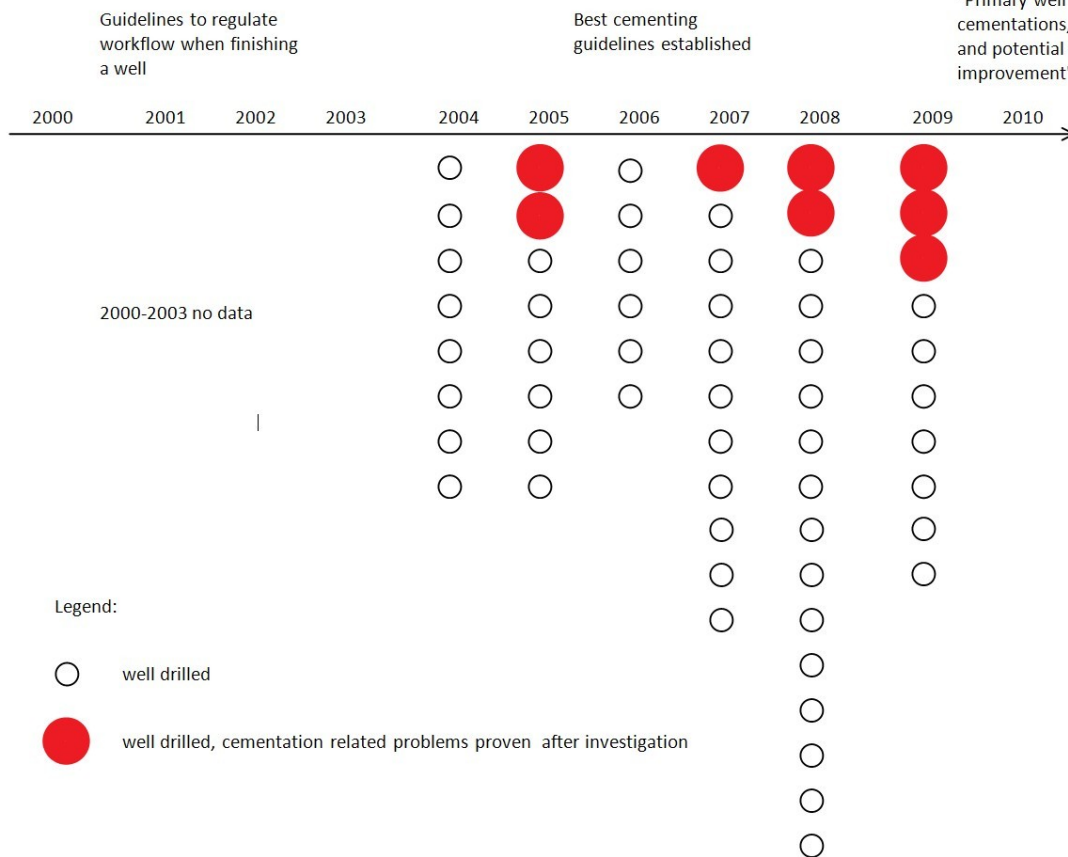


Figure 2 - A primary well cementing overview of the last decade.

## 3.1 Year 2000 : Master thesis, Mr. Doschek - Cementing in highly inclined and horizontal wellbores.

In 2000 a master thesis was written by Mr. Markus Doschek for OMV<sup>3</sup> with the goal to obtain more knowledge about primary cementing techniques specifically in highly inclined and horizontal wellbores. Requirements were defined for optimal cementation

of these highly deviated wellbores. The existing cementing practices of OMV were identified and recommendations were given on how improvements could be made.

Special attention was given to identify requirements for optimal displacement efficiency during cement placement.

Three main topics were addressed in his thesis:

- Displacement mechanics during a cement job
- The design of the cement slurry with all variables that influence its performance.
- The simulation of a cement job with computer software

### ***3.2 March 2000 : Guidelines for the use of centralizers and scratchers on the production casing.***

In March 2000 EP-I/PT handed over a guideline to EP-I/SOB where the application of centralizers, and scratchers for cementing a production casing while reciprocating was recommended.

The document recommends a standoff of 80% in production layers and also regulates the use of scratchers. This document (in German; “Ausrüstung der Produktionsrohrtour“) can be found in Appendix B.

### ***3.3 Around 2001: Guidelines to regulate the workflow when finishing a well.***

Around 2001 a guideline was created to regulate the workflow between the drilling operations and the production and reservoir departments when testing a formation and cementing the production casing.

This document (in German; “Übernahme/Liquidation einer Neubohrung durch PRT“) can be found in Appendix B.

### ***3.4 Dec. 2006 Best Cementing Guidelines established in OMV AUT***

In December 2006 a meeting was held in Gänserndorf with the topic: Cementing Practices Review. This meeting was conducted by request of AUT/SOB (drilling and workover department in Gänserndorf) who assigned EP-EPP/WE with the job of reviewing the cement jobs on 11 wells which had been drilled in the years before<sup>4</sup>.

The work schedule was identified as below:

1. review of cementing practices of specific wells
2. review of cement recipe of specific wells
3. develop recommendation on recipe together with service company
4. create “Good Cementing Practices” document



Some general points were discussed which were also encountered while working on this thesis. Inconsistency of reporting cementing related data, some data and reports were not available to some of the involved parties, communication problems etc...

Six pages of cementing guidelines (attached in Appendix B) which were based on the guidelines of other major operators resulted. The guidelines prepared by EP-EPP/WE are known standard cementing practices applied globally within the industry. Rotating/reciprocating the casing while cementing and displacing with high flow rates are recommended.

Up to now there are is no obligatory standard defined which implements these guidelines when cementing a well in Austria. This often results in cement jobs which could have been technically optimized. But of course improved cement jobs also means increasing primary well cementation costs!

### ***3.5 Schlumberger wins global tendering for drilling related services in 2007.***

Halliburton had performed cementing jobs for OMV for over three decades. In 2007 OMV switched over to Schlumberger as service contractor for primary well cementations. The responsible engineers and heads of the operations in Gänserndorf at that time recommended extending the contract with Halliburton. Extensive experience and good knowledge of the regional oilfields resulted in good quality cement jobs. The last cementing job done by Halliburton was in Mai 2007 on the Strasshof T6.

The decision to employ Schlumberger for all drilling related services which includes the cementing operations was taken after a global tendering process and after global comparison of all available service providers.

The main criteria for a global contract were:

- to create commercial benefits for E&P due to recognized purchasing volume
- establishing of a global Master Service Agreement (MSA) for E&P and Petrom
- establishing standardized contracts for certain job categories
- to harmonize legal / commercial contract terms
- to standardize and harmonize technical requirements for E&P and Petrom

OMV wanted to

- commit itself to a long term relationship with a service provider
- integrate the service company into project planning at an early stage
- establish a learning environment in cooperation with the contractor

Further objectives of a MSA were to build up a global supply chain and get recognized at top management level within the contractor's organization. An additional benefit achieved by the MSA with Schlumberger was a global discount of 13% on all drilling related services

The tables are from a presentation prepared in 2006<sup>5</sup> when the tendering for a global contractor was ongoing.

This table shows the availability of drilling related services in the different regions where OMV is operating. Schlumberger clearly had the best coverage of the needed services

OMV Exploration & Production

### DRS availability globally per supplier

Countries	Austria	Tunisia	Pakistan	New Zealand / Australia	PETROM
Companies					
<b>Schlumberger</b>	DD EWL CEM TEST	DD EWL CEM TEST	DD EWL CEM TEST	DD EWL CEM TEST	DD EWL CEM TEST
<b>Baker Hughes</b>	DD	-	DD	-	DD
<b>Halliburton</b>	DD CEM TEST	- CEM* TEST*	- - -	DD CEM TEST	DD CEM TEST
<b>BJ Services</b>	CEM*	CEM*	CEM*	CEM	CEM
<b>Weatherford</b>	EWL+ DD	EWL* -	EWL* -	EWL+ DD	- DD

\* No supply base      + Limited technical capability



Figure 3 - Availability of drilling related service for OMV's global locations

In this table the costs for standard cement jobs as they are performed in Austria are compared. It is interesting to note that for cementing in Austria Schlumberger was not the cheapest bidder but nevertheless for global considerations a master service agreement contract with Schlumberger was established.

## Commercial Evaluation Cementing OMV-AUT

### Halliburton Sample Job Calculations Austria

Discount rate 3%	
13-3-8 Lead Tail Cement Job	
Total after discount - Casing equipment	27133,81 EUR
9-5-8, 2 Stages Cementing Job	
Total after discount - Casing equipment	142721,92 EUR
9-5-8, FOAM Cement	
Total after discount - Casing equipment	150452,82 EUR
7" Gas Tight Cementing	
Total after discount - Casing equipment	57883,27 EUR

### Schlumberger Cementing OMV-AUT Global tender 2006

Discount rate 3%	
13-3-8 Lead Tail Cement Job	
Total after discount =	36771 EUR
9-5-8, 2 Stages Cementing Job	
Total after discount =	119937,77 EUR
9-5-8, FOAM or Light Cementing	
Total after discount =	175681,64 EUR
7" Gas Tight Cementing	
Total after discount =	56687,03 EUR

	I)	II)	III)
1)foam	235.469,90	1)two stage	227.739,00
2)foam	235.469,90	2)foam	235.469,90
		3)foam	235.469,90
			4)
			5)
			6)
			7)
			8)
			9)
Total each	470.939,80	688.678,80	1.407.402,36
TOTAL per year			2.577.020,96

	I)	II)	III)
1)light weigh	270.939,67	1)two stage	215.295,80
2)light weigh	270.939,67	2)light weigh	270.939,67
		3)light weigh	270.939,67
			4)
			5)
			6)
			7)
			8)
			9)
Total each	541.879,34	757.175,14	1.397.942,24
TOTAL per year			2.696.986,72

Figure 4 – Cost comparison of the costs for cement jobs from Halliburton and Schlumberger

## 4 Design parameters

This chapter gives an overview about all the factors that can influence the quality of a cement job.

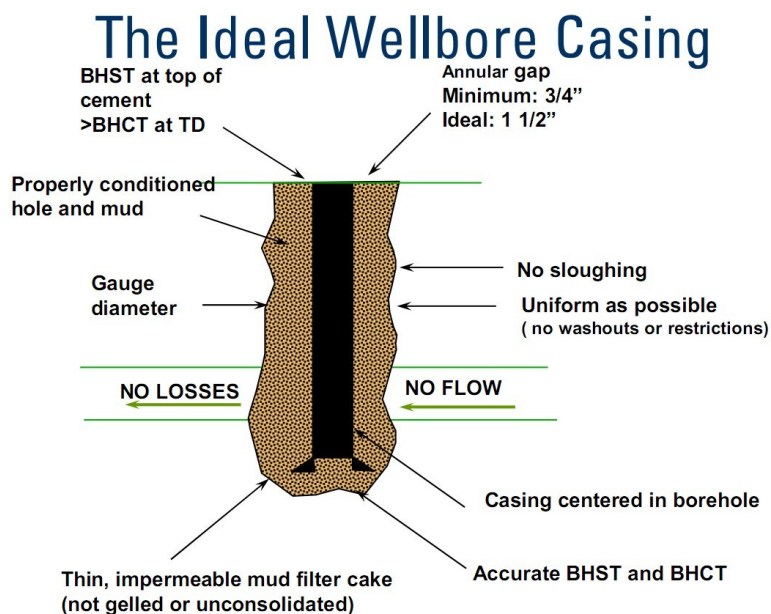
### 4.1 Borehole geometry

The geometry of the wellbore has a significant influence on the cement job quality. A caliber run is usually done with a 4 arm caliber to measure the borehole.

Good geometry data enables:

- Correct calculation of cement slurry volumes needed. This is very important to ensure enough cement is pumped and all sections are properly cemented up to desired depth. Too much slurry volume means excess pressure on the formation and maybe cement slurry returns to surface which have to be discarded costly.
- Best possible centralization of casing string when planning the placement standoff devices.
- Calculations on the displacement and hole cleaning efficiency of the fluids pumped during cementing.

The graphic illustrates the most important factors influencing the quality of a cement job.



**Schlumberger**

Figure 5 - Ideal conditions before the cementation job <sup>6</sup>

### 4.2 Mud Removal

The main objective of a primary cement job is to provide complete and permanent isolation of the zone behind the casing. To accomplish this task the drilling mud in the

annulus has to be fully removed before the cement slurry can completely fill the annulus. Once in place the cement hardens and develops sufficient strength to maintain a hydraulic seal throughout the life of the well.

Mud pockets in the annulus, as a result of poor displacement in the preparation of the cement job can compromise the sealing properties of the cementation. Therefore it is very important to know the parameters influencing the displacement of the mud.

Mud displacement is much more complex than mud circulation. The most important factors are the physical properties (density, viscosity) and the resulting velocity profile and the flow regimes of the fluid used to displace the mud. Also the centralization of the casing in the wellbore is significant, only in an ideally centralized casing the velocity of the fluid is even in the annulus. The properties of the drilling mud which gets displaced also influence the displacement efficiency.

Spacers and washers, fluids which are pumped ahead of the cement slurry, designed for efficiently displacing the drilling mud in the annulus are beneficial for a good displacement.

#### **4.2.1 History of mud removal**

Common cementing practice up to the late 50's was to pump a single cement slurry which should remove the drilling mud and after hardening provides adequate strength and integrity. Tests showed that this single slurry cannot perform satisfactorily both tasks. This led to the use of two slurry systems, some fluid ahead of the cement designed to remove the mud and cement slurry pumped behind to establish zonal isolation. Today it is common practice to pump spacers, sophisticated (and expensive) fluids ahead of the cement slurry to achieve better mud removal.

#### **4.2.2 Velocity profile**

A very important parameter in mud removal is the velocity profile of the fluid. When a fluid flows along a surface, the velocity of the fluid particles which contact the surface is reduced as a result of friction with the surface. The further away from the surface the faster the fluid particles can move. In our case, the fluid in the annulus interacts with two surfaces, the outer wall of the casing and the wall of the borehole.

To achieve good displacement, turbulent flow is preferred because it creates a more evenly velocity profile. This profile enables the fluid to move faster near the surfaces and therefore has more energy for removing the stationary drilling mud in wellbore washouts. Note that turbulent flow alone does not automatically guarantee good displacement.

The graph shows the behavior of fluid flowing in a stationary pipe in laminar flow (left) and turbulent flow (right). In laminar flow the peak velocity of the fluid (in the middle of the pipe) is about two times faster than the average velocity of the fluid while in turbulent flow the velocity of the fluid particles is more evenly distributed.

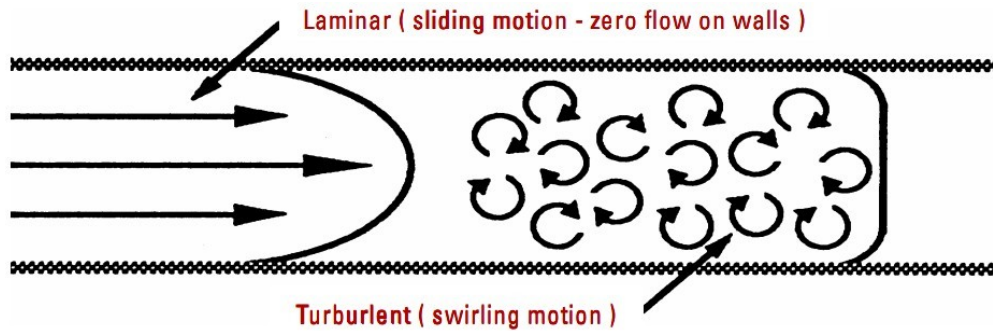


Figure 6 - Flow patterns: laminar flow on the left, turbulent flow on the right <sup>7</sup>

### 4.2.3 Turbulent and laminar flow

Engineers try to design cement job parameters (flow rate, fluid properties,..) in such a way that turbulent flow is achieved, however in some cases this may not be possible. Limitations like weak formations, low pressure gradients or limited power of pumping equipment can dictate laminar flow regimes while displacing.

The following simulations done by Schlumberger for this thesis show what pump rates are needed to achieve turbulent flow with a spacer and cement slurries when cementing 9 5/8in and 7in casing.

The conclusion of these simulations is:

- A good centralized standoff is of great importance to ensure a uniform flow pattern in the annulus.
- Water as Newtonian Fluid needs very small flow rates to achieve turbulent flow, 0.5 m<sup>3</sup>/s is the maximum rate needed even in the worst conditions.
- The 1.3SG Mudpush II spacer and the 1.5SG bentonic lead slurry actually have very similar properties concerning their flow rates needed for achieving turbulent flow

Ecc. Turb.		Ecc. Lam.		Friction/Shear Rate		Flow Rates		Setup	
Casing OD		7.000 in		Displacing		Fresh Water		Execute	
Standoff		Open Hole Size :						Reset	
%		in						Eng. Rep.	
100.0		8.800		9.100		9.400		9.700	
Qcrit		0.2		0.2		0.2		0.2	
85.0		Qcrit		0.2		0.2		0.2	
65.0		Qcrit		0.4		0.4		0.4	
50.0		Qcrit		0.6		0.6		0.6	

Figure 7 - Flow rates needed to achieve turbulent water flow with certain standoffs in the 8 1/2in section

Ecc. Turb.		Ecc. Lam.		Friction/Shear Rate		Flow Rates		Setup	
Casing OD		9.625 in		Displacing		Fresh Water		Execute	
								Reset	
Standoff		Open Hole Size :						Eng. Rep.	
%				12.300		12.600		12.900	
100.0		Qcrit		0.2		0.2		0.2	
85.0		Qcrit		0.3		0.3		0.3	
65.0		Qcrit		0.5		0.5		0.5	
50.0		Qcrit		0.9		0.9		0.9	

Figure 8 - Flow rates needed to achieve turbulent water flow with certain standoffs in the 12in section

Ecc. Turb.		Ecc. Lam.		Friction/Shear Rate		Flow Rates		Setup	
Casing OD		7.000 in		Displacing		MUDPUSH II13 :		Execute	
								Reset	
Standoff		Open Hole Size :						Eng. Rep.	
%				8.800		9.100		9.400	
100.0		Qcrit		2.0		2.3		2.6	
85.0		Qcrit		2.4		2.8		3.1	
65.0		Qcrit		3.3		3.7		4.2	
50.0		Qcrit		4.4		5.1		5.7	

Figure 9 - Flow rates needed to achieve Mudpush II 1.3SG turbulent flow with certain standoffs in the 8 1/2 section

Ecc. Turb.		Ecc. Lam.		Friction/Shear Rate		Flow Rates		Setup	
Casing OD		9.625 in		Displacing		MUDPUSH II13:		Execute	
Standoff		Open Hole Size :						Reset	
%								Eng. Rep.	
		12.300		12.600		12.900		13.200	
100.0	Qcrit	3.8	4.2	4.6	5.0				
85.0	Qcrit	4.5	5.0	5.4	5.9				
65.0	Qcrit	6.1	6.7	7.3	7.9	m3/min			
50.0	Qcrit	8.3	9.1	9.9	10.8				

Figure 10 - Flow rates needed to achieve turbulent Mudpush II 1.3SG flow with certain standoffs in the 12in section

Ecc. Turb.		Ecc. Lam.		Friction/Shear Rate		Flow Rates		Setup	
Casing OD		7.000 in		Displacing		BentonitHT_15		Execute	
Standoff		Open Hole Size :						Reset	
%								Eng. Rep.	
		8.800		9.100		9.400		9.700	
100.0	Qcrit	2.4	2.8	3.2	3.6				
85.0	Qcrit	2.7	3.1	3.6	4.1				
65.0	Qcrit	3.4	4.0	4.5	5.1	m3/min			
50.0	Qcrit	4.4	5.2	5.9	6.7				

Figure 11 - flow rates needed to achieve turbulent Bentonite Lead 1.5SG flow with certain standoffs in the 8 1/2 section



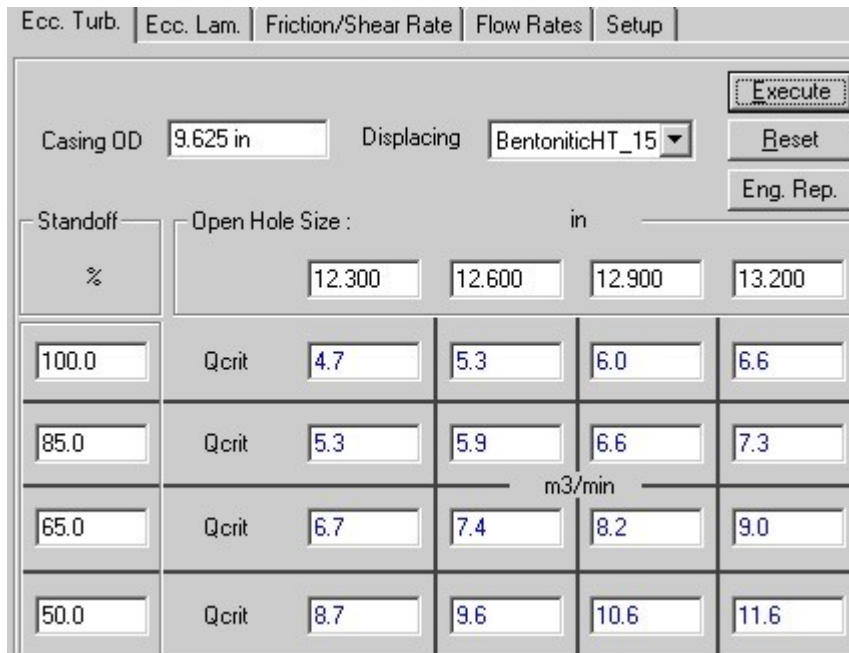


Figure 12 - Flow rates needed to achieve turbulent Bentonite Lead 1.5SG flow with certain standoffs in the 12in section.

#### 4.2.4 Centralization

As the velocity of a fluid particle is related to its distance to the next wall proper centralization of the casing in the annulus is of great importance. In poorly centralized annuli flow areas exist with very little clearance to the next surface which means the flow velocity of particles in these areas is much slower. The recommended practice to obtain good centralization is the use of computer simulations simulation to calculate the behavior of the casing string in a given trajectory with a certain caliper. The properties and design of the centralizers and also their distribution on the casing string are essential parameters influencing the standoff.

The next graphic shows how important it is to have the casing centralized for achieving sufficient flow in all regions of the annulus. The ratio given is the ratio of the velocity of the fluid in the wide section of the annulus to the velocity of the fluid in the narrow section of the annulus

Example: Standoff of 50% The flow in the wide section of the annulus is four times faster than in the narrow section

# Casing Centralization

- Relative Variation of flow rate ratio as a function of eccentricity

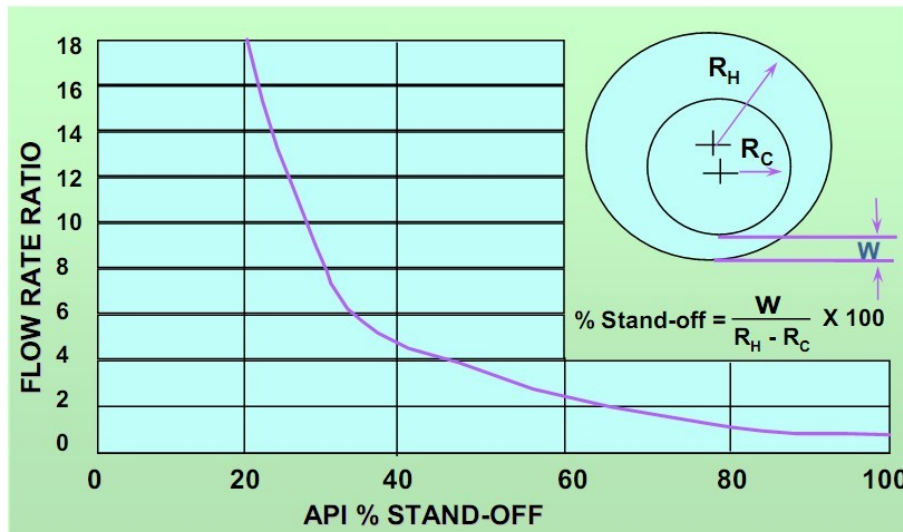


Figure 13 - The ration of the flow rate in various sections of an eccentric annulus<sup>8</sup>

The graph illustrates how the displacement of the mud is influenced by the standoff

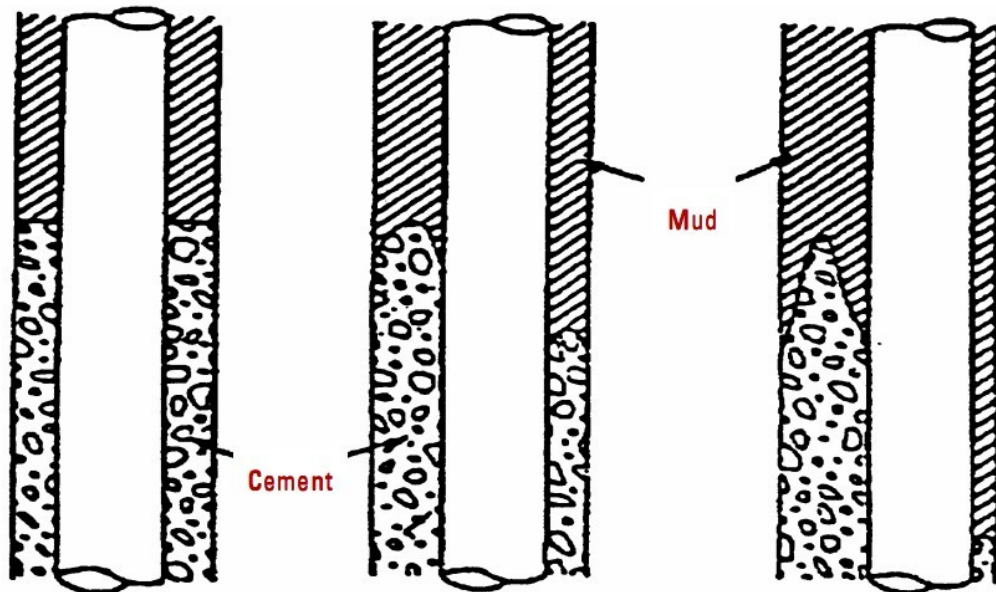


Figure 14 - Effects of standoff on mud displacement with decreasing centralization from left to right <sup>9</sup>

## 4.2.5 Drilling mud conditioning

Drilling mud is not originally designed for getting displaced easily, it is designed to carry the cuttings up to surface, to cool and lubricate the bit and to control formation pressures. This can make it necessary to condition the mud prior to a cementing operation. The mud should be free of cuttings, the gas content at background level, the density evenly distributed in the hole and the yield point as low as possible

#### 4.2.5.1 Types of Mud

Modern drilling muds are a suspension of solids in a liquid phase. Three major types of mud are in use, water-based, oil based and emulsion type mud. Water based muds are cheapest and commonly used in the oilfield. When drilling water sensitive formations (e.g. clay) the use of the much more expensive, oil based muds and emulsion type muds can be necessary.

#### 4.2.5.2 Mud Weight

The mud weight of the drilling fluid is defined by the mass of a given sample divided by its volume. The density depends on the quantity of the solids either in solution or suspended in the mud. Before cementation it is recommended to reduce the mud density to the minimum value possible for better displacement by spacer/washer fluids.

#### 4.2.5.3 Rheological Properties

The most important parameters are plastic viscosity, yield point and gel strength.

- Viscosity is the property which describes the amount of shear stress created when one layer of fluid slides over another. It is the measurement of force needed to deform a fluid. The viscosity depends largely on the temperature of the fluid usually decreasing with increasing temperature. The unit we use to measure the viscosity is centipoises, the hundredth of a poise.  $1000 \text{ cP} = 1 \text{ Pa s}$  or  $1000 \text{ cP} = 1 \text{ kg}/(\text{m} \cdot \text{s})$ . It is recommended to condition the plastic viscosity as low as possible prior to cementing.
- The yield point is an indicator of how strong the forces are between negative and positive charged mud particles. In our case these forces cause the mud to gel. The higher the yield point the better the mud can hold in suspension, the more weight the mud can support. The unit of the yield point is given in force divided by area usually in  $\text{lb}/100\text{ft}^2$ . A yield point below  $20 \text{ lb}/100\text{ft}^2$  is recommended prior to cementing.

The various types of oil field fluids can be classified in three major categories: the Newtonian, the Bingham and the Power Law fluid.

- A Newtonian fluid is defined by a linear relationship between shear stress and shear strain. The slope of the line defines the dynamic viscosity of the fluid. In this case the viscosity is constant and is only changing with temperature and pressure. Most of the fluids used in cementing operations are NOT Newtonian fluids.
- In a Bingham plastic fluid deformation takes place after a minimum value of stress is exceeded. This minimum stress is called the yield point. After passing the yield point the relationship between shear stress and shear strain is linear like in a Newtonian fluid
- In a Power Law model fluid shear stress and shear strain are related by a logarithmic expression with some input parameters like  $n'$  which indicate the degree of non-Newtonian behavior and  $k'$  refers to the consistency of the fluid.

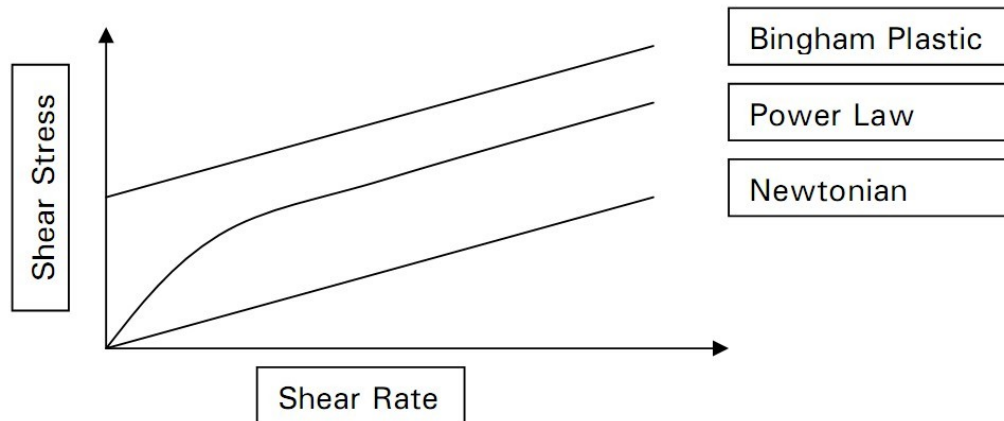


Figure 15 - The shear rate / shear stress relationship of the different flow regimes <sup>10</sup>

#### 4.2.5.4 Compressibility

Compressibility is defined as the change of volume when pressure is applied. The term used to measure the compressibility is the bulk modulus of elasticity. It is the ratio of applied stress to the change in volume of a medium. Solids and liquids are next to incompressible media. Gases are very compressible media. Gas phases change the compressibility of a mud and influences the displacement efficiency.

#### 4.2.6 Spacers and Washers/Flushes

Spacers and washers are used for two purposes:

- to separate fluids that may be incompatible
- to improve the displacement process.

For example: when cement slurry is pumped to displace the mud and these two fluids are not compatible a highly viscous layer may be created at the cement/mud interface. If this happens the cement will create channels through the drilling mud which results in pockets of contaminated mud sticking to the surfaces (casing and borehole wall)

Therefore special fluids are used to create a buffer between cement slurry and drilling mud and wash the mud from the annulus walls. These fluids can be:

- Washers or flushes consist of water and possibly a surfactant, the simplest and cheapest way to clean the annulus. Since they are typically not weighted they will readily go into turbulent flow. When the use of unweighted washers may cause well control or wellbore stability problems some weighting material has to be added.
- Spacers are designed more sophisticated than washers. Spacers are buffers used to avoid contact between cement slurry and drilling mud. Spacer fluids must not react with the mud or with the cement slurry. Spacers should have a cleaning effect on the annulus surfaces. The optimum density is right in between the density of the drilling mud and the density of the cement slurry that follows the spacer. To enable turbulent flow of the spacer fluid also at low pump rates, the viscosity needs to be as low as possible. On the other hand the yield point must be high enough to suspend weighting solids in the spacer. Depending on the pumping equipment and other

limitations turbulent flow can often not be achieved, therefore laminar flow spacers are used.

## 4.2.7 Slurry properties

### 4.2.7.1 Slurry Weight

The weight of (advanced) cement slurries can be adjusted from super light 0.9SG up to really heavy slurries of about 2.88SG. Different mixtures are used to achieve this wide range of specifications

- 0.90 SG (7.5 ppg) Ceramic Spheres
- 1.92 SG (16 ppg) Sand
- 2.88 SG (24 ppg) Hematit

Another possibility is to use foam cement to cut down the specific gravity of the slurry mixture

The weight of the slurry depends on several factors like well control or weak formations. If problems with weak formations are encountered either a two stage cementation can be performed or special cement systems can be used like foam cement or cement with ceramic spheres

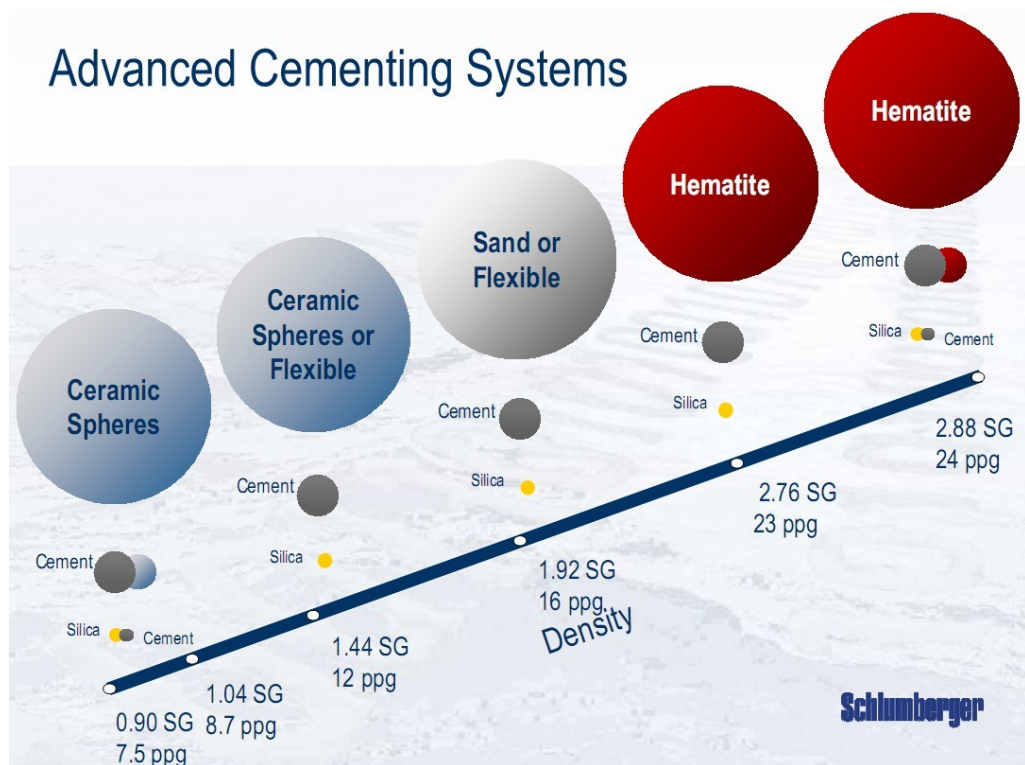


Figure 16 - The different cement slurries available from Schlumberger sorted after their density and rheological properties <sup>11</sup>

In modern cement slurries, many additives are available to exactly define the desired properties of the cement slurry.

#### 4.2.7.2 Additives

- Accelerators and retarders are used to change thickening time and influence the rate of compressive strength development.
- Extenders reduce slurry density and increase slurry yield
- Dispersants are used to improve mud removal and improve mixability of the components and to reduce hydraulic friction pressures
- Fluid loss control additives are used to reduce losses into the formation. It is highly recommended to cure problems with losses before pumping the cement. Losses of volume during cementation can heavily affect the integrity of the cement sheath. Lost circulation materials like fibers can be included in the cement slurry to help prevent losses.
- Other additives used are antifoam agents, bonding agents, gas migration control additives etc...

#### 4.2.7.3 Compressibility

Compressibility is only an important factor during transition time and for certain special applications.

- Foamed cements are three phase systems (liquid, solid, gas) Pressure variations in different levels of the cement job change the properties of the slurry. When foam cement is pumped down the hole the foam quality will decrease because of higher pressures encountered, when raising up the annulus the bubbles in the foam get bigger again. This variation in quality can be predicted approximately as we know the compressibility laws for nitrogen and its solubility in the slurry.
- In situ gas generator slurries are designed to maintain the cement pore pressure by chemical reactions which create gas down hole. The produced gas may be hydrogen or nitrogen.

### ***4.3 Pipe movement***

Pipe movement during displacement helps to remove the mud which is otherwise trapped in areas of low velocity flow (e.g. on the narrow side of the eccentric annulus). Studies and field tests<sup>12 13</sup> concluded that displacement efficiency is greater when the casing is moved. This is valid for laminar and turbulent flow!

- Reciprocating moves the casing string up and down. The drag forces will move the mud up and down and induces surge and swab pressures. This can affect well control, especially if annular clearance is small. When running in the casing already caused troubles, it is not recommended to reciprocate the string. Furthermore also pipe stretch and buckling have to be considered when reciprocating
- Rotating the casing drags the (gelled) mud away from areas where it cannot be removed by circulating. The drag forces also act while cementing and pull the cement slurry into the narrow gaps. Technically, rotating a casing is more

complicated because special equipment is needed to rotate a casing string (rotating cementing head, rotating centralizers, torque rings, etc...)

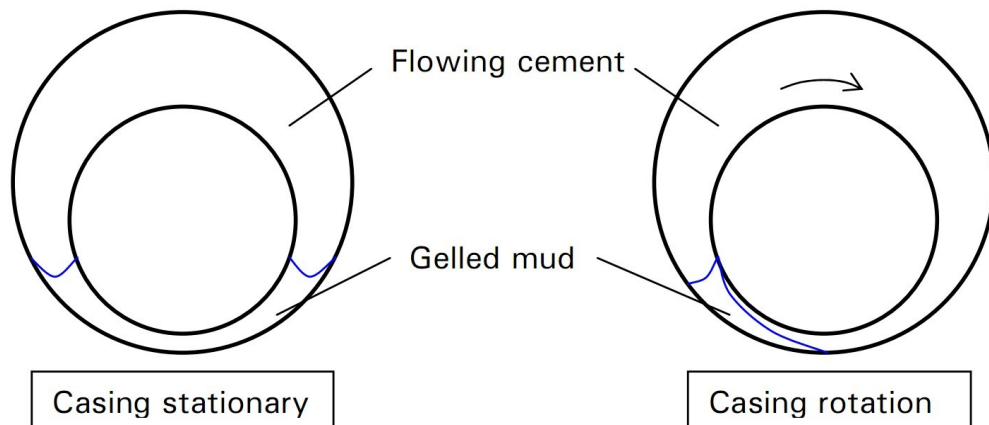


Figure 17 - Effect of casing rotation on mud displacement in a not centric annulus <sup>14</sup>

## 4.4 Bonding between casing and cement

In a wellbore there are two types of bond

- Shear bond supports the pipe in the hole mechanically and is measured by trying to move the pipe in a cement sheet. This force divided by the area of the contact area yields the shear bond (force/area). Usually the hardened cement provides adequate mechanical support to hold the pipe in place.
- Hydraulic bond blocks the migration of fluids or gas in the cement filled annulus and is usually measured by applying pressure difference on the pipe/cement interface. For zonal isolation the hydraulic bond is of great importance.

Removal of drilling mud from the smooth and uniform diameter casing surface is easier than from the inhomogeneous formation surface

## 4.5 Bonding between cement and formation

The quality of bonding between cement and formation is of great importance for zonal isolation. The most critical task is to clean the wellbore wall and to remove the filtercake to enable good bonding.

Scratchers are usually used to mechanically clean the formation surface.

### 4.5.1 External Casing Equipment : scratchers and flow enhancement tools

There are different types of mechanical devices to improve the removal of the filtercake from the borehole wall. To prevent buildup, scratchers should be placed in a way that overlapping of areas, worked by adjacent scratchers, is guaranteed. Circulation has to be established prior to pipe movement.

- Rotating scratchers consist of a split collar which houses external and internal bristles. The external bristles are inclined which reduces abrasive action when the casing is run in the hole. When moving the string the bristles are placed in a new



position thus helping to clean every section off the borehole wall. Internal bristles assist in cleaning the outside of the casing string.

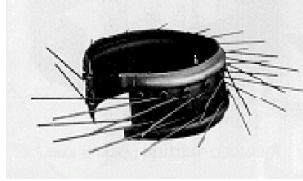


Figure 18 - rotating scratcher

- Reciprocating scratchers are constructed with stronger wire fingers than the rotating scratchers. They are designed to remove tough layers of filter cake and their design with the large working diameters enables them also to reach in enlarged scale sections and remove gelled mud there

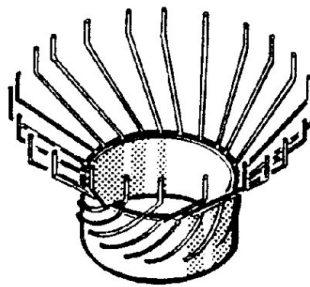


Figure 19 - reciprocating scratcher

- Flow enhancement tools do not only center the casing but also modify the annular flow pattern. This is done by increasing the fluid velocity across the spiral blade tools to give the fluid a spiral vortex flow around the casing. This swirling motion in the annulus can help to improve mud and filtercake removal.
- Stop Collars are rings firmly attached to the casing by stop screws or tack welding to limit the sliding movement of scratchers on the casing string

## 4.6 Cement properties

Portland cement is used in most well cementing operations. The conditions to which the cement is exposed in a well differ significantly to cementations on the surface. Therefore special Portland cements are manufactured for use as well cements. Portland cement is so called hydraulic cement, those cements set and develop compressive strength as a result of hydration. A chemical reaction occurs between water and the ingredients of the cement. It is not a simple drying out process where water is removed. The development of the strength is predictable, uniform and progresses at a certain speed. The hardened out cement has low permeability and does not dissolve in water. These criteria make cement very suitable for the oil field application of maintaining zonal isolation.

### 4.6.1 Characteristics and manufacture of cement<sup>15</sup>

Portland cement consists of four major compounds:  $C_3S$ ,  $C_2S$ ,  $C_3A$  and  $C_4AF$ . These ingredients are formed in an oven at up to 1500 deg. C. by a series of reactions between



lime, silica, alumina and iron oxide. The raw materials are ground to fine powder and mixed to the desired chemical composition. After cooling down a small amount of gypsum is added (3% to 5%) and the mixture is pulverized.

This procedure results in Portland cement.

Portland cement basically is prepared from two groups of raw materials;

- Calcareous: This material contains lime is the largest amount present during cement elaboration. .
- Argillaceous materials like  $Al_2O_3$ ,  $SiO_2$  and  $Fe_2O_3$  are a small part of the mixture.
- Some other materials are considered as impurities and despite the relatively small amount they can still influence the properties of the hydrated cement. (magnesia, fluorine compounds, phosphates, lead oxide, zinc oxide and alkalis)

#### **4.6.2 Properties of hardening cement paste<sup>16</sup>**

Ordinary cement slurries are a mixture of Portland cement and water, the cementing powder consists of irregular shaped particles sized from less than  $1\mu m$  to about  $100\mu m$ . During the hardening process the microstructure of the paste changes drastically for about one week and after that minor changes are still happening for up to months. What is happening is that single cement particles connect with each other and block all the flow paths through the cement.

Immediately after mixing with water the slurry is a viscous fluid. By random growth of reaction products the particles interconnect. The point when a solid framework occurs is called the set point. When the cement is further hydrated the capillary pore size as well as the overall capillary pore space is reduced and eventually their connectivity is lost.

#### **4.6.3 Cement Degradation**

Even the best cement is always a very low porous and low permeable material with very low values. Over time the cement degrades, usually in the form of cracking and chemical alteration. Degradation of cement materials is also a problem in civil engineering. Several chemical alteration processes are known: carbonation, sulfate attack and leaching.

# 5 OMV AUT – Current cement job practices

## 5.1 Introduction

### 5.1.1 Challenges in cementing in the area

#### 5.1.1.1 Low formation pressures

In the area of the surveyed wells the oil fields are very mature and often pressure reduced horizons are encountered while drilling the well.

These low pressure horizons are highly permeable layers which can cause fluid loss problems during cementation.

#### 5.1.1.2 Tight economics

The predicted oil production for a new well in the Gänserndorf area usually limits the budget available for drilling the well to an absolute minimum. This makes it hard to enforce high standards in cementation quality and sometimes compromises are made.

### 5.1.2 Cement job design

#### 5.1.2.1 Rotating & reciprocating the casing

- The drilling rig contractors KCA/Deutag and Nafta Pila do not allow cementing through the top drive system. This limits the possibility to rotate the casing during the cement job
- Reciprocating the casing up and down would be possible with the existing rig setup but is not done because of the risk of getting stuck while the string is pulled up and possible surge and swab effects.
- A rotating cement head was assessed as too expensive for the tight economic schedule.

#### 5.1.2.2 Borehole geometry

A 4 arm caliper log is performed before the casing is RIH, the data is then forwarded to the cementing company who revises the cement volume needed. The LWD trajectory data could be used to simulate the expected RIH forces and the torque necessary to rotate the casing in the hole. Unfortunately mid 2010 no tools are available for the drilling engineers to run such simulations.

#### 5.1.2.3 Pump rates

The pump rates for the job are calculated by Schlumberger engineers on the basis of the ECD in the annulus. The displacement rates are designed very conservatively, displacing

the first third with about 1000l/min, the second third with 800l/min and finishing off the last third with 600l/min. When losses occur during the job the rate is even reduced to 400l/min.

#### 5.1.2.4 Two stage cementing

Two stage cementing technique: Approximately in the middle of desired cement column (usually above a weak formation) a two stage sub is inserted between two casing pipes. When the first half of cement is pumped down and the bottom plug bumped at the shoe a so called opening bomb or opening plug is dropped from surface which lands in the two stage sub, now pressure can be applied which opens the ports of the two stage sub. Then the cementation of the second stage can be performed.

There are several reasons that can make a two stage cementing operation necessary

- weak formations which cannot support the load of a full cement column
- hot wellbore conditions which make it hard to cement the whole stage at once because of cement hardening time
- cement is only needed in certain sections of the wellbore

An alternative to two stage cementing is the use of lightweight cement slurries or foam cements which are reduced in density and therefore reduce the pressure on the bottom of the slurry column.

### 5.1.3 Slurry design

The slurry design is engineered by Schlumberger, then proposed to the drilling engineers and further refined during several meetings.

#### 5.1.3.1 Determination of needed slurry volume

The slurry volume for a job is based on the borehole geometry resulting from the caliper log data and the desired height of cement in the previous casing. Some 10-18% slurry excess is added to this volume.

About 5m<sup>3</sup> of water are pumped into the casing ahead of the spacer followed by a plug.

The volume of the spacer is determined by a contact time in the annulus of about 8-10min, which yields also about 5m<sup>3</sup>. The spacer is separated from the lead slurry with a plug.

The lead slurry is the main cement used, the volume needed is the volume of the annulus in the section which has to be cemented.

The tail slurry is pumped at the end to ensure extra good cement quality at the casing shoe and in the reservoir sections.

### 5.1.4 Simulating the cement job

Several software tools are available within the industry to simulate the cement job and calculate important parameters like maximum ECD and can be used to predict the actual job.

Typical functions of these programs are:

- Detailed input dialogues where the design properties (trajectory, casing properties, caliper, fluid and slurry properties) can be specified.
- Every simulation of interest for the cement job can be displayed (pressures, flow velocities, U tubing effects, free fall, flow regimes, pressure losses in the casing/annulus etc...)
- An animation of the cement process makes it easy to understand what is going on in the wellbore at the moment.

Numerical tools like Wellclean II from Schlumberger can be used to predict the integrity of the cement job by calculation

- Fluid position during and at the end of placement
- The likelihood that fluid channels are created or mud is bypassed and not removed
- The risk of leaving mud on the casing or on the formation

Simulations can be done for vertical, inclined and horizontal wells. Laminar and turbulent flow regimes can be computed.

## ***5.2 Current cementing practices***

In this chapter the cementing practices of SOB AUT are documented. The information presented was collected by research on past cement jobs and by interviewing key personnel and witnessing cementing the 9 5/8 casing in place on the Husky 1 on April 19, 2010.

### **5.2.1 Pumping and storage system**

- The Schlumberger cementing unit is available on location with a maximum flow rate of 1200l/min (one flow line to the rig floor). This pump is used for injecting the slurries into the casing string and for displacing the cement. Schlumberger also brings in its batch mixing tank, a tank for the slurry fluid and a on the fly mixing hopper.
- The rig hydraulics system is available as backup system but not used for the actual cementing operation.

### **5.2.2 On location job preparation**

- A caliper is run before RIH casing and the caliper data forwarded to the cementing company who adapt their final cementing program.
- The service company usually rigs up their equipment on the day before the cement job.
- The mix water for the cement is prepared when the casing run is close to reach TD, the treated water has to be used within 12 hours.
- The cement head gets filled with the various plugs and is screwed on top of the casing string

- Several m<sup>3</sup> of water are injected into the casing string afterwards the system is pressure tested.

### **5.2.3 Spacer/Washer**

While the mud gets conditioned the spacer is batch mixed and stored on location until the job can start. The spacer is following the few m<sup>3</sup> of water which were injected before the pressure test. A plug is separating the two fluids.

### **5.2.4 Cement slurries**

The first cement slurry is lighter lead slurry which is mixed on the fly with the hopper attached to the Schlumberger cementing truck.

The tail slurry which is also mixed on the fly follows the lead slurry

### **5.2.5 Displacement**

Displacement is done by the cement pump with about 800-600 l/min using mud from the rigs tank system.

### **5.2.6 Bumping the plug**

For the last 10-20 m<sup>3</sup> the pump rate is reduced to about 400-600 l/min to bump the plug. As the volume inside the casing string can be calculated and the flow in is known because calibrated flow meters are used by Schlumberger it would be sufficient to reduce the pump rate only for the last few m<sup>3</sup>. Keeping the flow rate high results in better annular mud displacement.

### **5.2.7 Cement job monitoring**

The parameters and details of a cement job are recorded in various details by most service providers on location. This information can provide useful information about the cement job. The data is usually recorded vs. time or volume pumped in the job.

### **5.2.8 Data monitoring**

The most important parameters are recorded by Schlumberger and Geoservices

- The main recording is done by the Schlumberger cementing unit which records and plots the pump pressure, the flow rate and the density of the slurries going in the well. Schlumberger has no information about returns from the well.
- The second recording is the Geoservices log which displays flow out of the well (not in volume/time but in % with a flow paddle) and changes in pit volume. Schlumberger uses own tanks for preparing and delivering slurry to the well which are not included in the Geoservices pit volume recording system.

This setup makes it hard for the operator to get real time information about what is going on during the cement job.

### **5.2.9 Calibration of sensors**

- Schlumberger's pumps are calibrated by comparing the volume of strokes pumped with a flow meter which records the mud leaving the pumping unit
- Geoservices has to rely on the information provided by the rig contactor which supplies the pumps. The effectiveness of the pumps can be tested by pumping fluid from one tank to another and comparing the recorded volume with the volume actually in the tanks.

## ***5.3 Evaluation of cement job quality***

### **5.3.1 Introduction**

There are several possibilities which can compromise the quality of the cement job

- Losses of cement volume - If the pressure in the annulus exceeds the fracture gradient of the formation fractures can open into which cement slurry can get lost.
- Losses of fluid in the cement slurry - Usually the pressure in the annulus is higher than the pore pressure in the formation. As the mud filtercake is removed by scratchers a spurt loss has to be expected from the cement slurry. If too much water is lost it is possible that the hydration of the cement slurry is not fully completed.
- Microannuli - Defined as very small gaps (<0.2mm) between casing and cement sheath which can be created due to pressure changes before the cement has developed enough compressive strength or by a mud film left on the casing. All cement logs are sensitive to Microannuli to varying degrees. Acoustic logs are less affected if the gap contains liquid
- Decentralization – It is difficult to predict the exact bond status at 360 degrees behind the casing if the pipe is not centralized. Most likely there will little cement on the low side of the hole where the distance between casing and formation face is small. Direct casing contact can result in distinctive patterns on a USIT log
- None effective mud removal – Pockets of mud are not displaced by the slurries and left in the annulus.
- Exceeding the maximum yield strength of the cement (e.g.: when pressuring up the casing for a frac job) induces cracks and fractures in the hardened cement

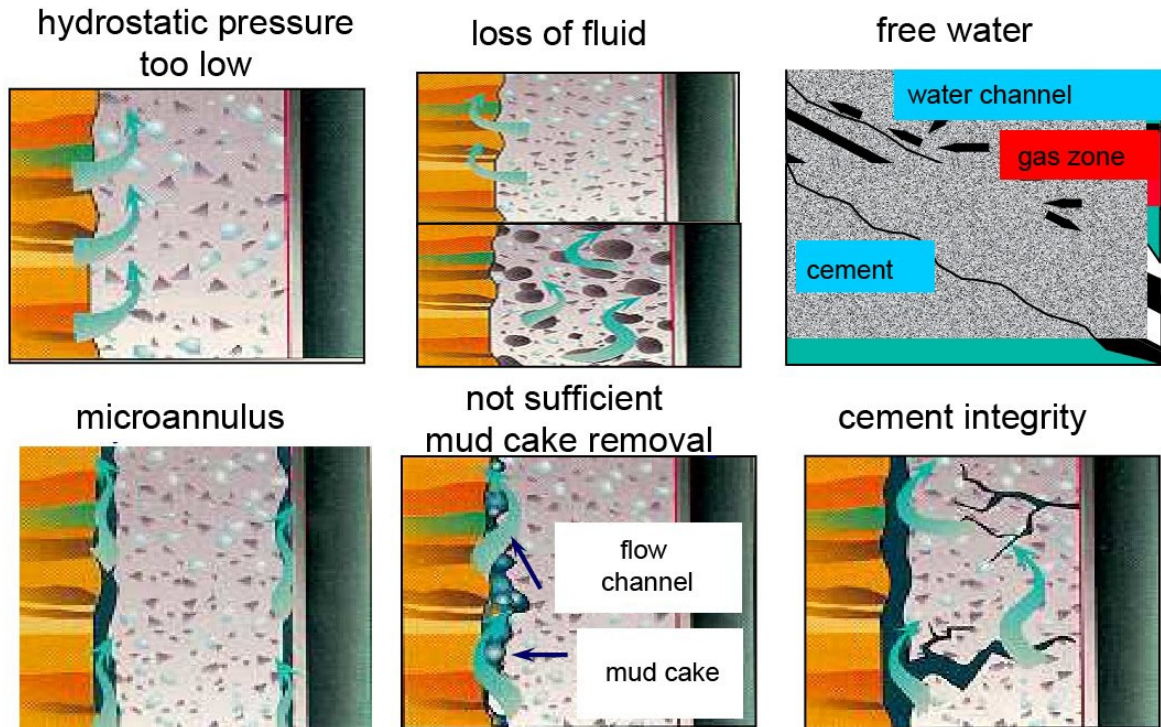


Figure 20 –sources of possible cement integrity problems

The most reliable test to determine zonal isolation quality is to set a packer between to perforations and create a pressure difference, the drawback is that these tests only cover a small zone and need a lot of effort to be performed. On the other hand a range of logging tools are used to evaluate if one or more of the above may compromise the integrity of our cement layer. The advantage of using logging tools is that a full wellbore can be covered in short time.

### 5.3.2 Reliability of acoustic logs

A widely used method to evaluate the quality of oil well cementations are acoustic logs.

An excellent SPE paper exists<sup>17</sup> which reviews the reliability of Cement Bond Logs (CBL) to determine behind-casing cement quality and derive the quality of zonal isolation between different layers from the log.

Acoustic bond logs do not measure a hydraulic seal. These tools measure the travel time, the reflections and the loss of acoustic energy as the sound waves travel through the casing cement interface. This information is used to calculate the quality of the bonding. There are two main types of cement bond logging tools:

- CBL/variable density log or segmented bond tool (SBT) which gives an average volumetric assessment of the cement in the casing-to-formation annular space.
- Ultrasonic Imaging Tool (USIT) provides a high-resolution 360° scan of the casing to cement bonding conditions.

Several factors have an effect on the quality of output of the acoustic tools:

- Logging tool centralization - It is absolutely necessary that the USIT and the CBL tools are well centralized. The tool centralization can be checked in the log files where it is

constantly plotted versus depth. Centralizers on the tool must allow smooth and even tool movement. The more friction a tool has to overcome the higher the risk of jerky movements which decrease the quality of log display.

- Fast formations are formations with very high velocity and short transit times e.g. anhydrites, low-porosity limestone and dolomite. When the acoustic signal travels such formations it may happen that it reaches the receiver ahead of the pipe signal. Fast formations effect CBLs but not USIT interpretation as a different principle is used. Fast formations make CBL logs not interpretable because the fast formation signal suggests that the cement-to-formation bond is present.
- Lightweight cement. Cement quality evaluation relies on the different acoustic properties of the cement and liquid. The higher the contrast between liquid and hardened cement the better a log can be interpreted. In lightweight slurries hollow ceramic microspheres, nitrogen and other low density materials are used to achieve a light density while still providing good compressive strength. These cements are used to stay below the fracture gradient when cementing weak formations.
- Setting time of cement. It is important to wait for the cement to set before running the bond log. If the log is run before the cement is set the result will be a pessimistic analysis and may cause unnecessary remedial operations. On the other side waiting on the cement causes the rig to stand by idle. The hardening time of the slurry depends on the type of cement used with its different additives. Other influencing parameters are the downhole temperature, pressure conditions and the degree of drilling mud contamination. Also the cement on top of the column due to different pressure/temperature environments has different hardening time properties than at the bottom of the hole.

### 5.3.2.1 Cement Bond Log (CBL)

A CBL is used to measure whether the cement is adhering solidly to the outside of the casing, it can, to a certain degree also provide information of the quality of cement-formation bonding. The log is usually obtained from a sonic type tool. Newer versions of the CBL called cement evaluation logs can give detailed 360° degree representations of the integrity of a cement job. Older versions may only display a single line which represents the average integrity around the casing.

### 5.3.2.2 Ultrasonic Imaging Tool (USIT)

This tool measures the acoustic impedance  $Z$  (definition:  $Z = \text{velocity} * \text{density}$ ) of the medium in the annulus. An ultra-sonic impulse is delivered by a rotating sender and the decline of the received signal is measured.



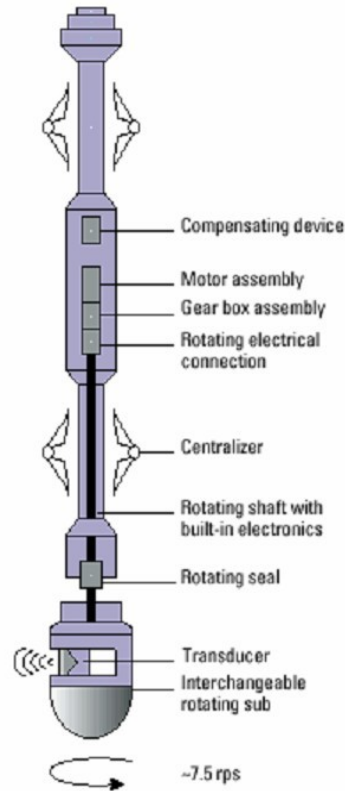


Figure 21 - USIT tool assembly<sup>18</sup>

### 5.3.3 Cement quality evaluation via pressure testing

Communication tests are regarded as the most definitive method of testing behind-casing isolation<sup>19</sup>. Two horizons are perforated, a packer is set between them and one of the zones is pressured up. If there is instantly communication between the zones this is a clear indication of integrity problems.

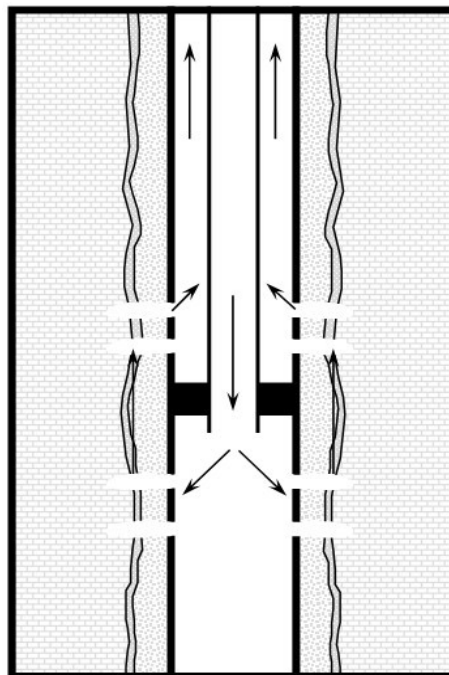


Figure 22 - communication testing<sup>20</sup>

### 5.3.4 Research on perforation induced cement bond damage

An assumption for possible leaks in the cementations of OMV AUT was that the originally good cement above and below the perforation zone gets fractured and shattered during the perforation process.

Experiments which denied this effect have been carried out by W.K. Godfrey in 1968<sup>21</sup> and the results can be considered still valid up to today. In his research Godfrey carried out experiments to determine if the detonation of the shaped charges has any effect on the casing and the integrity of the cementation behind.

An example from OMV is shown on the following page which shows that the perforation has no recognizable impact on the cement integrity.

The most important points from his paper are:

- Perforation tests conducted at atmospheric pressure cannot be used to determine casing deformation and damage that will result under down-hole conditions. It was shown that the higher the hydrostatic pressure, the more restricted the expansion of gases generated by the charge will be. Less stress and damage occur under downhole conditions than at atmospheric pressure<sup>22</sup>.
- Some damage occurred when using expandable capsule jets in examples with very weak cement. Weak cement is defined as cement with a compressive strength less than 2000 psi (~14N/mm<sup>2</sup>)
- No damage whatsoever could be identified when using hollow carrier guns. This makes sense as the charge is encapsulated in a piece of pipe and only the perforation jets exit the gun on predefined spots to punch through the casing and shoot into the formation. The major force of the expanding gases stays inside the steel housing of the gun
- The abstract of this interesting research is quoted below

*“The highest compressive strength cement has the highest bond strength in tests in which the cement is subjected to a confining pressure. After perforating the bond strength is reduced to nearly zero when the pipe is supported by weak cement. Perforating does not affect the bond strength, however, when the pipe is supported by strong cement. Pipe supported by weak cement is damaged by perforating with expandable capsule jets, but is not damaged by perforating with the hollow carrier. High strength cements are recommended for oil wells that are to be perforated.”*

All wells covered in this thesis are perforated with a hollow carrier gun system therefore it is very unlikely that the perforation process itself causes any damage in the cementation

### 5.3.5 Field example from OMV: Cement Bond Log of a perforated section

An example of Bockfließ 201a exists where the CBL was run after the perforation process in Feb. 2009. The perforated interval from 1639m to 1642m can be easily identified with

its characteristic sharp boundaries. No perforation induced damage on the cement above and below the cementation can be detected on the CBL.

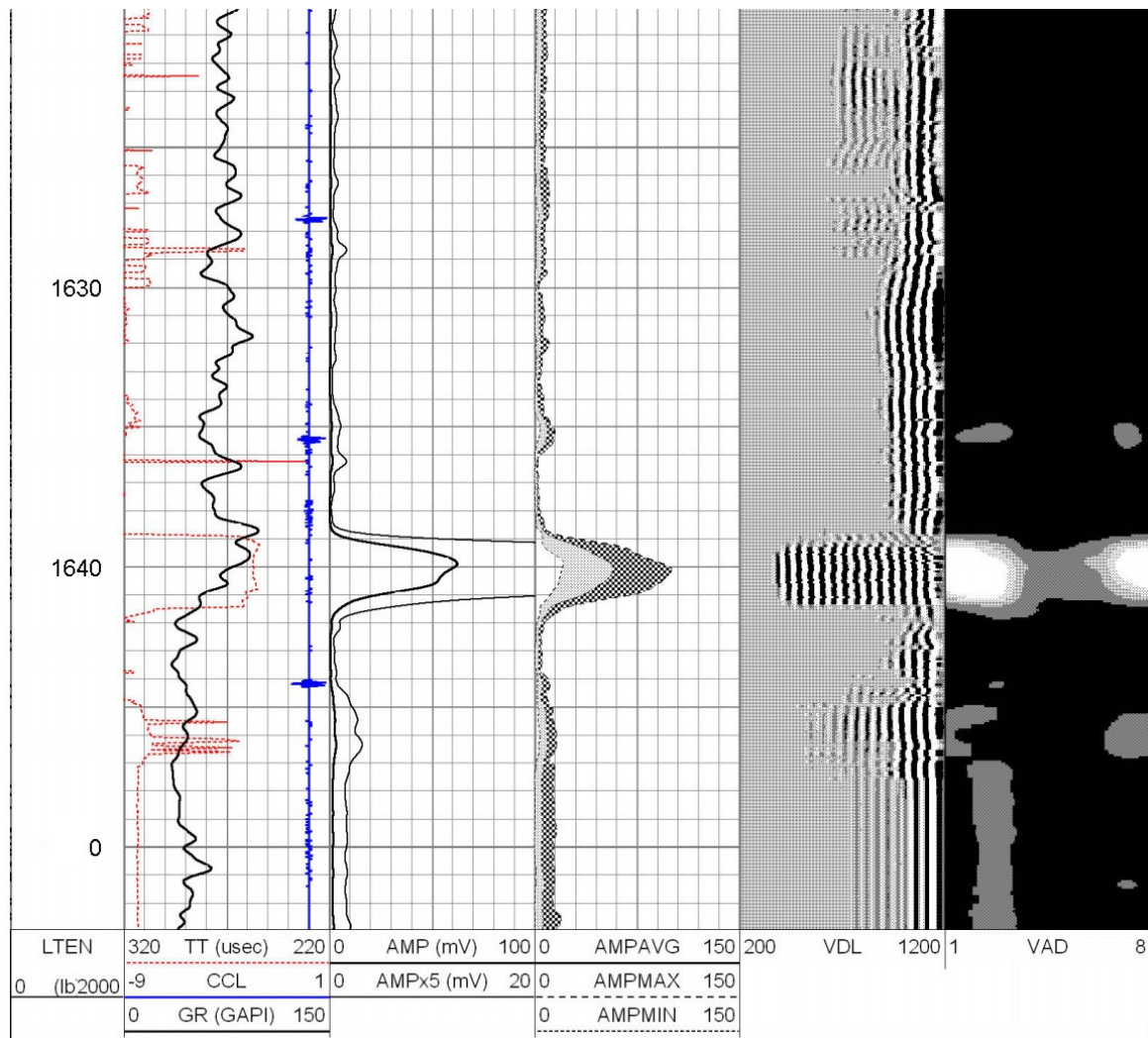


Figure 23 - CBL of Bockfließ 201a AFTER perforation job

### 5.3.6 Assuring correct perforation depth

For assuring that correct depths are perforated, Kabelservices Gänserndorf uses the following procedure, which is also common oilfield practice:

1. When assembling the perforation string, above the tubing conveyed perforation gun (TCP) a short piece of pipe (~0.5m) is attached to the system.
2. The workover crew lowers the TCP into the hole, deep enough to be BELOW the desired perforation zone.
3. A casing coupling location log (CCL) is run together with a gamma ray log through the tubing string. By the signature of the short piece of pipe the location of the TCP can be correctly identified
4. By comparing the formation logs of the gamma ray in combination with the casing coupling location with previous run logs the exact position of the TCP relative to the desired perforation zone can be determined.

5. The workover crew now pulls up the TCP by the distance calculated in point 4.
6. The shot is usually ignited by drop bar.

### **5.3.7 Perforation systems used**

In all the surveyed wells standard hollow carrier guns were used which are assembled by Kabelservice Gänserndorf for perforation jobs. All the guns used are closed systems, which means the explosives are encapsulated in a piece of pipe. All systems applied on the evaluated wells are very similar, they only differ slightly in penetration depth.

## 6 Case studies of selected wells

The cement jobs on the following wells were compared with the 2006 “good cementing practices” found in Appendix B, various simulations were done by the author to examine if the guidelines could have been implemented.

### *6.1 Selection of wells covered in the case studies.*

The wells covered in the case studies were selected by the following criteria

- Incidents during cementing like high losses, TOC found way to low, stage tool could not be opened, basically all signs that the cement integrity may be compromised
- Production with a fast increase in watercut
- The CBL log evaluation showed poor cement bonding in the reservoir sections
- Cross flow was proven by communication tests on two or more perforated horizons
- An analysis of the produced media showed that the influx does not come from the desired horizon.
- The engineers responsible for the production of the wells informed the author about possible compromised zonal isolation on their well

### *6.2 Evaluation of water coning effects*

A comparison of watercut trends and coning effects on several wells was done because it was assumed that bad cement integrity may have led to the rapid increase in watercut at the Bockfließ wells.

The watercut profile of the Bockfließ 201 was compared with several similar offset wells with a vertical distance of about 4 meters from the new perforations to the OWC. All wells increased the watercut to > 95% after 5 months of production.

This increase in watercut is due to normal water coning effects, it is very unlikely that the cement job has something to do with that development.

The production profiles of the evaluated wells (Bockfließ 201, Bockfließ 048, Matzen 70, Matzen 80 and Matzen 269) can be found in the Appendix A.

Information about the properties of the 16. TH horizon where all these wells are targeted can be found in the following SPE Paper “Case History of the Matzen Field – Matzen Sand (16<sup>th</sup> TH)”<sup>23</sup>

### *6.3 Case Studies*

#### **6.3.1 Husky 1 – 9 5/8 casing cementation on Apr 19<sup>th</sup> 2010**

The Husky 1 is included in this thesis not as a result of actual cementation problems but because it was the only possibility for the author to witness an OMV AUT cementing operation live.

### 6.3.1.1 Problems

A CBL was done by Schlumberger on May 5<sup>th</sup> 2010. The CBL evaluation of the 9 5/8 casing<sup>24</sup> showed in most sections very little bonding of the cement in the annulus. This could be related to poor mud displacement because of the low circulation rates during the cement job.

A four arm caliper done ahead of the casing run showed a very smooth 12in hole.

### 6.3.1.2 Detailed schedule of cement job

- circulation was stopped and the 9 5/8 casing was run to TD without problems
- when circulating and conditioning the hole high gas readings (32%) were recorded for a short time interval
- in the meantime the spacer and the mix water for the cement were prepared by the service company
- no reciprocation was done during job, rotating the casing was not possible due to use of non-rotating cement head
- the cementing program was carried out like this:
  1. 5m<sup>3</sup> water @ 800l/min
  2. cement head loaded with three plugs
  3. bottom plug 1
  4. 6m<sup>3</sup> spacer @ 1000l/min
  5. bottom plug 2
  6. 16m<sup>3</sup> lead slurry @ 800l/min
  7. 16m<sup>3</sup> Isoblock slurry @ 800l/min
  8. 12m<sup>3</sup> tail slurry @ 800l/min
  9. top plug
  10. 1m<sup>3</sup> water @ 1000l/min
  11. 85m<sup>3</sup> mud @ 1200l/min
  12. 26m<sup>3</sup> mud @ 830l/min
  13. reduced flow out rate was reported by Geoservices, losses were assumed, the pump rate reduced
  14. 30m<sup>3</sup> mud @ 400l/min
  15. bumped top plug with additional 50bar
  16. back flow check

### 6.3.1.3 Conclusion

#### Pump rates:

The pump rates used in pumping and displacing the cement were chosen very conservative in the past. A simulation was performed by the author using actual rheology data to determine the ECD which would result of higher displacement rates.

The graph shows that high displacement rates are possible at the beginning until the cement starts to rise in the annulus, than the rate has to be adapted.

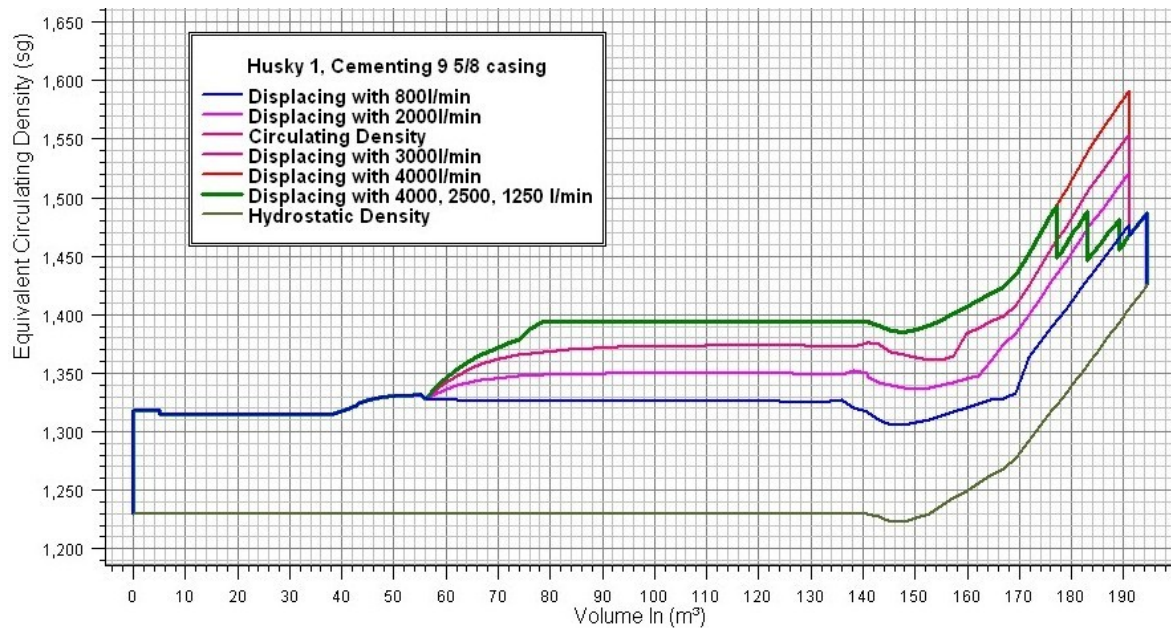


Figure 24 - Husky 1 9 5/8 cement job, OptiCem simulation with Schlumberger rates (blue) and higher rates of ECD at casing shoe at 3794m MD

The height of the cement column has big influence on the hydrostatic pressure on bottom, additional 100m of cement in this setting would increase the SG at the bottom of the hole by about 0.01 to 0.02SG.(depending if lead or tail slurry is increased) A pump schedule with high flow rates at the beginning and then reducing the displacement rates towards the end (green saw-toothed line) may be suitable for jobs like this. (see figure above)

Note that the maximum ECD of this modified job does not exceed the ECD of the original job planning (dark blue line, displacing with 800l/min)

#### 6.3.1.4 Free fall of cement, inflow – outflow recordings

Inflow recordings are done by Schlumberger, the outflow recording is done by Geoservices.



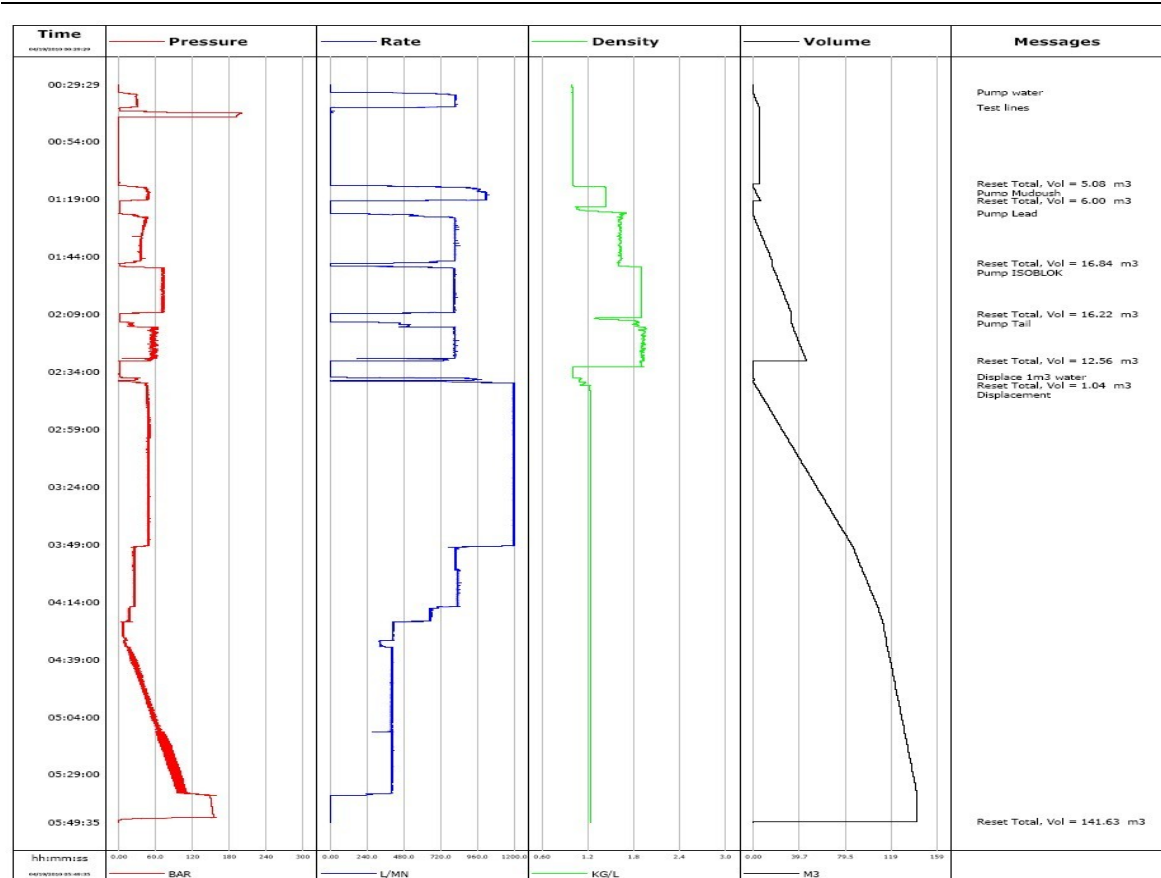


Figure 25 - Inflow chart of Schlumberger's cementing unit during the cement job

Schlumberger cementing unit records the pressure, rate, density of volume in the total volume pumped in each step. The rate is measured with a flow meter.

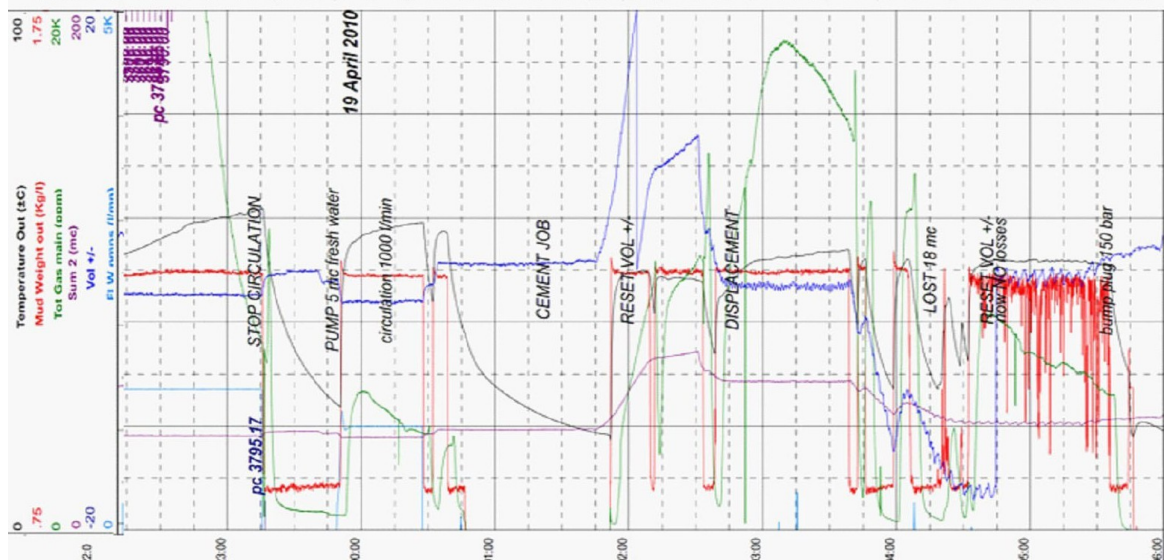


Figure 26 - Outflow chart provided by Geoservices; red line : Mud weight out, dark blue line: cumulative volume in all mud tanks (equipped with sensors). The outflow recorded by the flow paddle is not shown in this graph but was recorded and will be included in later investigations

It's clearly not easy to filter out the information needed from the recordings Geoservices provide on a figure like above



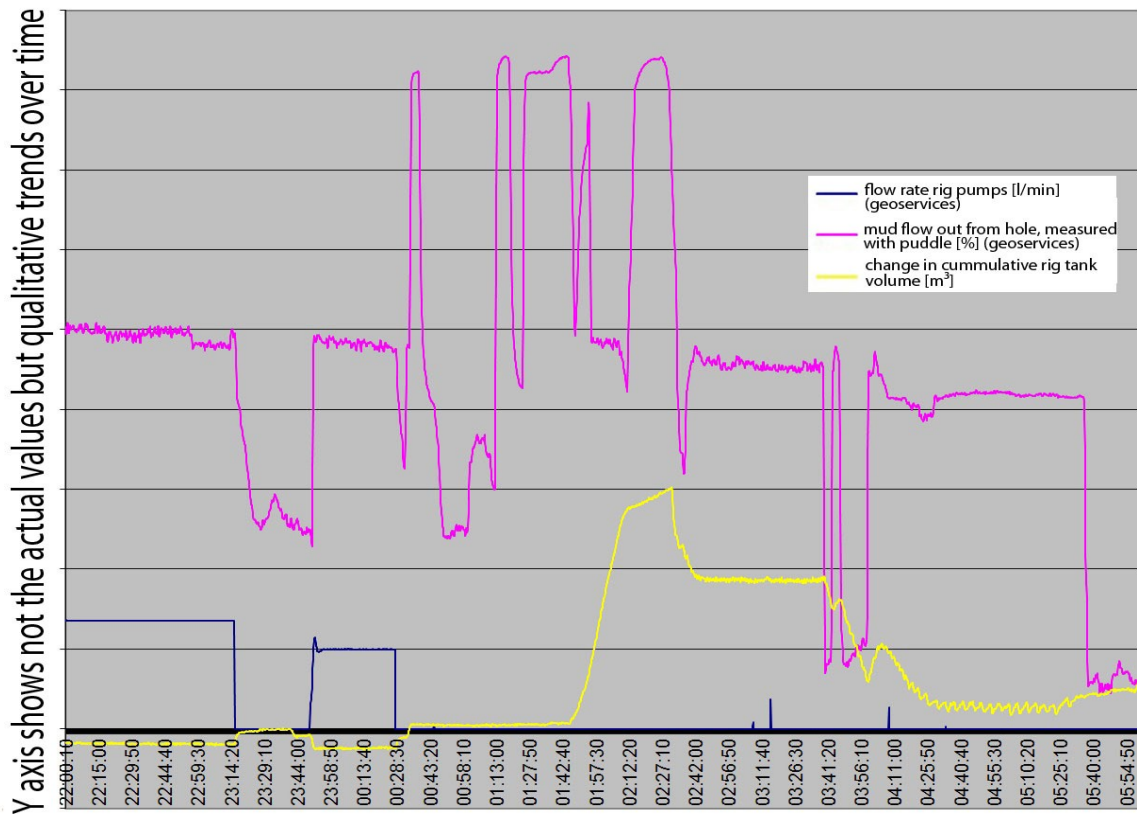


Figure 27 - Paddle movement, mud pit changes and the flow of the rig pumps were isolated from Geoservices chart

. To compare the recorded results with simulated ones the following steps were taken.

- The cumulative mud volume and the paddle movements were digitally isolated and plotted in a MS. Excel diagram. (figure above)
- An outflow simulation was performed using the actual time schedule as the job happened. Also the cement slurry properties were measured on location and used in the simulation
- These two graphs were sized to the same scale and put on top of the Schlumberger inflow plot.
- Please note that the y axis on the merged diagrams does not show actual values but qualitative trends. The x axis shows the time of the operation.

- 9 5/8 cement job of the Husky 1 on April 19th 2010
- Data: Schlumberger charts, selected data from geoservices, outflow simulation OptiCem
- |  |  |                                       |  |
|--|--|---------------------------------------|--|
| 1. 5m <sup>3</sup> water @ 800l/min    | 5. bottom plug 2                               | 9. top plug                           | 13. reduced flow out rate was reported by geoservices, losses were assumed pump rate reduced |
| 2. cement head loaded with three plugs | 6. 16m <sup>3</sup> lead slurry @ 800l/min     | 10. 1m <sup>3</sup> water @ 1000l/min | 14. 30m <sup>3</sup> mud @ 400l/min  |
| 3. bottom plug 1                       | 7. 16m <sup>3</sup> isoblock slurry @ 800l/min | 11. 85m <sup>3</sup> mud @ 1200l/min  | 15. bumped top plug with additional 50bar  |
| 4. 6m <sup>3</sup> spacer @ 1000l/min  | 8. 12m <sup>3</sup> tail slurry @ 800l/min     | 12. 26m <sup>3</sup> mud @ 830l/min   |  |

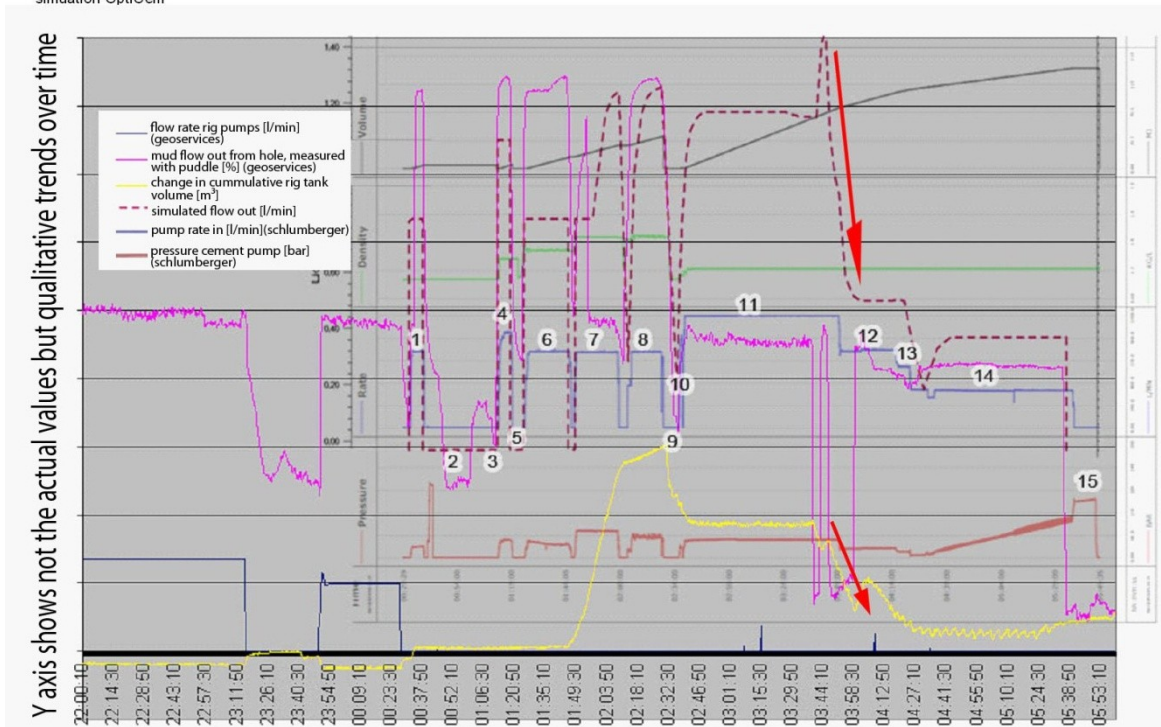


Figure 28 – Simulated flow out, recorded flow out, on top of Schlumberger's flow in

The simulation showed that after ~90m<sup>3</sup> of displacement at about 03:40 o'clock) a sudden reduction in flow out rate had to be expected (top arrow). The reason for that phenomenon is that the cement was free falling ahead of the pumped mud, when cement rises in the annulus and the pressure in annulus and casing is balanced the outflow is reduced. It takes some time for the displacement mud to reach the cement and push it further up the annulus. Therefore while the mud is catching up reduced flow out (bottom arrow) has to be expected. This happens with every cement job where the displacement rate is not sufficient to follow the free falling cement immediately.

The reduction in ECD at bottom by reducing the pump rate to 400l/min as done at this job would be equalized very quickly by the increasing hydrostatic pressure of the cement column rising in the annulus.

### 6.3.2 Bockfließ 72A

1650m MD 83deg deviated producer

#### 6.3.2.1 Problems

After the first perforation end of 2008 there was hardly any influx which is strange at a porosity of about 20%. After the perforations were set higher to the 5<sup>th</sup> TH mainly water was produced with traces of oil.

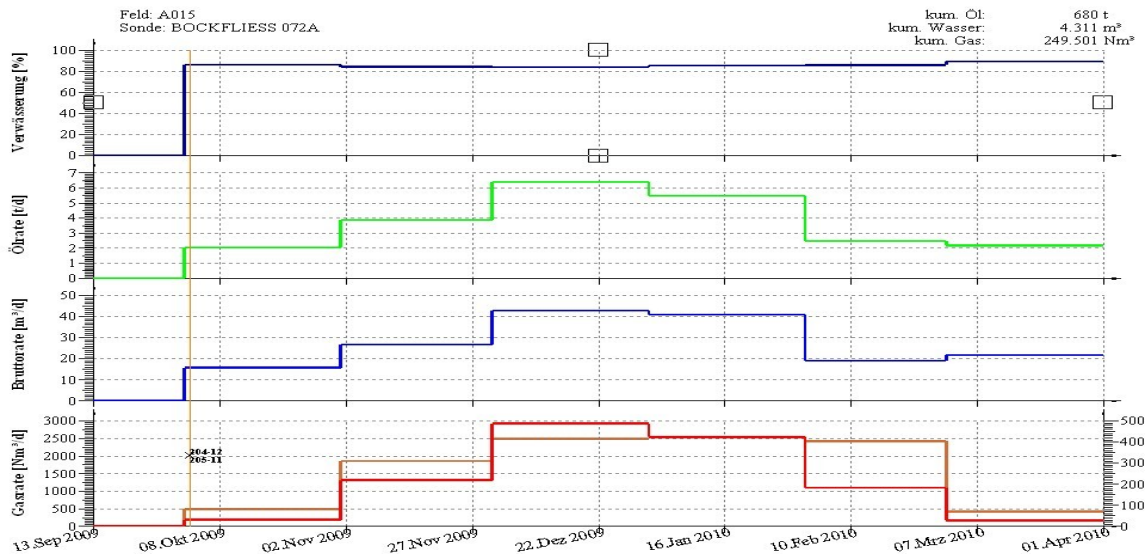


Figure 29 - Production Profile of the Bockfließ 72a

The calculated standoff in the reservoir section is around 60% , a minimum standoff of 80% is recommended by various guidelines.

## Centralization and Standoff

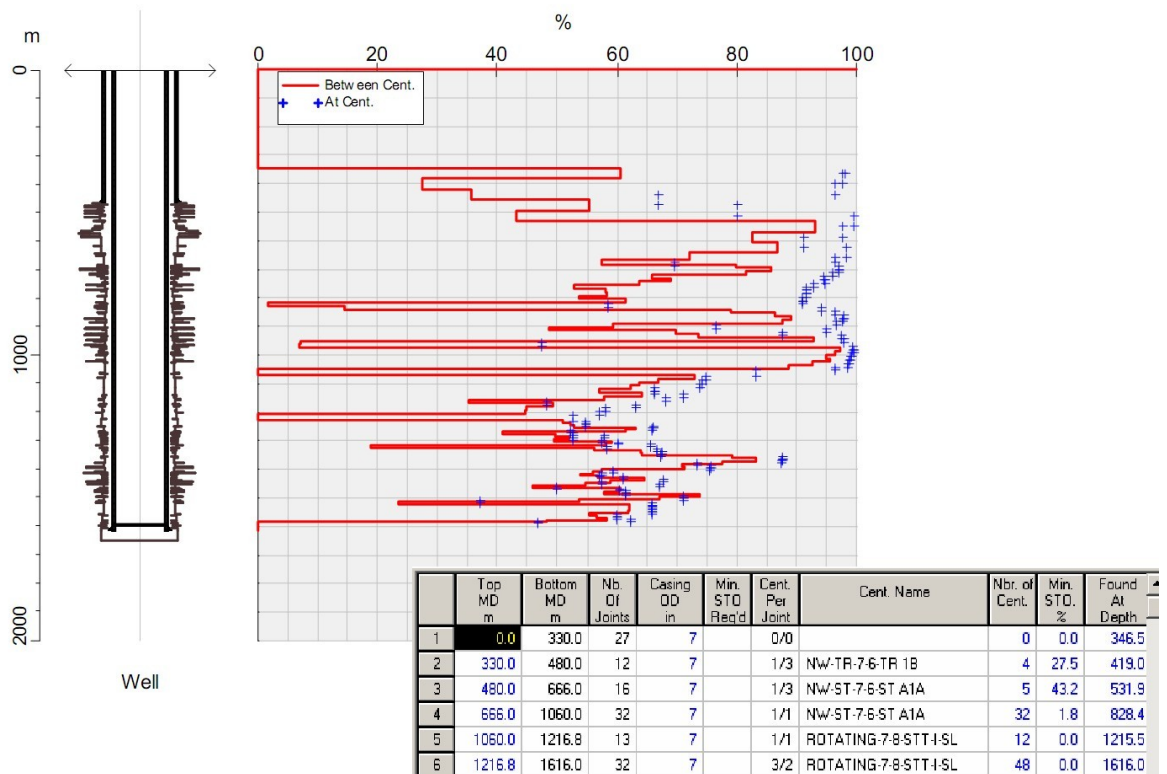


Figure 30 - Standoff calculation Bockfließ 72a, Weatherford

### 6.3.2.2 Conclusion

The poor production at this well cannot be brought in context with the cementing practices.

A simulation showed that rotating the casing would have been possible during cementation with the use of torque rings. (Appendix A)

### 6.3.2.3 Workover details

<b>Bockfließ 72a</b>	work done	start date	costs (EUR)
general workover	Perforate. casing,	21.08.2008	230,200
general workover	Acidizing	25.02.2009	90,500
general workover	perforate higher horizon	02.03.2009	49,200
general workover	perforate higher horizon	01.10.2009	73,500
minor workover	check tubing, change sucker rod pump	15.03.2010	32,600

Table 1 - Work overs done at Bockfließ 72A

## 6.3.3 Bockfließ 201

1756m MD 16deg slightly deviated production well

### 6.3.3.1 Problems

Perforations close to the oil water contact, therefore water break through

Initially very high watercut, formation water may rise in the annulus from high water saturated layers 4-5m below the perforations. Watercut normalized after shutting the lowest perforation.

The Cement Bond Log shows very poor bonding in the reservoir section

### 6.3.3.2 Conclusion

The increase in watercut at the Bockfließ 201 well was compared with similar wells. (Appendix B). It is very likely that the increase in watercut is due to normal coning behavior and not cement integrity problems.

### 6.3.3.3 Detailed job

Bad caliper, centralization not good

### 6.3.3.4 Workover details

<b>Bockfließ 201</b>	work done	start date	costs (EUR)
general workover	perf. casing, prod. testing	17.01.2008	108,900

minor workover	change sucker rod pump	05.02.2009	62,700
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Table 2 - Bockfließ 201 workover

### 6.3.4 Bockfließ 202

1774m MD 27deg slightly deviated producer

#### 6.3.4.1 Problems

After some production, inflow was reduced, the oil level dropped below pump level, Probable very small compartment The problems on this well could not be brought in context with poor cement integrity.

#### 6.3.4.2 Conclusion

Probably a small compartment was targeted and produced, no communication possible due to very limited influx. Oil level was found lower than pump level.

#### 6.3.4.3 Workover details

<b>Bockfließ 202</b>	work done	start date	costs (EUR)
general workover	perf. casing, prod. testing	07.08.2008	119,600
minor workover	memory gauge removed	09.01.2009	59,200
minor workover	run CBL log	13.05.2009	21,300
general workover	set perf. to higher horizon	25.09.2009	81,600

Table 3 - Bockfließ 202 workover

### 6.3.5 Bockfließ 203

1853m MD 35deg deviated producer

#### 6.3.5.1 Problems

Unexpected high increase in watercut, formation water may rise in the annulus from high water saturated layers 4-5m below the perforations

#### 6.3.5.2 Conclusion

Watercut normalized after shutting the lowest perforation. Probably the high watercut resulted from water coning that is normal for that permeability/distance setup.

#### 6.3.5.3 Workover details

<b>Bockfließ 203</b>	work done	start date	costs (EUR)
general workover	perf. casing,	12.08.2008	259,200
general workover	set perf. to higher horizon	24.04.2009	263,100

minor workover	check tubing, change sucker rod pump	10.02.2010	48,500
----------------	--------------------------------------	------------	--------

Table 4 - Bockfließ 203 workover

### 6.3.6 Spannberg 23

3602m MD 67deg deviated producer, no CBL available.

The last stage of this well was cemented in Jun 2008 without troubles. Three intervals were perforated in Nov 2008 followed by extensive swabbing, testing and major troubles setting packers in the deviated hole section, finally the lowest perforation was closed with a packer in Jan 2009 because high water production from that perforated interval was expected.

The well is now producing since Nov. 2009 with an acceptable water cut.

#### 6.3.6.1 Problems

Possible bad cement integrity causes high water cut when producing the lowest horizon. It is possible that the water comes from a formation with 80% water cut about 10m below the lowest perforation. While swabbing the lowest perforation the water cut of the fluid was about 65%, The water swabbed from the lowest perforations was described as reservoir water by the OMV lab.

Severe problems were also encountered when RIH packers for selective testing the perforations. Packers got set during running, problems occurred when POOH packers and damaged seals were identified.

#### 6.3.6.2 Conclusion

Due to many uncertainties no reliable statement can be given whatsoever.

No CBL / USIT log (which would cost about 100,000 Euro) was done on questioned section which could indicate bad cement integrity. Packer seals were damaged when trying to evaluate the potential of the lowest formation, this creates even more uncertainties when evaluating the swabbing results. At least once the packer did not provide a sufficient seal when a pressure difference of tubing annulus was created (see workover details below)

The decision to close the lowest perforation for production resulted in a production with an acceptable, steady watercut

#### 6.3.6.3 Workover details

Workover from 20.11.2008 - 19.01.2009; costs: EUR433,800 (this excerpt gives a rough overview and does not cover all details about the workover job)

<b>Spannberg 23a</b>	work done	start date	costs (EUR)
general workover	perf. casing, production tests	20.11.2009	433,800

Table 5 - Spannberg 23a workover

- Tubing was lowered to TD, 20m<sup>3</sup> A-Oil pumped down as cushion for perforation
- Tubing was raised to 1800m and swabbing was initiated,
- Water and A-Oil swabbed until 1100m, A-Oil did not stay down at desired depth, tubing was POOH
- Perforation gun lowered into the hole, tubing filled while RIH
- Perforated the intervals 3465.5-3470.0 and 3505.5-3510.0 and 3535.5-3540.0
- POOH tubing with gun, RIH tubing with packer.
- setting packer between middle and lower formation
- swabbing 1.5 times the tubing volume, high water cut of at least 70% during these swabbing operations. Laboratory tests indicated that the swabbed water was formation water, this led to the assumption that this water is coming from the high water cut formation underneath.
- packer released and set above the highest formation, pressured up casing with 50 bar, lost 10 bar in 10min while tubing pressure is increasing. packer leaking.
- POOH – RIH new packer set above highest formation. swabbing
- packer released POOH
- new packer RIH and set as seal between middle and lower formation
- production started from upper two formations in Oct 2009

#### 6.3.6.4 Formation details

The preliminary log interpretation shows in which horizons the three perforations were made. Below is a table where the properties of the different layers were interpreted.

There could be communication in the annulus from the last perforated interval (3535 – 3540m MD) with a high water cut horizon about 10m MD below from 3550-3554m MD.

The high water cut from the lowest perforation can come from water coning. Because of the inclination of ca. 60° the vertical distance between perforation top and water contact is only 5m TVD.

The rock in the lowest perforated section was evaluated with a porosity of 13% and a water saturation of 57%. The rock below from which the water inflow is assumed was characterized with a porosity of 8% and a water saturation of 80%.

The water saturation and the porosity in the perforated zones are comparable.



# Spannberg 23 Preliminary Loginterpretation

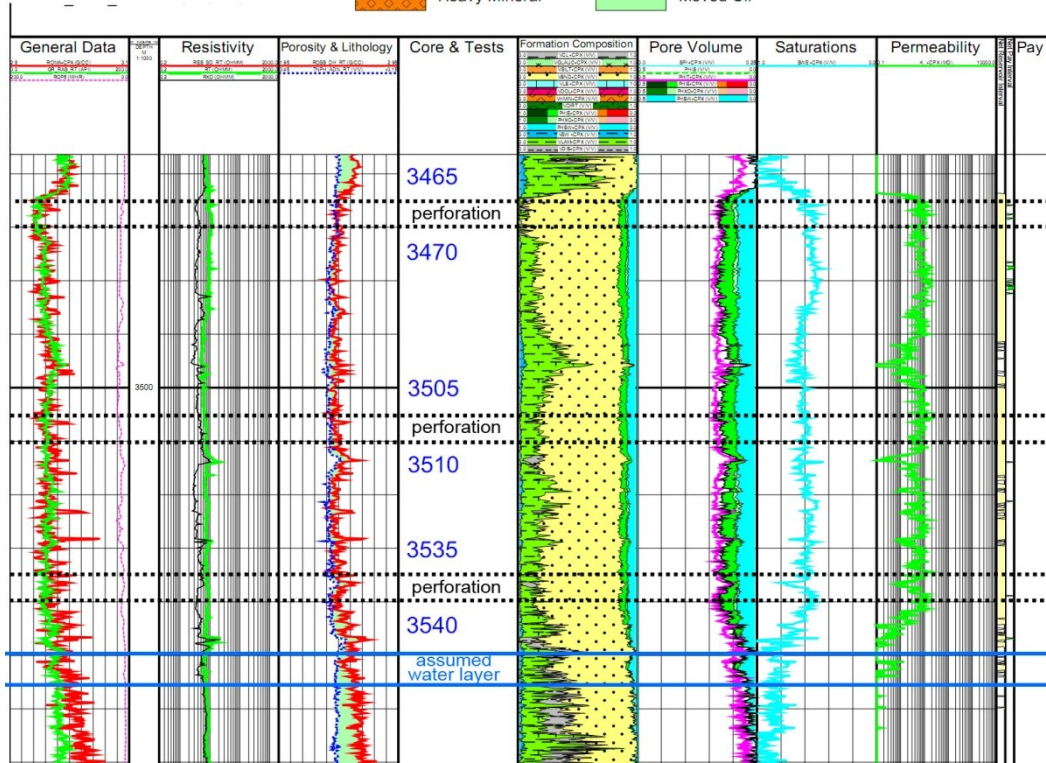
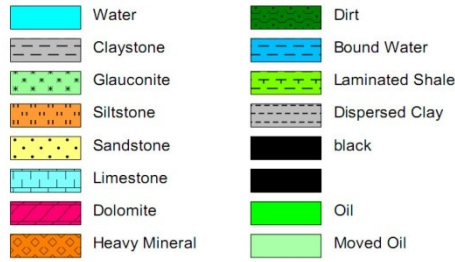


Figure 31 - Preliminary log report of the Spannberg 23 with perforations.

Bockfless 15 (low)										(3462.5 MD, 2923 TVD, 2923 TVDSS )	
MD		TVDSS		Thickness			Por	SW	Fluid		
Top	Bottom	Top	Bottom	MD	TVD	Devi					
3,463.0	3,472.7	2,923.2	2,927.9	9.7	4.7	61	14	50	Oil		
3,473.3	3,485.3	2,928.2	2,934.0	12.0	5.8	61	15	49	Oil		
3,485.7	3,490.4	2,934.2	2,936.6	4.7	2.4	60	13	65	Oil		
3,490.5	3,495.4	2,936.7	2,939.2	4.9	2.5	60	11	68	Oil		
3,496.0	3,519.0	2,939.5	2,951.4	23.0	11.9	59	14	62	Oil		
3,519.6	3,521.5	2,951.7	2,952.7	1.9	1.0	59	13	51	Oil		
3,522.2	3,528.2	2,953.1	2,956.2	6.0	3.1	59	13	58	Oil		
3,529.0	3,535.8	2,956.6	2,960.1	6.8	3.5	59	13	57	Oil		
3,536.0	3,544.2	2,960.2	2,964.4	8.2	4.2	59	13	58	Oil		
<b>3,463.0</b>	<b>3,544.2</b>	<b>2,923.2</b>	<b>2,964.4</b>	<b>77.2</b>	<b>39.1</b>		<b>14</b>	<b>57</b>	<b>Oil</b>		
3,550.0	3,553.4	2,967.4	2,969.2	3.4	1.8	59	8	78	Oil and SW		
<b>3,550.0</b>	<b>3,553.4</b>	<b>2,967.4</b>	<b>2,969.2</b>	<b>3.4</b>	<b>1.8</b>		<b>8</b>	<b>78</b>	<b>Oil and SW</b>		

Figure 32 - Preliminary Log interpretation Spannberg 23



This is the production profile of the Spannberg 23 showing a significant lower water cut when producing from the top and the middle perforation than the watercut recorded when swabbing the low perforation.

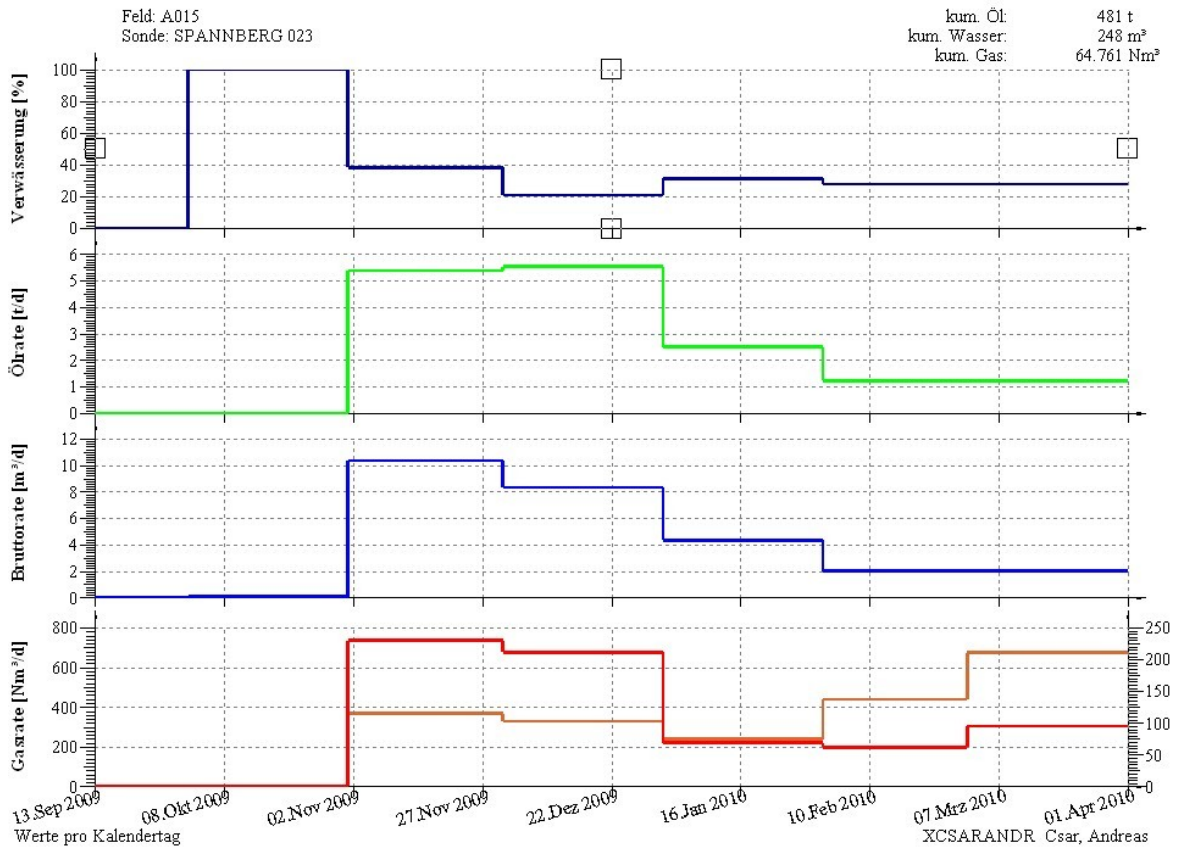


Figure 33 - The production profile of the Spannberg 23

### 6.3.7 Reference Spannberg 21

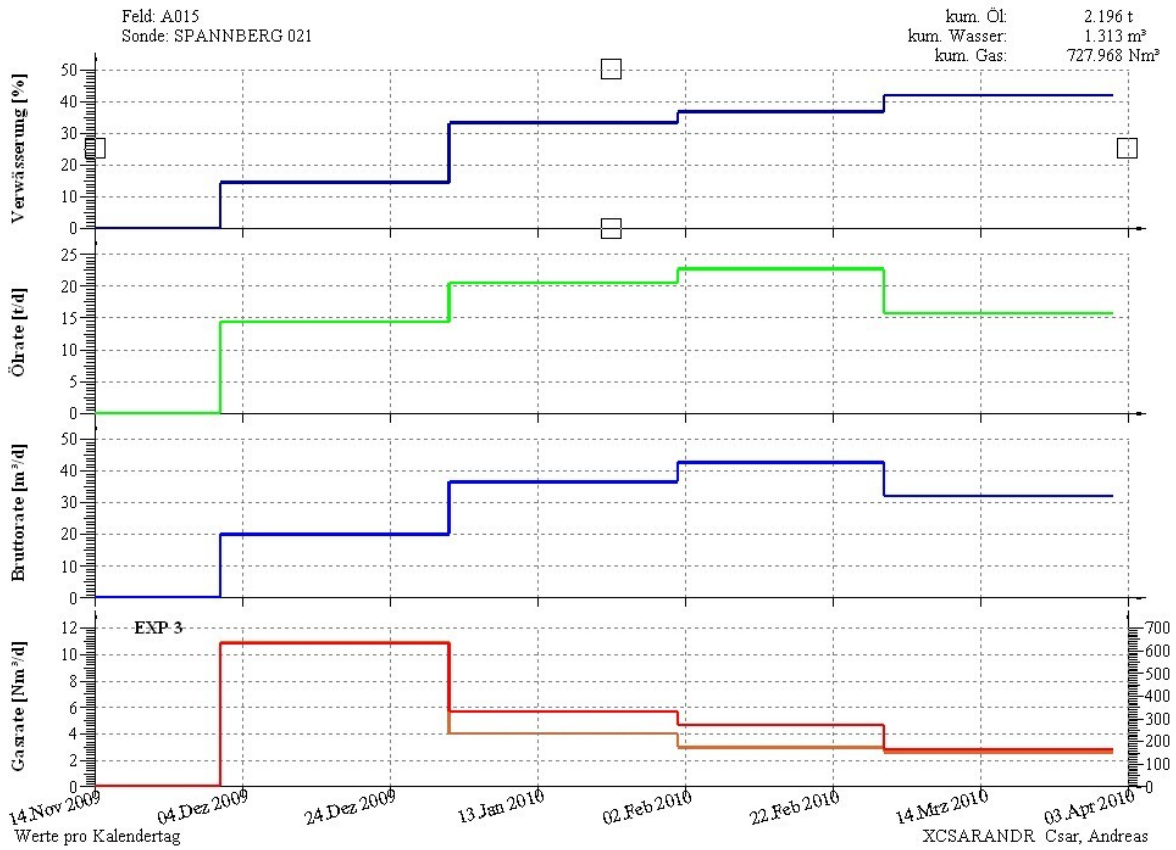


Figure 34 - Production profile of Spannberg 21

### 6.3.8 Ebenthal F19 (injector well)

2470m MD, 50 deg. deviated injector.

#### 6.3.8.1 Problems

While drilling the last section losses were encountered. Two intervals were perforated in December 2009.

- A cross flow test of the perforated intervals proofed communication between 2429m and 2432m although a CBL log showed excellent bonding.
- No caliper log available for the 8 ½ in section
- Top of cement after primary cementation of the 8 ½ in section at about 850m instead of expected 410m MD (previous shoe at 588m)

#### 6.3.8.2 Drilling job details

No caliper information was available for calculating the hole volume<sup>25</sup>.

The effective hole diameter drilled by the 8 1/2inch bit was assumed to be 9.1" (note that the same section on the Ebenthal F18 had a measured caliper of 9.91")

Losses occurred during the cement job, unfortunately no time log data is available from Geoservices (the recording crew was probably already released before the cement job)

The cement job was carried out with an assumed hole diameter of 9.1” which should result in a TOC at 410m MD.

A simulation was done by the author assuming a 9.6” hole while keeping the slurry volumes the same. This calculation resulted in a TOC at 870m MD. This is close to the actual TOC which was measured at 850m MD.

At the neighboring Ebenthal F18 a caliper log resulted in an average hole size of 9.91”, probably the hole size at the Ebenthal F19 was underestimated.

Quality 4 arm caliper data is very essential for planning the volume and performing good cement jobs.

### 6.3.8.3 Workover details

workover from 03.12.2009 – 05.02.2010., costs: EUR 368,460 (this excerpt gives a rough overview and does not cover all details about the workover job)

<b>Ebenthal F 19</b>	work done	start date	costs (EUR)
general workover	perf. casing,	09.12.2009	268,500

Table 6 - Ebenthal F 19 workover

- 09.12.2009 the hole was perforated from 2415m to 2429m and 2432m to 2442m
- when POOH the gun was lost, fishing operations were successfully performed.
- 22.01.2009 injection tests were performed and memory gauge recordings started
- 28.01.2009 acidizing jobs were performed
- 29.01.2009 POOH, gauges recording stopped

the packer was set between the perforations several times, circulation tests indicated bad isolation between the perforated intervals.

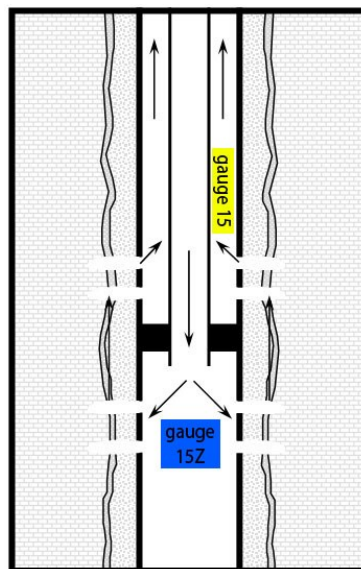


Figure 35 - Position of memory gauges during testing

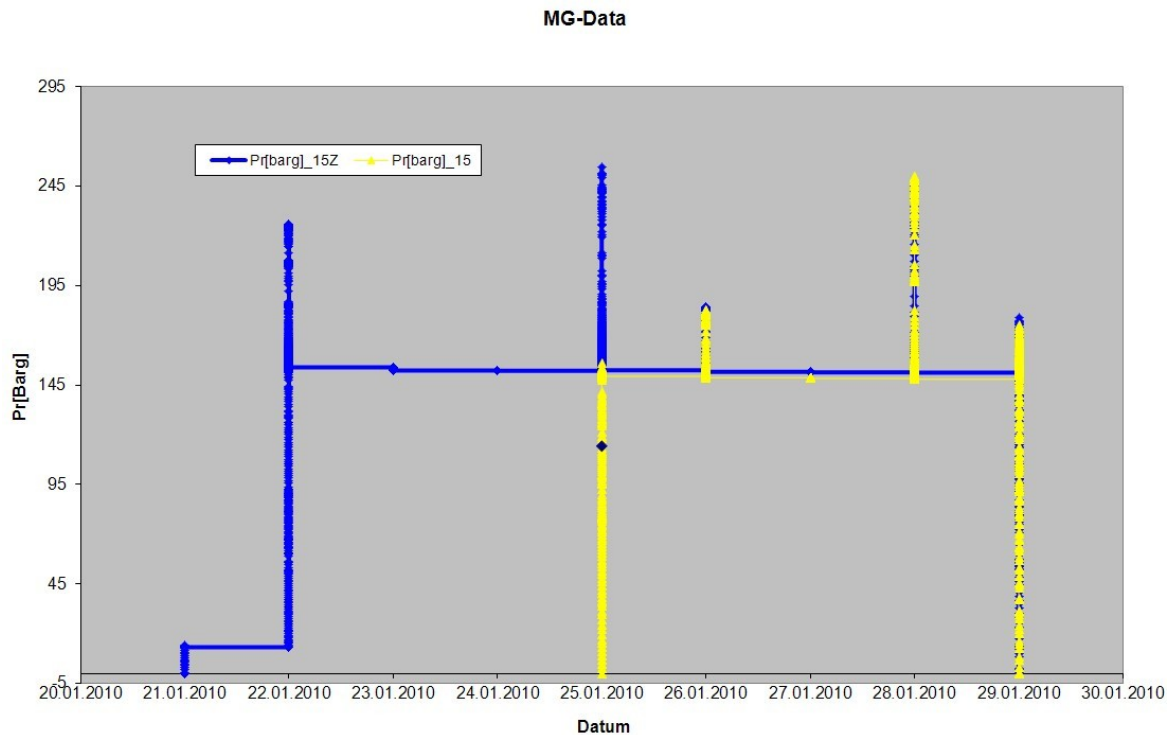


Figure 36 - Memory gauges recordings during testing

#### 6.3.8.4 Reference Ebenthal F18 (injector well)

The Ebenthal F18 had the same drilling and casing program as the Ebenthal F19, also the same two horizons were perforated as in the F19.

Some major differences of these two injector wells are listed here:

- no losses during cementation of the F18, 23m<sup>3</sup> losses on the F19 during cementing
- higher flow rates during displacement on the F18 (800l/min), on the F19 reduced pump rate 300l/min due to losses
- a caliper log was run on the F18, the caliper was assumed at the F19
- the TOC of the F18 is at about 150m (evaluated by CBL), at 850m at the F19
- no cross flow was identified during injection tests on the F18, positive indication when testing F19

<b>Ebenthal F 18</b>	work done	start date	costs (EUR)
general workover	perf. casing,	13.11.2009	219,500
general workover	injection test	24.11.2009	NAV
general workover	acidizing	26.11.2009	NAV

Table 7 - Ebenthal F 18 workover

### 6.3.9 Matzen F 261

1840m MD vertical injector

#### 6.3.9.1 Problems

>700m<sup>3</sup> losses during drilling, 40m<sup>3</sup> losses during cementation, TOC at 1580m MD instead of planned 225m MD (Reservoir only 100m below actual TOC)

#### 6.3.9.2 Conclusion

What probably happened is that cement slurry went into the formation.

Below the red line of actual cement pump pressure recordings, is a simulation how the job should have looked like in theory.

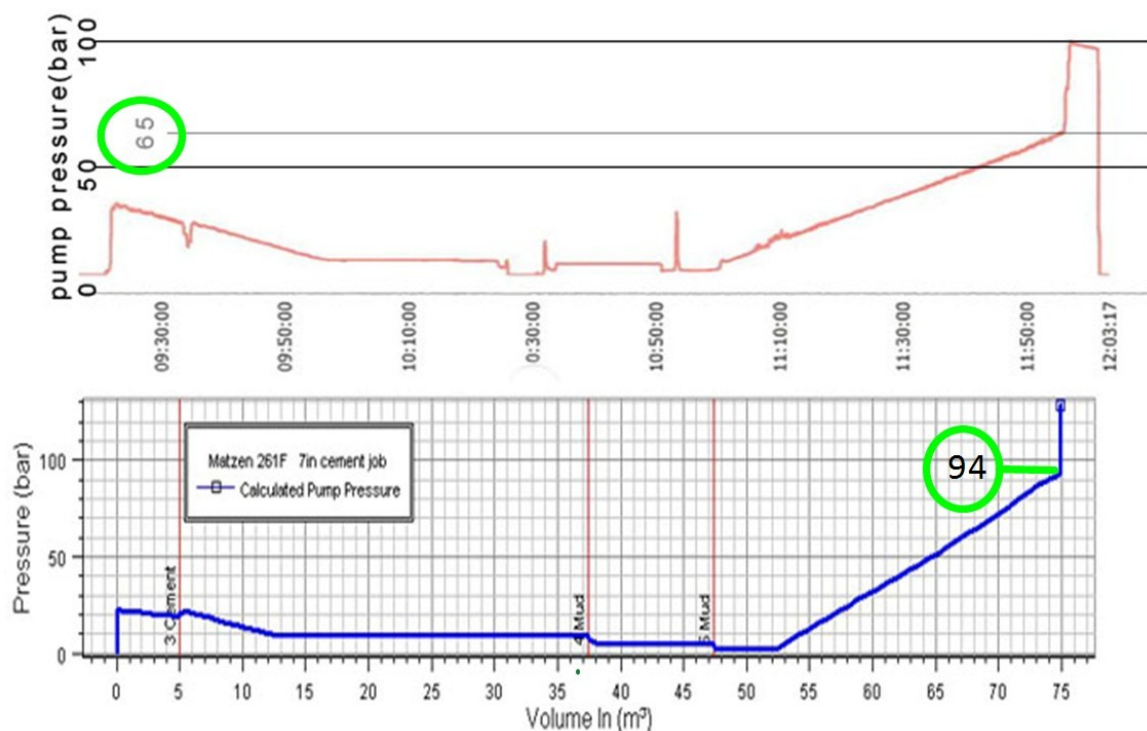


Figure 37 - On top is the actual pump pressure recorded at location by Schlumberger, the graph on bottom shows the pump pressure simulation without any fluid losses (note that the units on the horizontal axis are not the same)

The missing 30 bar may result of the cement column not lifted high enough in the annulus. Doing a quick calculation:

- density Cement (1.43SG)- density Mud (1.12SG) ~ 0.3SG
- 900m more cement are needed in the annulus to equalize the missing pressure of 30 bar from actual to theoretical pressure recordings
- So the TOC must be at least 900m lower than expected, by logs it was actually found 1355 m lower than planned.

A thermal log (Figure 38), showed the TOC at about 1580m and furthermore a sharp temperature decrease at about 1680 (16. TH). It is very likely that the massive amount of cold fluid lost while cementing causes a temporarily temperature drop at that section.

What could have happened is that some kind of flash set occurred at a depth of around 1650m MD, a sudden pressure increase caused the formation to open and many m<sup>3</sup> of cement slurry went into the rock. Although the cement column is not rising higher than 1580m, the pump pressure is still steadily increasing as less and less heavier cement inside the casing needs more pump pressure to keep the cement job going. Additionally the section with a possible flash set creates a bottleneck and therefore additional pressure losses.

Unfortunately there are no flow-out recordings available on this job which would add valuable information what may have happened at this cement job.

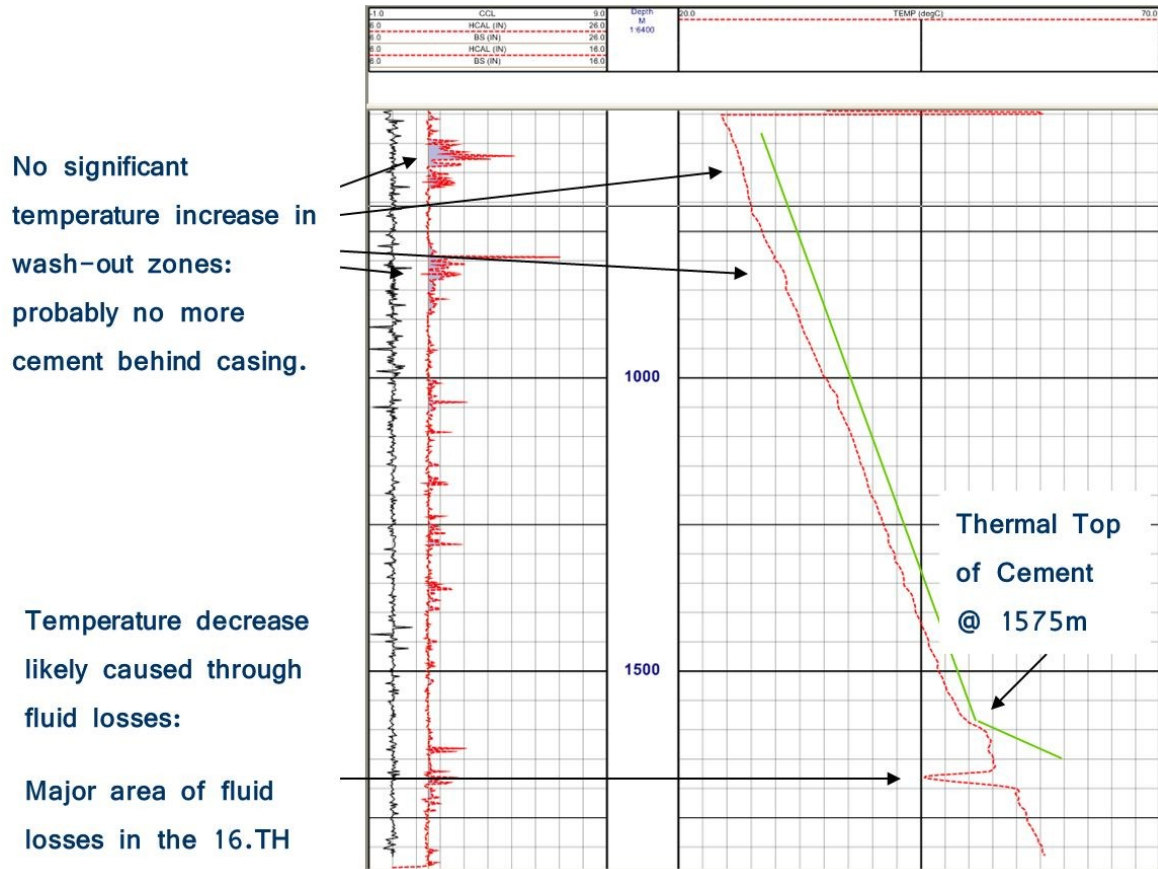


Figure 38 - Thermal log after cementing the 7in casing on the Matzen F 261

### 6.3.9.3 Workover details

Matzen F 261	work done	start date	costs (EUR)
general workover	perf. casing,	22.07.2009	132,000
general workover	injection test	11.08.2009	NAV
general workover	acidizing	12.09.2009	17,800

Table 8 - Matzen F 261 workover



### 6.3.10 Mühlberg S2a

2047m MD 35deg deviated producer

#### 6.3.10.1 Problems

Losses during cementing two stage job. 1<sup>st</sup> stage 15m<sup>3</sup>, 2<sup>nd</sup> stage 10m<sup>3</sup>

In the reservoir section at 1943m MD the CBL was interpreted as not good by Hotwell, above and below the oil horizon there are gas horizons the well also produces unexpectedly high gas – oil ratios.

#### 6.3.10.2 Conclusion

Maybe gas enters the annulus from a layer underneath, migrates upwards behind the 7in casing and enters the wellbore through the perforations.

#### 6.3.10.3 Workover details

Mühlberg S 2a	work done	start date	costs (EUR)
general workover	Perf. Casing, inside casing gravel pack	10.07.2009	230,200
general workover	acidizing	08.09.2009	19,200

Table 9 - Mühlberg S 2a

### 6.3.11 Mühlberg S1 (good reference)

This is a comparison of the production profiles of the Mühlberg S 001 which and the Mühlberg S 002a

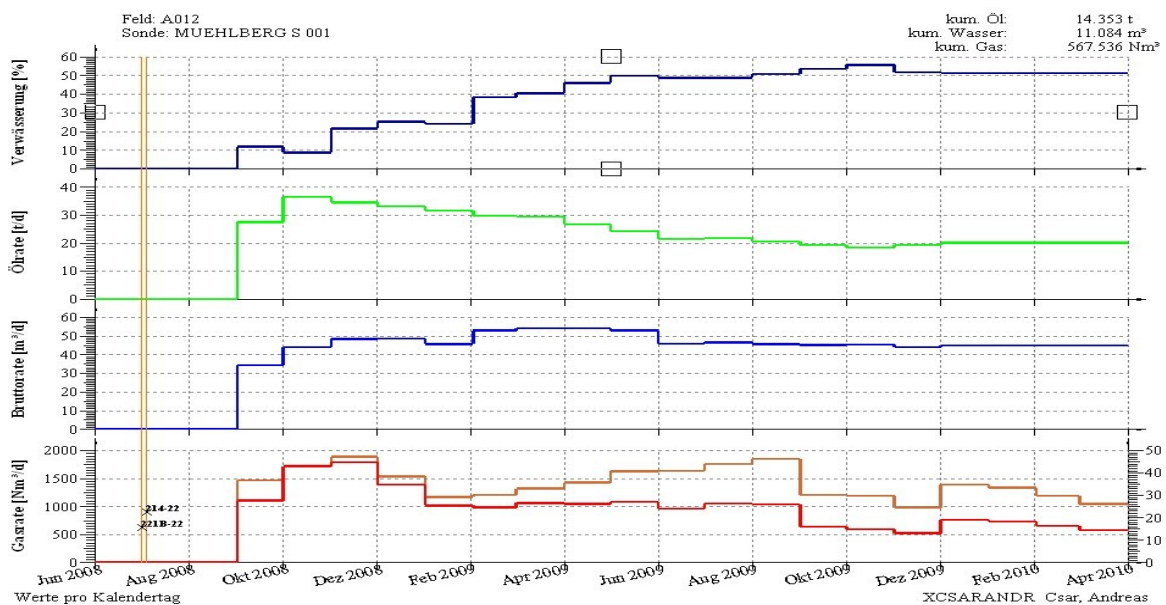


Figure 39 - Production history of the Mühlberg S 001 the scale on the lower right side is the Gas Oil Ratio

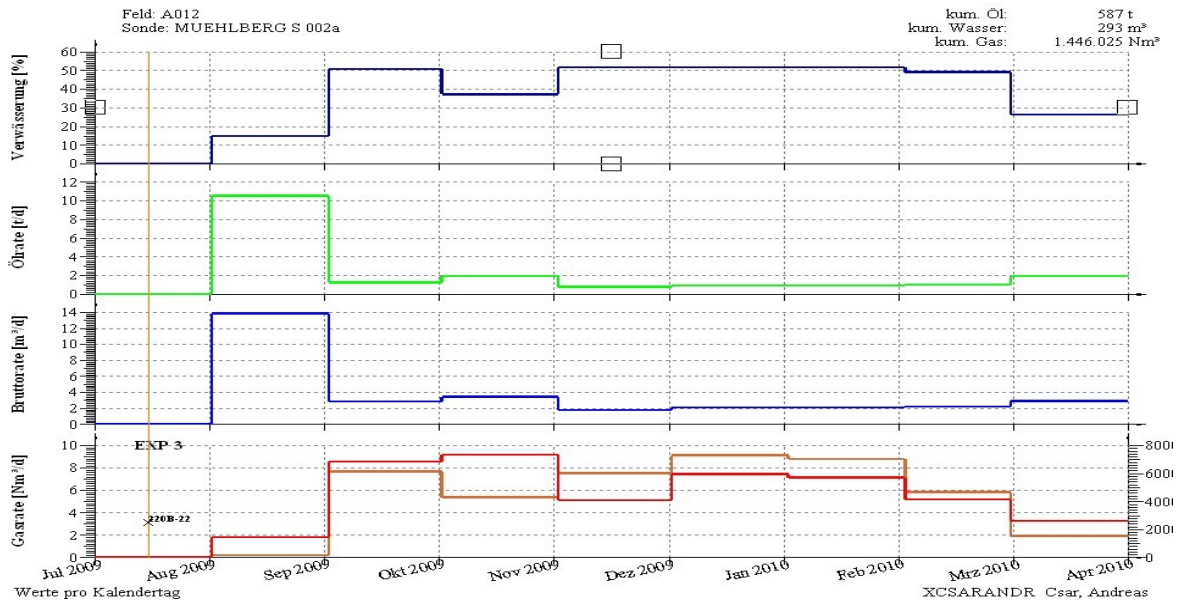


Figure 40 - Production history of the Muehlberg S 002a (note that the gas rate is in a 1000's scale) the scale on the lower right side is the Gas Oil Ratio

Muehlberg S 1	work done	start date	costs (EUR)
general workover	perf. casing,	27.06.2008	295,700

Table 10 – work over on the Muehlberg S 1



## **6.3.12 Prottes Tief West 1**

3400m MD deviated production well

### **6.3.12.1 Problems**

While cementing the lower stage on the 9 5/8 intermediate casing the cement hardened out and prevented circulation on the upper stage. After several remedial cementing operations the perforated gas storage horizons could be sealed off to surface.

### **6.3.12.2 Conclusion**

- From the cement data available fluid loss control additives were only added to the tail slurry which filled the lower 400m (up to 700m) but not in the HOZ light slurry pumped ahead. Evaluating the CBL this 400m section shows better isolation than the above sections. Another reason for the varying quality could be a gas storage horizon, pressured very low at 51 bar located at ~750m.
- The two additional cement jobs (bullhead top job & perforation squeeze job) performed after identifying bad cementation via CBL were carried out at moderate success. No further CBL was run after squeezing cement into the perforations.
- When running a CBL it is recommended to keep a minimum waiting time of 48 hours<sup>26</sup> to ensure that the cement has hardened out sufficiently to provide good CBL readings. The lowest waiting times in that stage of the well were around 34h and 23h. Running the CBL too early can result in pessimistic interpretation and therefore in unnecessary squeeze jobs. Of course the waiting time has to be balanced with rig idle costs.

### **6.3.12.3 Detailed job**

The two stage cement job of the 9 5/8 casing (from 2767m MD to surface, stage tool at 1150m MD) could not provide the planned zonal isolation from weak storage horizons in the upper stage

The steps taken in cementing this section are summarized below:

- cementing the lower stage as planned, 10% excess cement volume pumped to encounter possible losses, cement in place ~150m above stage tool
- opened stage tool
- no circulation could be established in the top section
- circulated inside the casing at stage tool depth, finally closed stage tool
- after injection tests, cement was bullheaded down the annulus
- the stage tool was drilled and a CBL was run (cement hardening time lower stage ~55h, upper stage ~ 34h) bad cement in the upper section was identified
- after another inflow test a second top cement job was performed where 30m<sup>3</sup> cement slurry were bullheaded down the annulus, after that job, gas migrated up the annulus

- a CBL was run for the upper 800m which showed limited zonal isolation (cement hardening time after top job~23h)
- drilling of the next section (8 ½ inch) continued
- at 505m and 434m the casing was perforated, circulation was tried without success, finally two squeeze jobs were performed through the perforations with the goal to seal a gas storage horizon
- no further CBL was run on the upper section
- after several days no gas influx anymore in the annulus.

### 6.3.13 Reference Schönkirchen Tief 91

On Feb. 23<sup>rd</sup> 2009 a similar two stage cementation was successfully performed at the well Schönkirchen Tief 91.

Below is a timetable which compares the properties of the slurries used in the two wells and the time it took until the stage tool was opened. (time count starts when the first cement is pumped into the casing)

A delay when opening the stage tool in the Prottes T W 1 resulted in probably already hardened out normal cement slurry behind the stage tool. The thickening time of the normal slurry was declared with 314min while it took 310min to open the stage tool.

The extra retarded cement meant to be at the stage tool was pumped further above the stage tool (total cement above the stage tool 150m). No circulation was possible anymore.

On the Schönkirchen Tief there was still one hour safety margin to the normal cement slurry when the stage tool was opened and circulation initiated.

	Prottes T W 1	Schönkirchen Tief 91
lead slurry (extra retarded) minimum thickening time	441 min	490min
normal slurry minimum thickening time	<b>314 min</b>	320 min
tail slurry minimum thickening time	280 min	250 min
time until stage tool was opened and circulation initiated	<b>310 min</b>	240 min

Table 11 - Schönkirchen Tief 91 and Prottes Tief West 1 cementing properties table

#### 6.3.13.1 Workover details

<b>Prottes T W 1</b>	work done	start date	costs (EUR)
general workover	perf. casing,	18.11.2009	201,200

Table 12 - Prottes Tief West 1 work over

# 7 Conclusions

## *7.1 Possible potential of improvement*

### **7.1.1 Financial evaluation of potential of improvement**

- It is highly recommended to follow the best practices recommended by the industry which actually hardly creates additional costs, e.g. increasing the flow rate and reciprocating the casing string during cementing needs minimal additional investments for scratchers to clean the borehole wall.
- Rotating the casing is more costly because a rotating cement head and couplings which withstand the torque are needed, the additional cost may be in the range of about additional EUR 50,000 per cementation.
- Just as a comparison, the average workover job costs about EUR 180,000. When troubles are encountered this sum can easily double.
- When doing the same workover job on very deep wells >3000m, a drilling rig has to be brought on location to do the job. This increases the costs of the workover by a factor of ten and shows that good cement integrity is even more important in deep wells.

### **7.1.2 Monitoring losses during the job**

Today sensors are placed all over the rig to record the cement job, but they are no substitution for OMV engineers which are on location and control what is going on while cementing the well. Simulations made on location, feed with the actual job data and updated as the job processes are recommended by the author to make sure that irregularities are recognized and correct actions can be taken immediately.

For pumping and displacing the cement usually Schlumberger's cement unit is used, therefore flow in is recorded only by the cementing company, flow out and change in pit volume is monitored only by Geoservices.

It is hard to determine volume losses during the job because of this split of recordings. Currently, it is only possible to identify losses after the job has finished by measuring the pit volumes before and after the job and include the slurries volume pumped for the cement job in that calculation.

The reason why the Schlumberger pumps are chosen for displacing the mud is that their volume recordings are described as more accurate than the rig's system.

This thesis recommends using the rig pumps for displacing the cement slurry for several reasons

- the maximum displacing rate by the Schlumberger unit is limited to 1200l/min by the 2" pressure line from the cement pump up the rig floor, with the rig pump there is no such limitation.

- as flow in and flow out are both monitored by Geoservices different values in flow in and out can be identified and interpreted during the job
- reciprocating the pipe up and down during the displacement would be made even easier when displacing through the rig pumps

### **7.1.3 Reciprocating during the job**

When the casing can be run in hole smoothly, without troubles, the casing should be moved up and down during displacement of the cement in the annulus even when the cement is in place. Reciprocating the casing improves the evenly distribution of the cement slurry in the annulus and therefore improves the integrity of the cement.

Swab and surge pressures have to be considered when running this operation.

Also the cement hardening time must not be exceeded otherwise there is a chance of getting stuck while the string is pulled up. The hardening times are available from the lab reports and sufficient time reserves can be established. Hook load readings also indicate when the cement starts to harden.

Of course, reciprocating is not recommended when severe troubles were already encountered when running the casing to TD.

### **7.1.4 Rotating during the job**

Rotating the casing string during displacement of the cement is highly recommended especially in deviated wells to ensure good mud removal and even cement distribution also in the narrower parts of the annulus. Rotating the casing is considered the most important parameter in establishing a good cementation.

Drilling rig providers usually do not allow pumping cement slurries through the top drive system, which is also the case for the rigs contracted by OMV AUT.

Rotating cement heads are available on the market which can be used in combination with a top drive system to rotate the casing while running in hole and during the cement job. The stand pipe is connected directly to the rotating cement head, therefore no cement is pumped through the top drive. Systems are available where plugs can be pre-loaded and released in a rotating cement head.

What has to be considered is that standard API BTC couplings, like they are on the casing strings in the OMV stock, have not very high torque ratings. Torque rings are necessary to roughly double the standard torque limits. These rings cost about EUR 100 /piece, installing them on 1,000m of casing are about EUR 10,000 Euro additional costs for a cement job.

## ***7.2 Additional recommendations***

### **7.2.1 Geoservices Time Logs**

- Some wells have no time log recorded during the final cementing operation. Probably the logging company was released after reaching TD. The author suggested keeping the logging company on location one more day and also log the cementing

operations. The time logs are a very reliable source to determine what was done while cementing the casing in place (conditioning the mud prior cementing, circulating, flow out rates, reciprocating, rotating, etc...)

- The general quality of the Time Logs can be improved, the logs are reported in automatically created PDF format and sometimes information and side notes are not readable because everything is displayed on top of each other. It would be better to supply the data in digital format, preferable comma separated values or excel files, and provide a software program where the user can decide individually which data from which timeframe he wants to view.

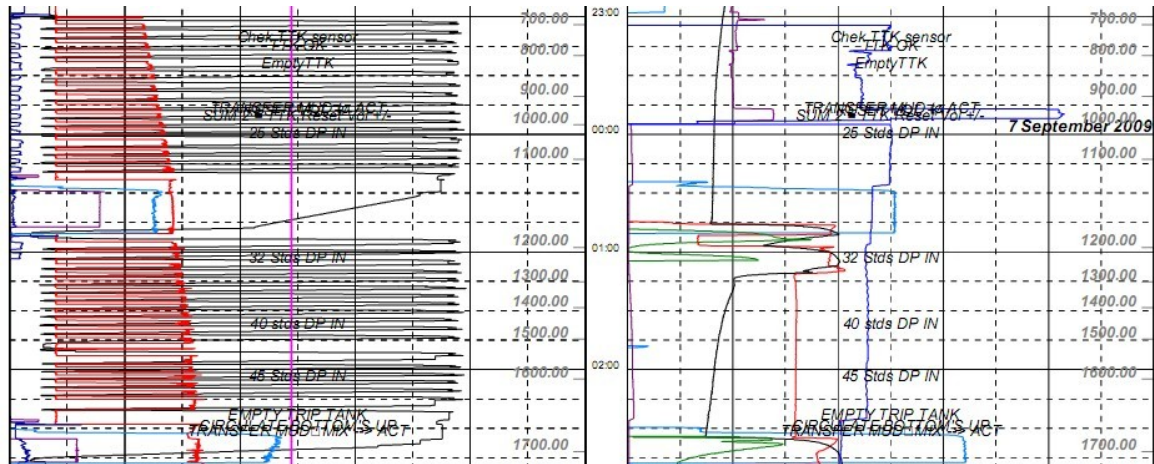


Figure 41 - example of a timelog which is hard to interpret because the labeling is badly placed

### 7.2.2 Daily Drilling Reports:

- The unit of measurement in which losses are reported should be standardized, in the various DDR's liters, m<sup>3</sup>, liters/30min etc. are always alternating

## 7.3 Room for improvement in the data archiving system of OMV AUT

The first few weeks of this thesis were spent working through the various databases which exist in OMV AUT. As all databases were established individually and differently by each department, it is very time consuming to collect all the data of a well from kick-off meeting to the most recent workover and production data

### 7.3.1 Well nomenclature

All departments have different abbreviations and nomenclature for the wells in their database system. This can make it hard to find a certain well in different databases. .

Example:

Full name:	Mühlberg Süd 2a
Name in SOB database:	Mühlberg S2 2a
Short name used by SOB	MUE S2a
Name in workover database:	Mü. S 2a

Name in production database (GDB)	MUEHLBERG S 002a
Code in GDB	field: A012 well: 005002a
Path in Sondenarchiv	A012 \ MUE_SUED_002

### **7.3.2 Nomenclature in the workover reports**

The abbreviation FW (could stand for floodwater OR formation water) can cause some trouble when evaluating workover reports.

# 8 Appendix A

## 8.1 Water coning graphs

This comparison of watercut trends was done because it was assumed that maybe bad cement integrity could have led to the rapid increase in watercut at the Bockfließ 201.

The production profile of the Bockfließ 201 is compared with several similar offset wells. At all wells with a vertical distance of about 4 meters from the new perforations to the OWC the watercut was at nearly 100% after 5 months of production. It is very unlikely that the cement job has something to do with that development.

### Bockfließ 201

4m vertical distance: OWC at -1458m TVD sea level, perforations from -1453 to 1454m TVD sea level.

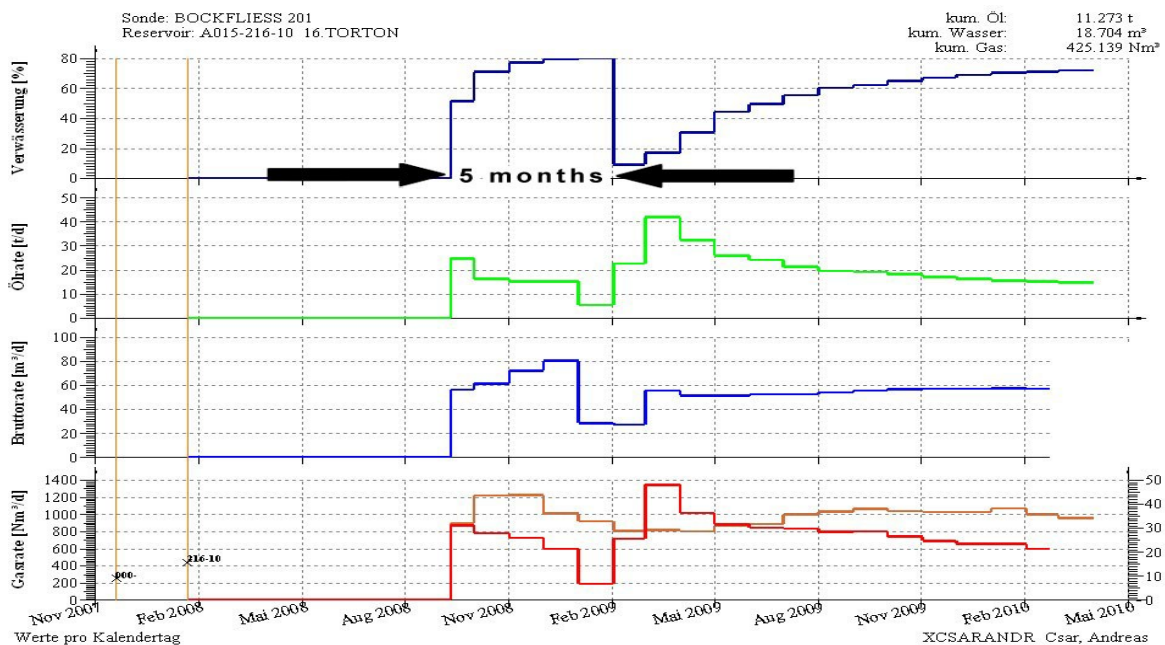


Figure 42 - Bockfließ 201 production profile for coning comparison

### Bockfließ 048

4m vertical distance: OWC at -1452m TVD sea level, new perforations from -1446 to 1448m TVD sea level.

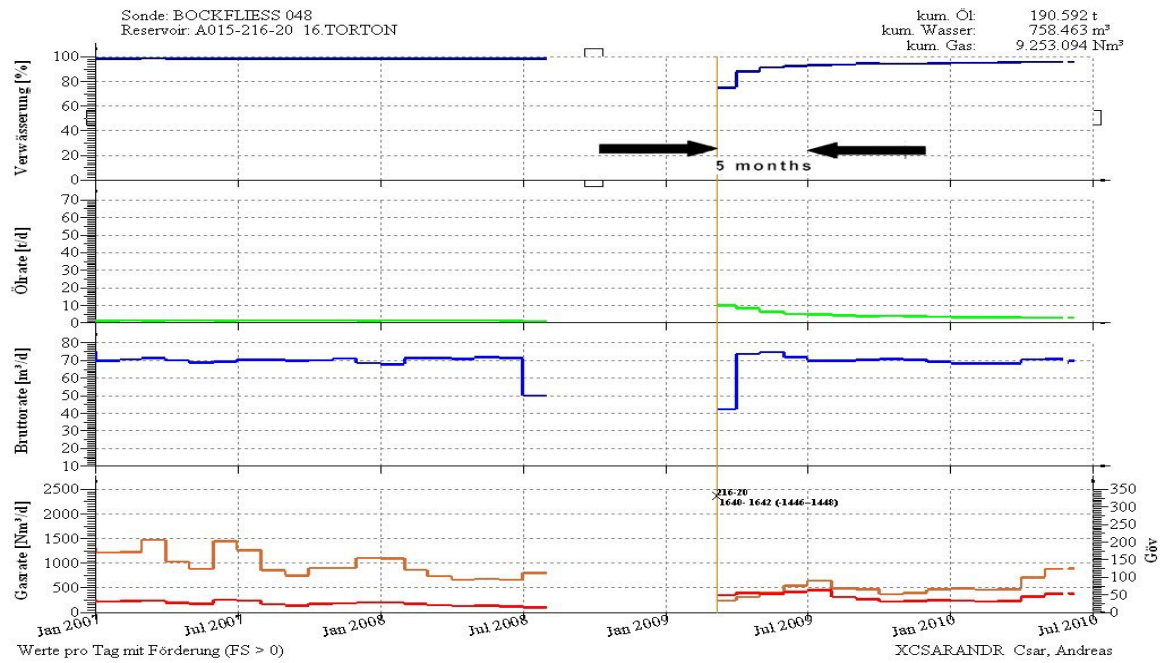


Figure 43 – Bockfließ 047 production profile for coning comparison

### Matzen 70

4m vertical distance: OWC at -1465m TVD sea level, new perforations from -1458 to 1461m TVD sea level

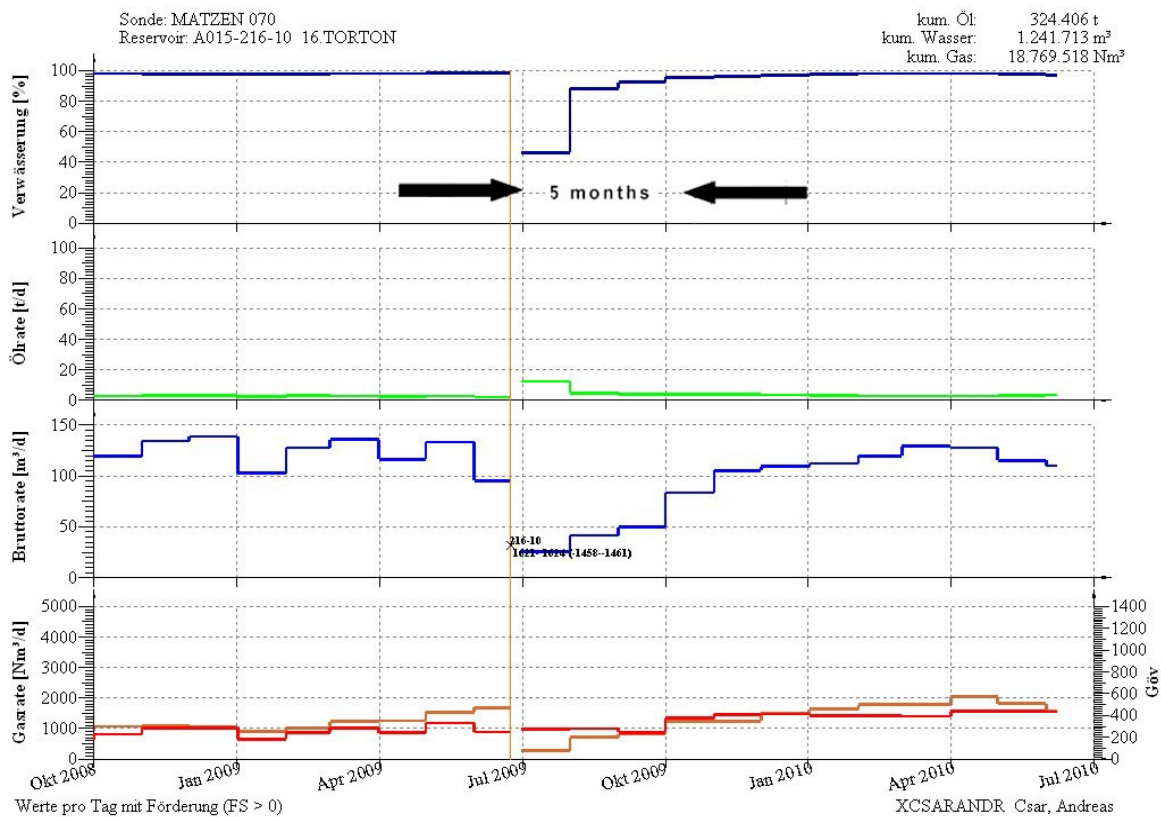


Figure 44 – Matzen 70 production profile for coning comparison



## Matzen 80

4m vertical distance: OWC at -1460m TVD sea level, perforations from -1452 to 1457m TVD sea level

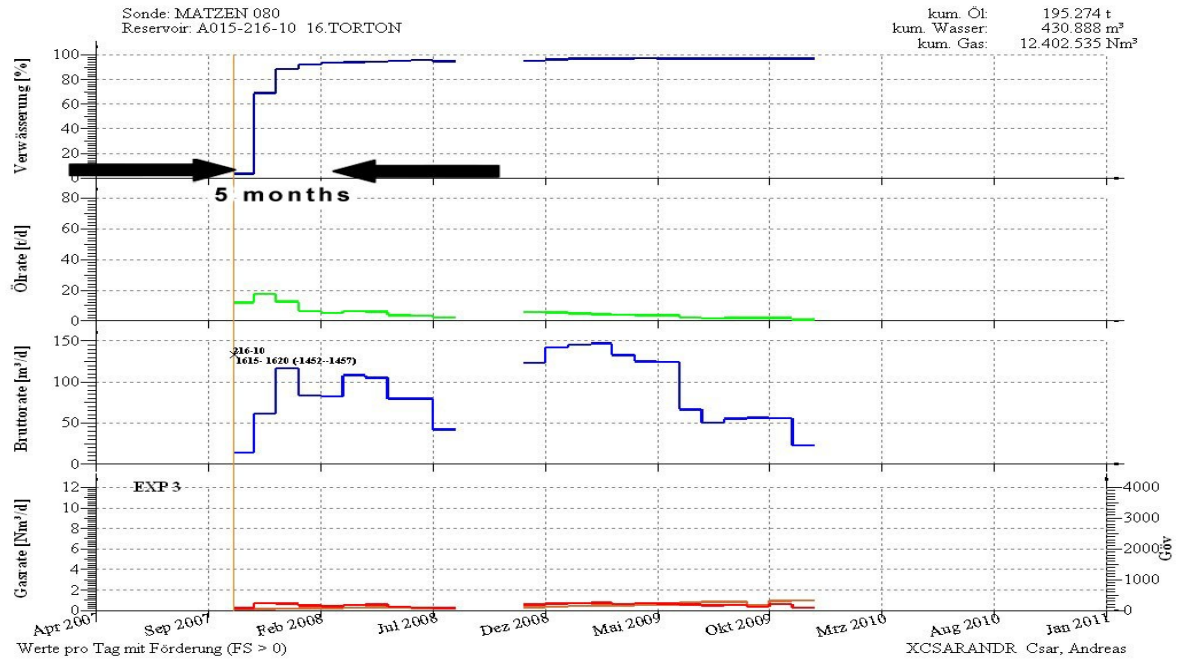


Figure 45 – Matzen 80 production profile for coning comparison

## Matzen 269

4m vertical distance: OWC at -1456m TVD sea level, perforations from -1449 to 1452m TVD sea level.

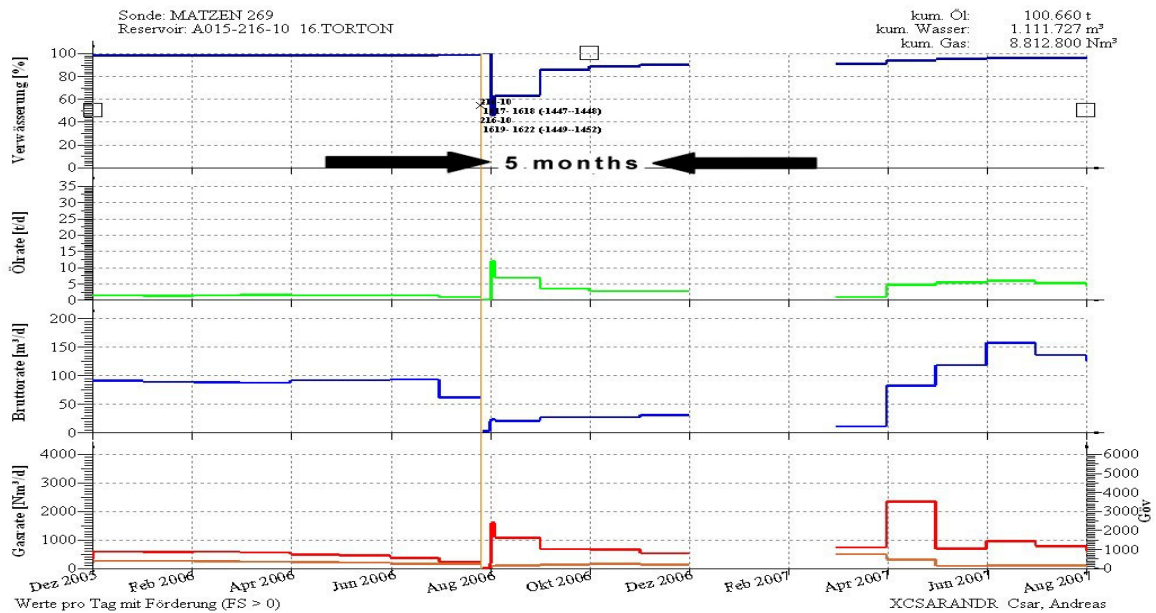


Figure 46 – Matzen 269 production profile for coning comparison

## 8.2 Simulations

### 8.2.1 Introduction to the simulations

Halliburton’s WellPlan with the modules “Torque Drag” and “OptiCem” was used to perform the simulations presented in this section.

The torque simulation was done using the logged trajectory data, a friction factor of 0.25 in casing and 0.30 in the open hole section (which are conservative friction factors). No standoff devices were included in the torque calculations. The maximum torque values were taken from the Tesco Field Make-Up Handbook27

The Equivalent Circulation Density (ECD) simulations were done using the slurry volumes and rheologies actually used at the job. Beside one example at the Husky 1 only constant displacement rates were simulated. For bumping the plug the last few m<sup>3</sup> of each job were pumped with reduced flow rate

The feasibility of increasing the displacement rates was not commented as no reliable fracture gradient data was available to determine a maximum allowed ECD.

### 8.2.2 Husky 1 simulations

#### 8.2.2.1 Displacement rates

A special focus was to determine how the ECD changes when the displacing rate is increased. The rheological properties were used from the slurries actually pumped in the field at 70°C temperature.

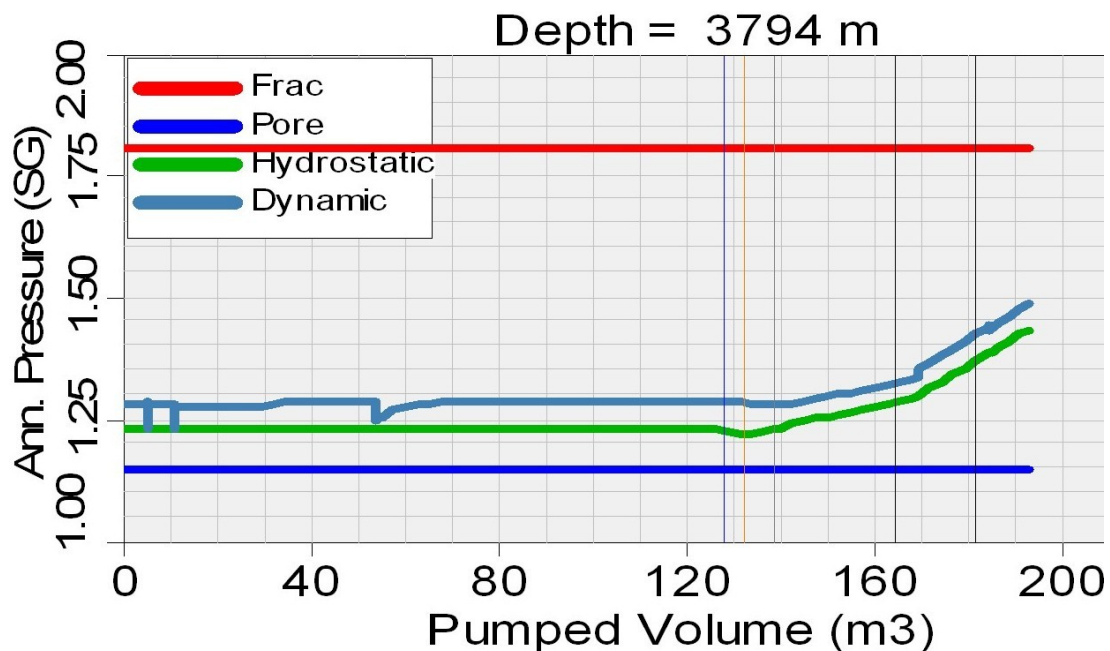


Figure 47 – Husky 1 9 5/8 cement job, original Schlumberger simulation of ECD at 3794m MD at a displacement rate of 800 l/min (at the end bump plug with 600l/min)

The following simulation shows that the maximum ECD can be controlled by reducing the flow rate accordingly (note the green line with reduced pump intervals)

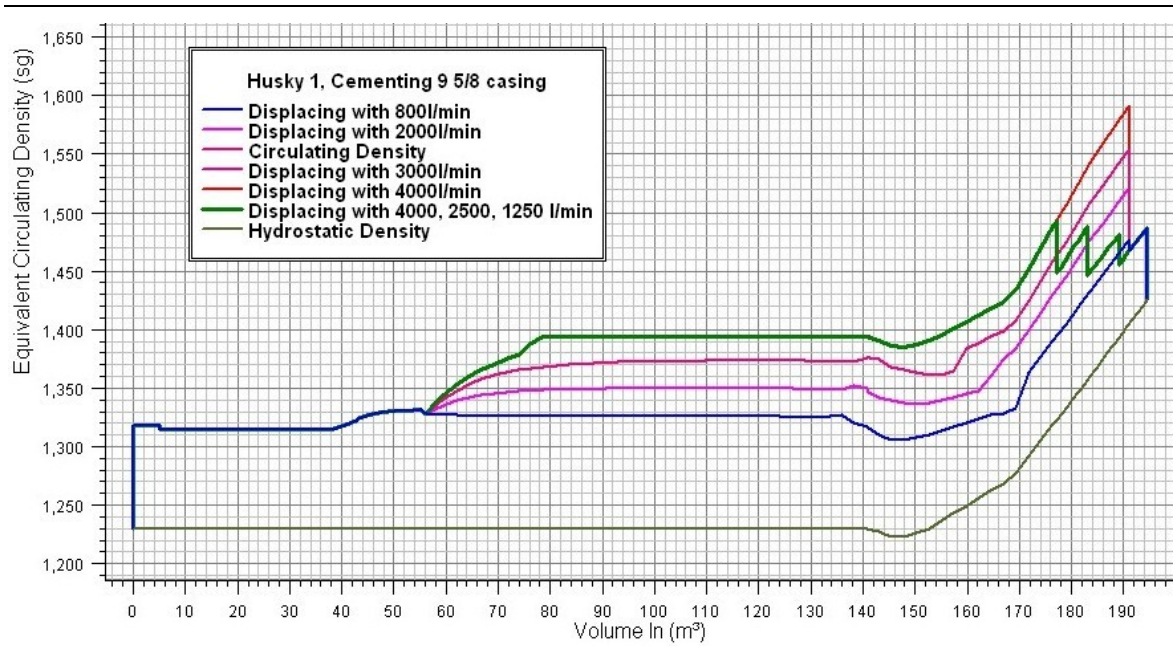


Figure 48 - Husky 1 9 5/8 cement job, OptiCem simulation with Schlumberger rates (blue) and higher rates of ECD at casing shoe at 3794m MD

### 8.2.2.2 Flow in flow out simulation

A flow in flow out simulation was done using the actual parameters (stand by times etc..) of the cement job, the red arrows highlight that the simulation (the dotted line) predicted the same trends in outflow as recorded at the actual job (yellow line)

The phenomena which causes this drop is called “u tubing effect” it occurs when the cement slurry inside the casing starts falling faster than the fluid getting pumped into the casing. Once the cement has reached total depth it takes some time for the displacement fluid to catch up with the cement, therefore the outflow is reduced for a certain time period

- 9 5/8 cement job of the Husky 1 on April 19th 2010
- Data: Schlumberger charts, selected data from geoservices, outflow simulation OptiCem
- |  |  |                                       |  |
|--|--|---------------------------------------|--|
| 1. 5m <sup>3</sup> water @ 800l/min    | 5. bottom plug 2                               | 9. top plug                           | 13. reduced flow out rate was reported by geoservices, losses were assumed pump rate reduced |
| 2. cement head loaded with three plugs | 6. 16m <sup>3</sup> lead slurry @ 800l/min     | 10. 1m <sup>3</sup> water @ 1000l/min | 14. 30m <sup>3</sup> mud @ 400l/min  |
| 3. bottom plug 1                       | 7. 16m <sup>3</sup> isoblock slurry @ 800l/min | 11. 85m <sup>3</sup> mud @ 1200l/min  | 15. bumped top plug with additional 50bar  |
| 4. 6m <sup>3</sup> spacer @ 1000l/min  | 8. 12m <sup>3</sup> tail slurry @ 800l/min     | 12. 26m <sup>3</sup> mud @ 830l/min   |  |

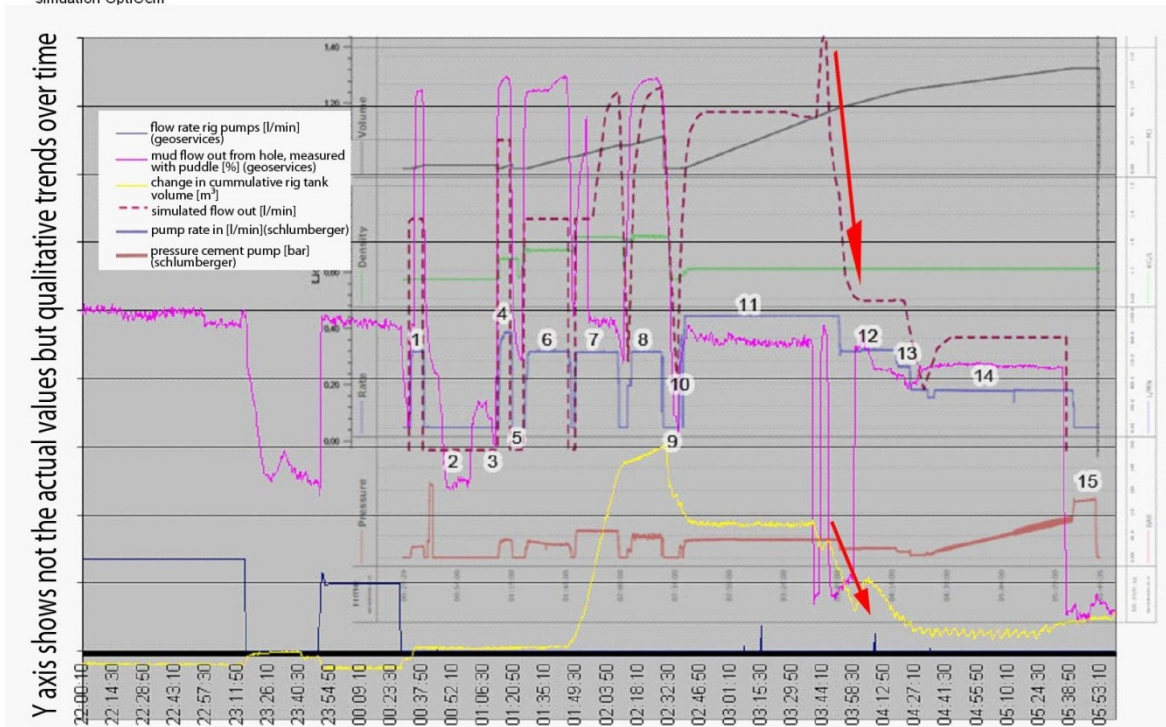


Figure 49 - Flow in flow out simulation vs. recorded data Husky 1 9 5/8 cementation

### 8.2.3 Bockfließ 72A simulations

With 1000m of torque rings in the upper section the 7in casing could have been rotated while cementing

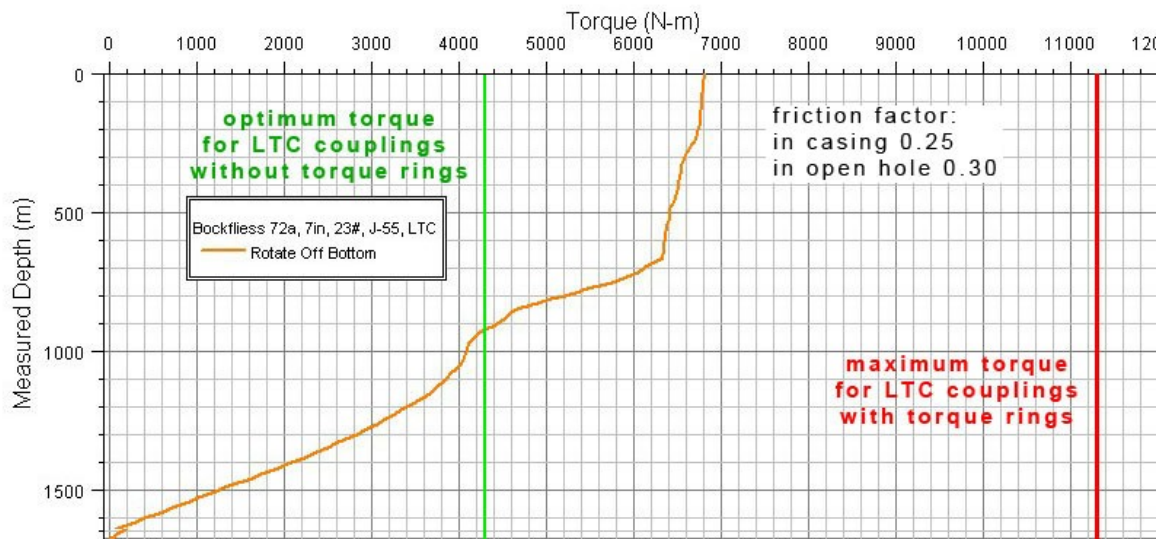


Figure 50 - Simulated torque on the Bockfließ 72a 7in casing and the mechanical limits of the used couplings.

The caliper of the open hole is quite over gauged at 9.51in, therefore the influence of big displacements rates on the ECD is reduced slightly.



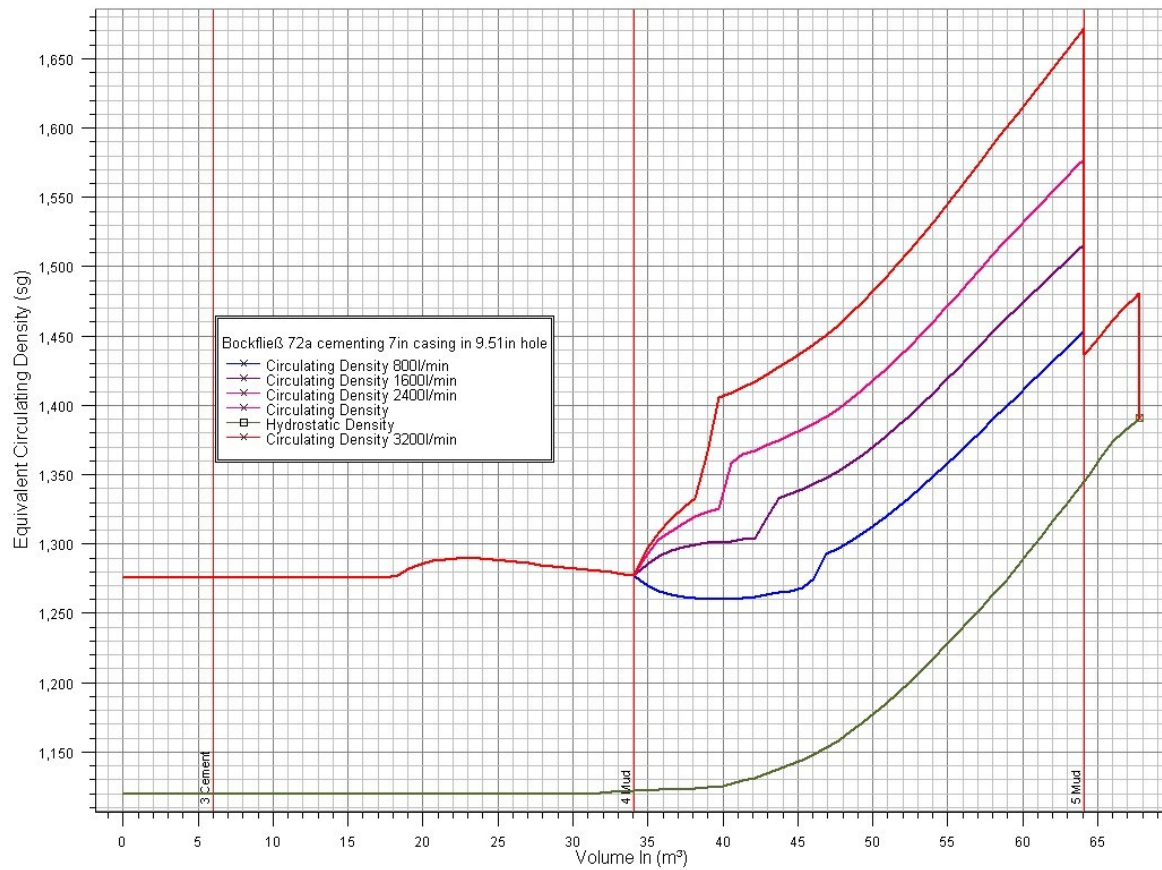


Figure 51 – Cementing the Bockfließ 72a 7in casing. Simulated ECD with different displacement rates while using the slurries, volumes and caliper data used in the real job.

## 8.2.4 Bockfließ 201 simulations

The 7in casing could have been rotated without any additional costs or effort.

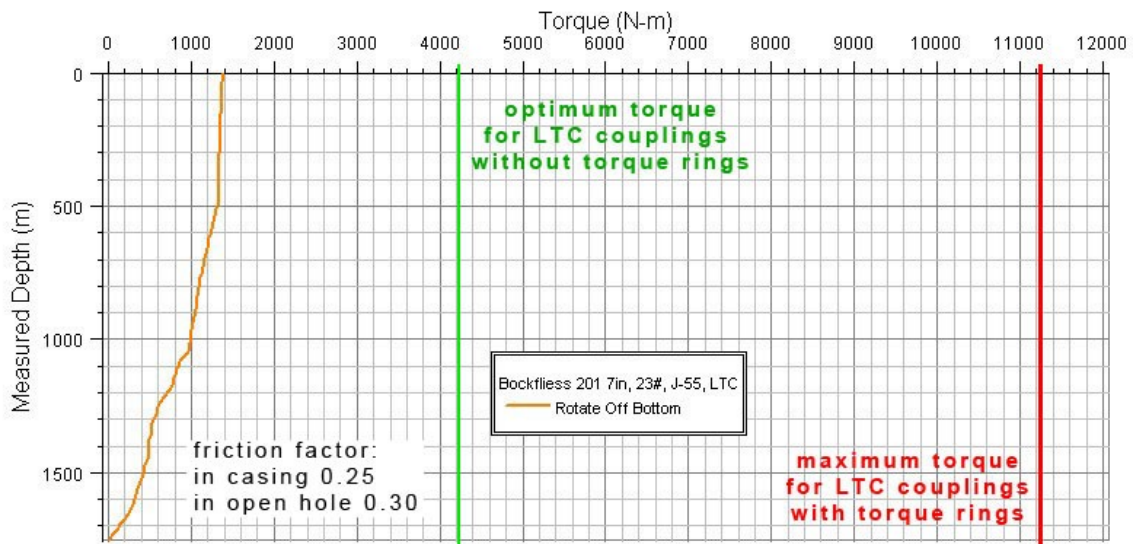


Figure 52 Simulated torque on the Bockfließ 201 7in casing and the mechanical limits of the used couplings.

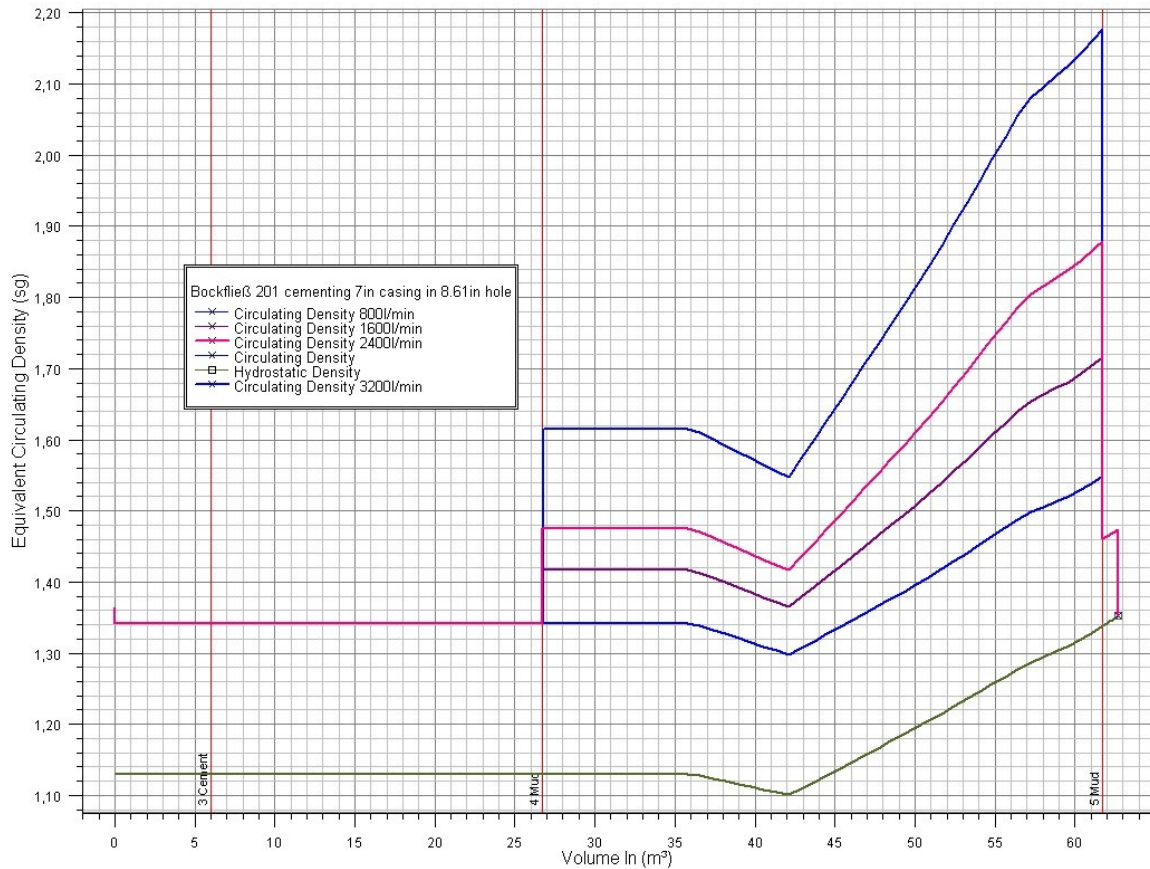


Figure 53 – Cementing the Bockfließ 201 7in casing. Simulated ECD with different displacement rates while using the slurries, volumes and caliper data used in the real job.

## 8.2.5 Bockfließ 202 simulations

The 7in casing could have been rotated without any additional costs or effort.

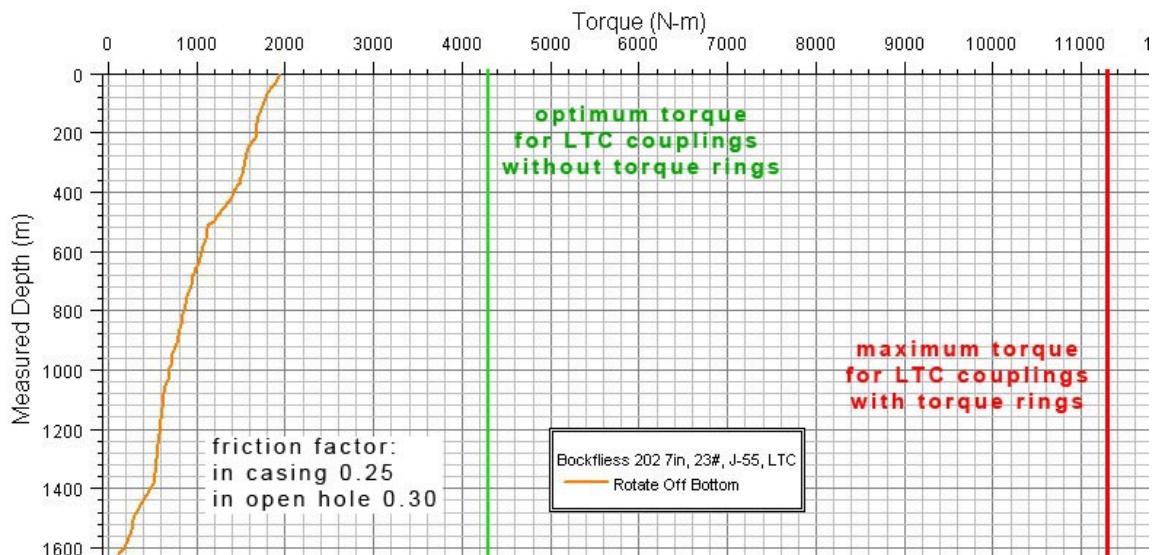


Figure 54 - Simulated torque on the Bockfließ 202 7in casing and the mechanical limits of the used couplings.

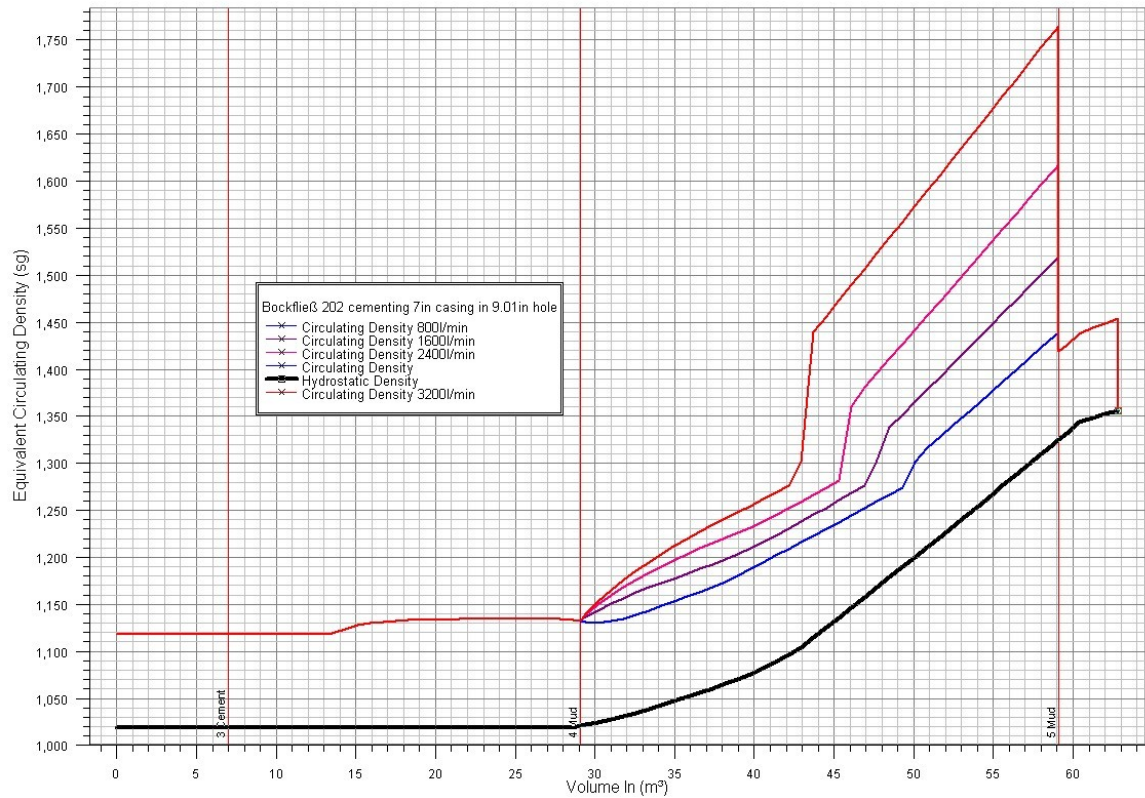


Figure 55 – Cementing the Bockfließ 202 7in casing. Simulated ECD with different displacement rates while using the slurries and volumes and caliper data used in the real job.

### 8.2.6 Bockfließ 203 simulations

With 1100m of torque rings in the upper section the 7in casing could have been rotated while cementing.

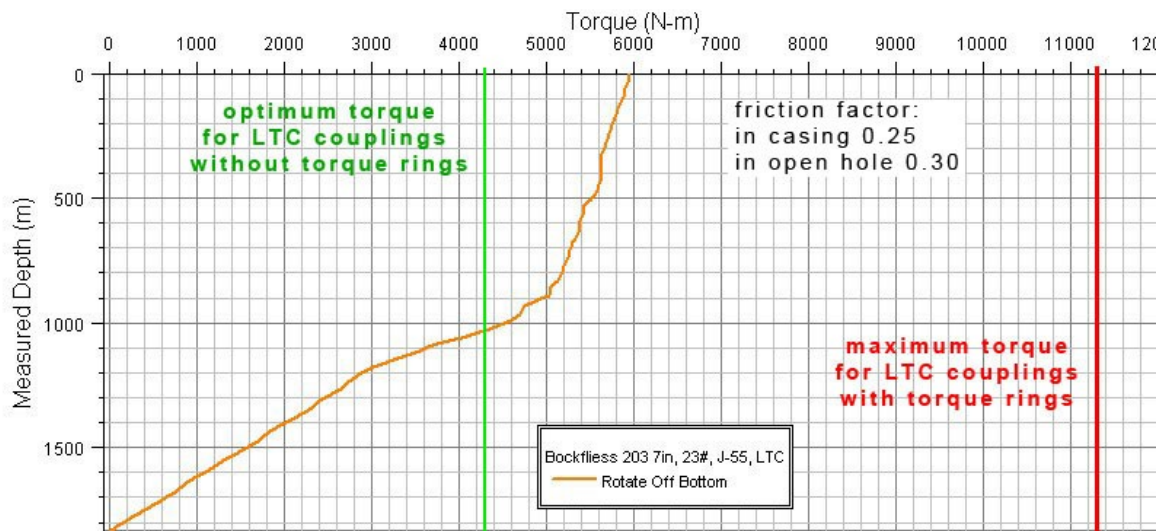


Figure 56 - Simulated torque on the Bockfließ 203 7in casing and the mechanical limits of the used couplings.

### 8.2.7 Spannberg 23 simulations

With the assumed friction factors rotating the 7in casing would not have been possible.



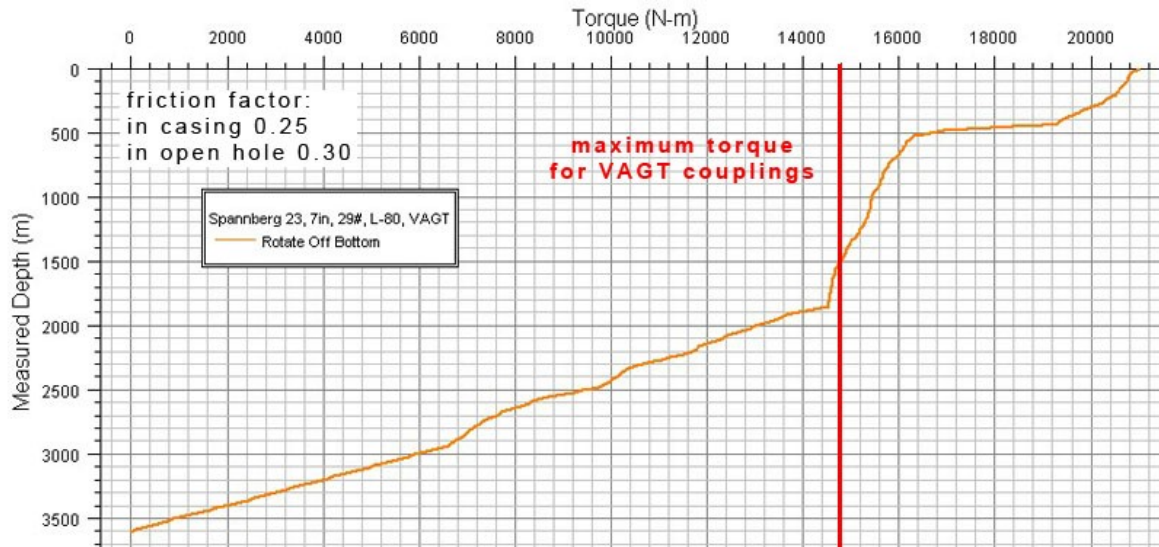


Figure 57 - Simulated torque on the Spannberg 23 7in casing and the mechanical limits of the used couplings.

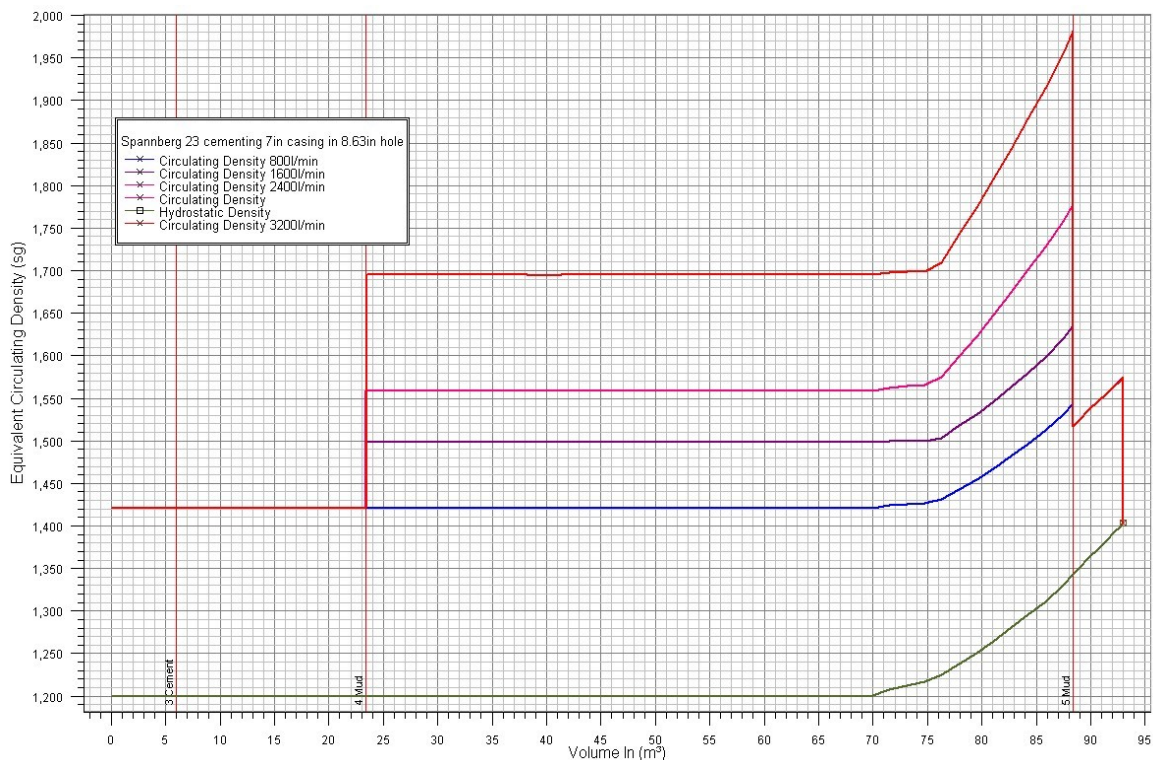
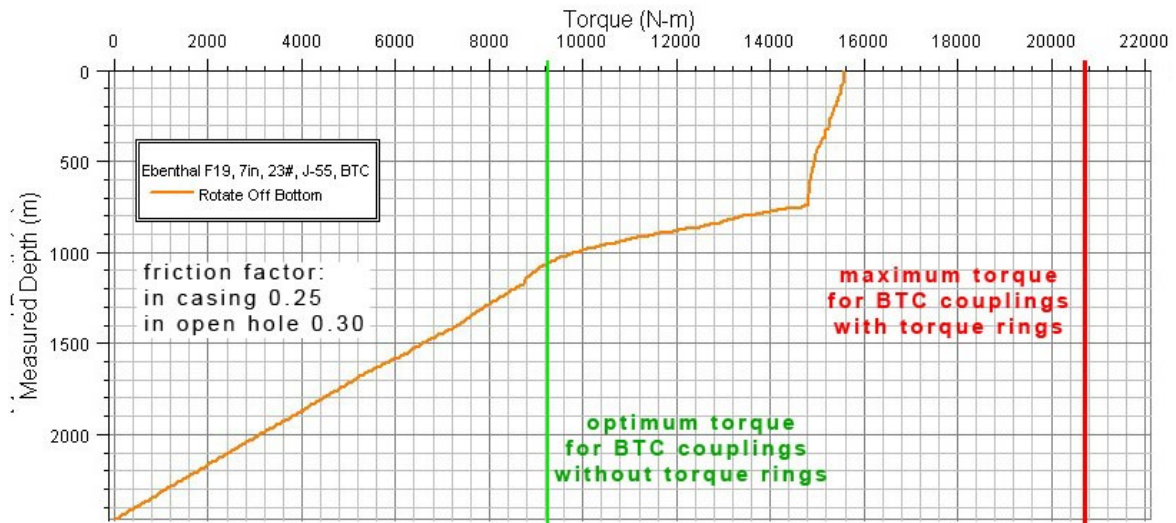


Figure 58 – Cementing the Spannberg 23 7in casing. Simulated ECD with different displacement rates while using the slurries, volumes and caliper data used in the real job.

### 8.2.8 Ebenthal F19 simulations

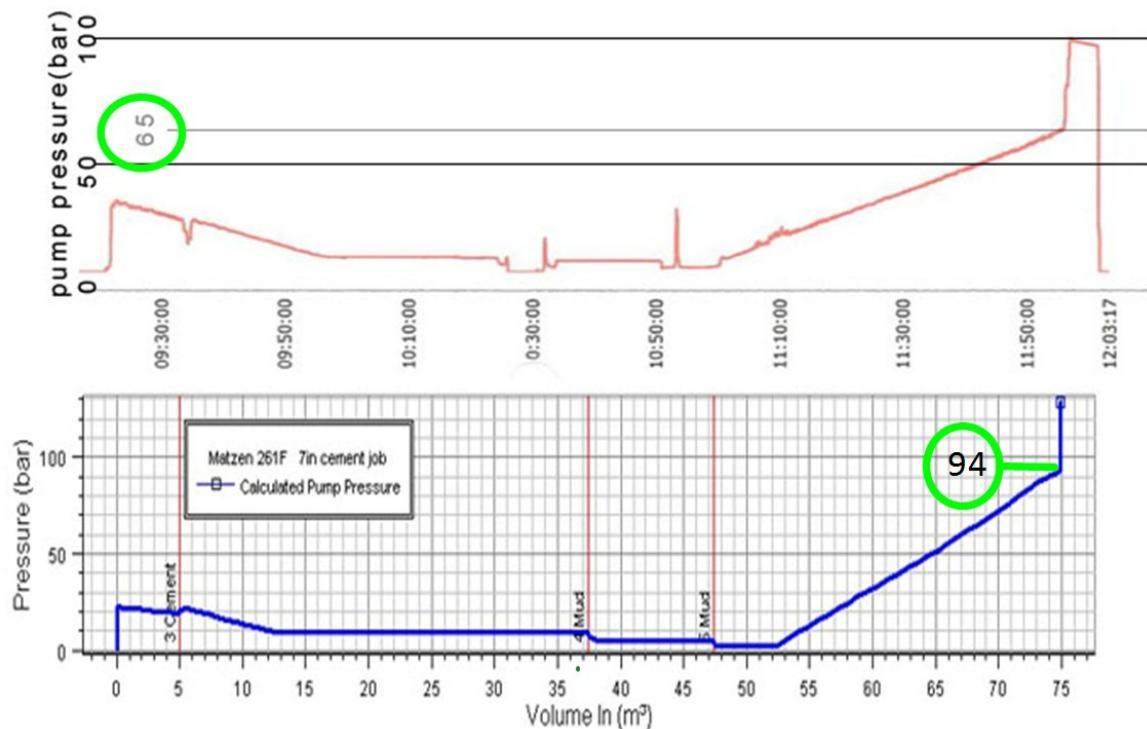
With 1100m of torque rings in the upper section the 7in casing could have been rotated while cementing.





### 8.2.9 Matzen F261 simulations

Below is a comparison of actual pump pressures recorded during cementing and a pump pressure simulation by the author. The recorded pump pressure is 30 bar lower than expected, this is a result of massive volume losses while cementing and therefore reduced hydrostatic weight in the annulus.



No torque simulation has been done as the well is drilled completely vertically.

## 8.2.10 Mühlberg S2a simulations

With 550 m of torque rings in the upper section, the 7in casing could have been rotated while cementing.

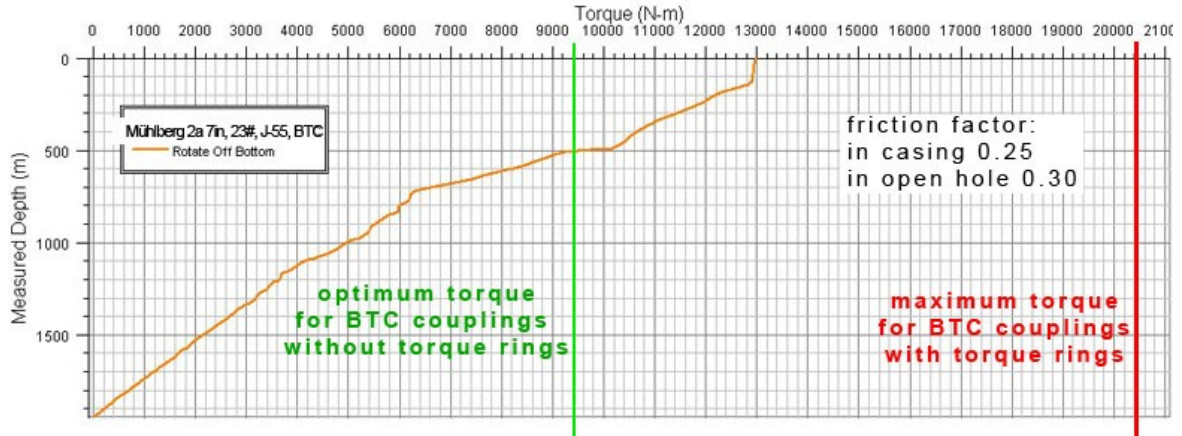


Figure 60 - Simulated torque on the Mühlberg 2a 7in casing and the mechanical limits of the used couplings.

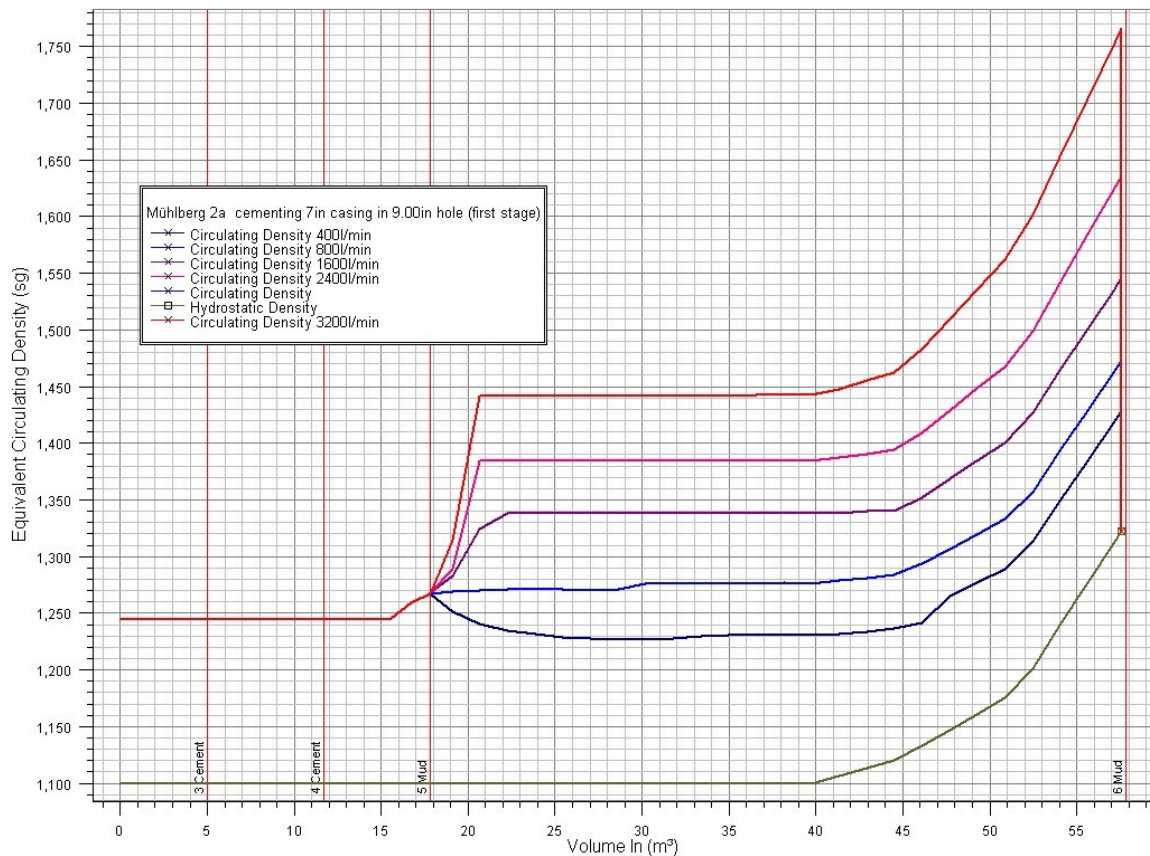


Figure 61 – Cementing the Mühlberg 2a 7in casing. Simulated ECD with different displacement rates while using the slurries, volumes and caliper data used in the real job.

### 8.2.11 Prottes T W 1 simulations

With the assumed friction factors rotating the 7in casing would not have been possible.

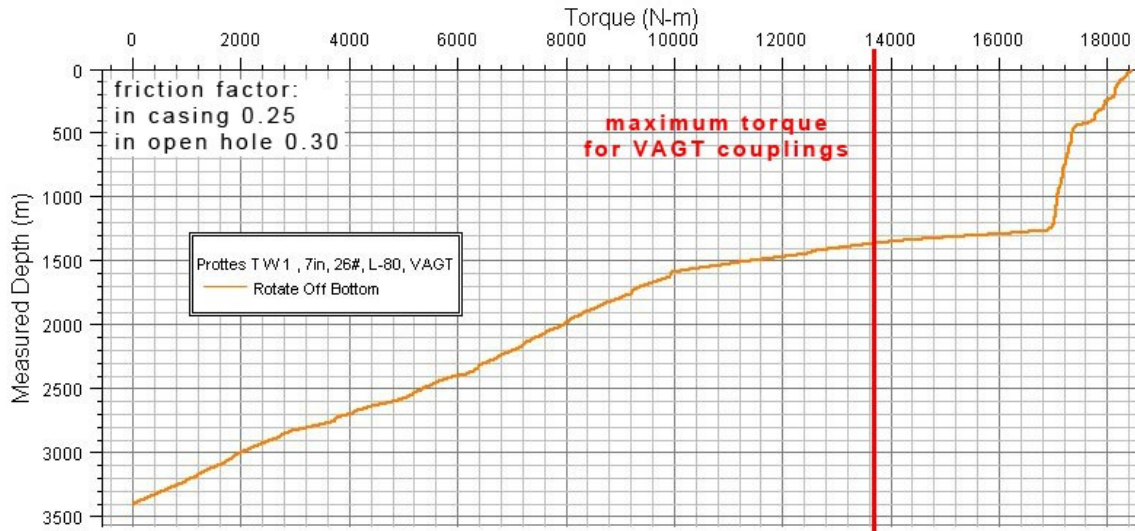


Figure 62 - Simulated torque on the Prottes T W 1 7in casing and the mechanical limits of the used couplings.

## 9 References

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- <sup>1</sup> OMV Cementing Guidelines 2006 (internal paper)
- <sup>2</sup> Meeting Minutes Cementing Review AUT-SOB Dec. 2006 (internal paper)
- <sup>3</sup> Doschek M. : "Cementing in highly inclined and horizontal wellbores", Diploma Thesis for OMV, 2000
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- <sup>5</sup> Gold T.: "OMV Global Contracting Strategies in times of limited resources", PowerPoint presentation, Nov. 2006 (internal paper)
- <sup>6</sup> Schlumberger : "Cement Bond Logging", PDF,(internal paper)
- <sup>7</sup> Schlumberger : "Cement Bond Logging", PDF,(internal paper)
- <sup>8</sup> Schlumberger : "Introduction to Cementing", PDF,(internal paper)
- <sup>9</sup> Schlumberger : "Cement Bond Logging", PDF,(internal paper)
- <sup>10</sup> Schlumberger : "Cement Bond Logging", PDF,(internal paper)
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- <sup>12</sup> Lindsey Jr., H.E. and Durham, K.S., "Field Results of Liner Rotation during Cementing", SPE 13047, Sept. 1984, Annual Technical Conference and Exhibition, Houston
- <sup>13</sup> Hyatt, C.R. and Partin Jr., M.H., "Liner Rotation and Proper Planning Improve Primary Cementing Success", SPE 12607, April 1984, SPE Deep Drilling and Production Symposium, Amarillo
- <sup>14</sup> Doschek M. : "Cementing in highly inclined and horizontal wellbores", Diploma Thesis for OMV, 2000, page 18.
- <sup>15</sup> Erik B. Nelson "Well Cementing" 1990
- <sup>16</sup> Chalturnyk R.J., Moreno F. Jimenez J. Talman S.: Assessment of Wellbore Integrity Weyburn CO2 Monitoring and Storage Project" Final Report. Geological Storage Research Team, University of Alberta, Canada.
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- <sup>18</sup> Schlumberger : "Cement Bond Logging", PDF,(internal paper)
- <sup>19</sup> Boyd D., Al-Kubti S. Khedr O. H., Khan N.: "Reliability of Cement Bond Log Interpretations Compared to Physical Communication Tests Between Formations" SPE 1014020, Nov. 2006, Abu Dhabi International Petroleum Exhibition and Conference.
- <sup>20</sup> Schlumberger : "Cement Bond Logging", PDF,(internal paper)
- <sup>21</sup> W.K. Godfrey of Shell Oil Co "Effect of Jet Perforating on Bond Strength of Cement" SPE Paper 2300, Houston, 1986
- <sup>22</sup> Bell, W.T. and Shore, J.B. "Casing Damage from Gun Perforators" *Drill. And Prod. Pract.*, API, 1964
- <sup>23</sup> Kienberger G., Fuchs R. "Case History of the Matzen Field – Matzen Sand (16<sup>th</sup> TH) A Story of Success; Where is the end?", SPE 100329 OMV AUT
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- <sup>25</sup> Schlumberger ,final cementing proposal "Ebenthal F19\_7in Csg\_CementProgram\_3FINAL\_(3)", Excel file, (internal paper)
- <sup>26</sup> Boyd D., Al-Kubti S. Khedr O. H., Khan N.: "Reliability of Cement Bond Log Interpretations Compared to Physical Communication Tests Between Formations" SPE 1014020, Nov. 2006, Abu Dhabi International Petroleum Exhibition and Conference.
- <sup>27</sup> TESCO, *Casing & Tubing Torque Tables*, first edition, [www.tescocorp.com](http://www.tescocorp.com)

# 10 Appendix B

Von				
EP-EOP/WE-DE, M.Doschek				
An				
Verteilerliste				
Ihr Zeichen	Unser Zeichen	Telefon	Datum	Vermerke
	MD	23388	07. Dezember 2006	

## Minutes

### Cementing Practices Review Meeting EP-AUT/SOB

Date: December 6, 2006, 14:00 – 16:30  
Venue: EP-AUT/SOB Meeting Room  
Participants: Peter Zehetleitner, AUT/SOB-BO  
Hildegard Möhrmann, AUT/SOB-BO  
Alexander Gerstner, AUT/SOB-BO  
Johannes Ladenhauf, AUT/SOB-BO  
Christopher Veit, AUT/AG  
Gerhard Nocker, AUT/AG-FDS  
Christian Pröglhöf, AUT/SOB-MDP  
Hermann Spörker, EPP/WE (partially)  
Markus Doschek, EPP/WE-DE

The meeting was conducted by request of AUT/SOB, with the intention of reviewing the cement jobs on following wells:

- Ebenthal T1
- Ebenthal T2
- Straßhof T4
- Straßhof T5 / T5a
- Zistersdorf 4
- Matzen 501
- Matzen 624
- Hohenrappersdorf 43
- Erdpress 4
- Erdpress 5
- Erdpress 6

A work schedule was identified as below:

1. Review of cementing practices of specific wells
2. Review of cement recipe of specific wells
3. Develop recommendation on recipe together with Service Company
4. Create "Good Cementing Practices" document

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*GENERAL COMMENTS:*

- Lack and inconsistency of reported cementing related data  
*There are some inconsistencies of reported data between DDR and Cementing reports. The DDR data are based on assumptions because of non availability of exact data during time of DDR preparation.*
  - No Cementing Prejob reports were available  
*SOB stated that all reports are available but on a Gänserndorf hard-drive without access of EPP*
  - No Onjob Instruction Reports (SID,...)  
*SOB alluded to the Prejob report created by Halliburton's CEMCADE program which is used for prejob meetings.  
The standard of these documents could be improved.*
  - Communication Problem reported by Halliburton  
*Halliburton personnel were interviewed and asked for more involvement on prejob planning and improvement of communication culture.*
- 

1. Review of cementing practices of specific wells

*RECOMMENDATIONS:*

- Prior to running the casing the hole should be circulated at the maximum rate possible (record rate & pressure) and the mud conditioned until its properties are optimum. A final mud conditioning should take place when casing on setting depth. A low mud rheology is necessary to obtain a good cement job; YP should be below 20 and PV alap. The gas level should be brought back to the background gas level recorded during drilling operation.



- The total amount of washer and spacer pumped guarantees the minimum recommended contact time of 10min for preflushes. Nevertheless the split should be 1/3 washer and 2/3 spacer. Using saltwater as a washer is the most effective fluid providing a wash in turbulent flow. The used spacer (Tuned Spacer E+) is a spacer which needs to be pumped in turbulent flow. In many cases the pumping rates necessary for turbulent flow cannot be achieved because of limitations imposed by resulting friction pressure or fracture pressure of the formations. Whenever turbulent flow cannot be achieved a laminar flow designed spacer should be considered to be used. The highest efficiency of a spacer can be achieved by placing the density right in the middle between mud and cement weight. In case of limitations by frac pressure the low density saltwater washer column can be extended to reduce the total hydrostatic on weak formations. A dynamic modelling should be run to simulate hydrostatic conditions on each point of the wellbore.
- Compatibility tests should be performed to guarantee compatibility between all pumped components (mud, washer, spacer, cement); these tests should not be limited to the interface components only. The test should be performed for each job where untested components are used.
- The most predominant cause of cement failure appears to be channels of gelled mud remaining in the annulus after cement in place. Once the cement is mixed and into the casing it should be displaced at the maximum rate possible. The specific pump rate depends on annular clearance and loss of return potentials.
  - Recommended pump rates for 9-5/8" casing in 12" hole (~3000m) would be 2500 l/min to start with until cement is reached and pressure starts increasing; then slow down to 1600 l/min until displacement comes close to bumping the plug where the rate should be reduced to 700 l/min.
  - Recommended pump rates for 7" liners in 8-3/8" holes (~4000m) would be 1800 l/min and then reduce to 1400 l/min and finally to 700 l/min before plug is bumped.
- Removal of the wall cake will improve cement bonding between casing and hole. Rotation and reciprocation of the casing string has proven that it is a valuable tool when used in the right application. All 7" liner hangers run in hole were from rotational type and should be rotated whenever possible. A heavy 9-5/8" casing string which were already brought downhole with troubles should not be reciprocated to ensure casing set in place.



- Good cement placement is also influenced by casing stand-off and pipe centralization. Centralizers should be placed in the liner lap section, on the joint immediately below the wellhead and on the joints in open hole to achieve a stand-off of minimum 80% and across the reservoir section a minimum of 90%.
- Several samples of the cement slurry should be taken throughout the whole job. The sample should be kept under in-situ conditions if possible to simulate the downhole settling and hardening process. In case of missing testing apparatus the sample can be put into an oven with temperature set to downhole-static-condition. A Styrofoam / paper cup filled 3/4<sup>th</sup> full is an adequate sample. The cup should be covered by an impermeable cover (e.g. plastic sheet).

## 2) Review of cement recipe of specific wells

### *RECOMMENDATIONS:*

- Class-G cement should be mandatory for each cement job deeper than 2000m.
- Laboratory testing and evaluating basic cement performance properties under downhole conditions is necessary for each job. Every slurry must be tested under downhole conditions independent on testing apparatus limitations.
- It is best to keep cement slurries as simple as possible, which means the use of as few additives as possible.
- More engineering work should be put into developing slurry recipes to be designed for different depth and downhole conditions achieving the optimum result. The same slurry composition was used for 9-5/8" casing cement jobs from a depth of 1900m to 3000m.

## 3) Develop recommendation on recipe together with Service Company

Because of cementing service tendering phase no recipe recommendation were developed with Halliburton.

## 4) Create "Good Cementing Practices" document

Please find attached document "Good Cementing Practices" for review.

# **CEMENTING GUIDELINES**

## **“GOOD CEMENTING PRATICES”**

The purpose of this section is to ensure that all well cementing programmes are:

- Designed & sufficiently optimised to reflect the learning's of the Well Engineering team.
- Designed to the relevant OMV standards. When deviation from the standards is required the appropriate change control procedures and risk assessment & management processes shall be carried out.
- Queried to ensure a lowest cost cement job design

### **Roles & Responsibilities**

#### Drilling Engineer (DE)

It is the role and responsibility of the DE to ensure that the cementing programme specified for each well is designed to satisfy th,e appropriate standards yet reflects the learning's and hence optimisations developed by the Well Engineering group.

The cementing programme for the well shall be included in the relevant section of the drilling program. It is the responsibility of the DE to ensure that all cement programmes are reviewed prior to the issuing of the drilling program.

The role of the DE is to ensure that all cement slurry recipes and programmes sent to the rig accurately reflect the intended cementation job.

#### Cementing Contractor Representative (CCR)

It is the role of the CCR to provide, in consultation with the drilling engineer, a cementing programme with appropriate weights and recipes to meet the well requirements.

### **Job Planning**

- 1) Prior to the cementing operation, a planning meeting should be held with all personnel that are directly involved with the cement job to ensure that key personnel understand the job and their particular responsibilities. The cementing procedure should be reviewed and it verified that job responsibilities and safety precautions are clear to all personnel.
- 2) A good communications system (rig phone or hand held radios) is a necessity and should be available between the rig floor and the cement unit.
- 3) Assign one individual (preferably the drilling supervisor) to coordinate and direct operations between rig floor and cementing unit.
- 4) All lines and the cementing manifold should be pressure tested to the pressure specified in the Drilling Program prior to cementing.
- 5) All cementing equipment, including the densi-meter, should be thoroughly checked.
- 6) Hole caliper information and bottom hole logging temperatures should be sent to the Drilling Engineer as soon as practical during logging operations in order to finalize cement volumes and confirm cement thickening times.
- 7) Whenever possible, a cementing chart recorder (pressure, volume, density vs. time) should be used for all operations (i.e. casing cementing, squeeze cementing, pressure testing of lines and equipment, PITs, etc.). The chart should be annotated with all significant events such as pressure testing, pumping spacers, mixing lead and tail slurries, displacement, bumping the plug, etc.
- 8) Cementing contractor to quote pumpable time (40bc) and thickening time (100bc). Always use pumpable time for job calculations. Thickening time is used as a guide to timing the tagging of cement, or drill out of shoetracks.

- 9) Check that the time required to pump the tail slurry has been included in the lead slurry pumpable time.
- 10) Compatibility tests between mud / cement, mud / spacer and cement / spacer have to be performed to assure compatibility exists between fluids being displaced in the annulus. If incompatibility is given the cement slurry will tend to form channels through the viscous mass.
- 11) Cement thickening time is dependant on bottom hole temperature. A cement slurry re-design and test should be requested if the bottom hole temperature is found to be higher than anticipated.

## **Cementing Head/Manifold**

- 1) All valves on the cementing head/manifold, as well as the releasing mechanisms, should be checked to ensure they are in proper working order and that safety devices are in place to prevent premature launching of plugs.
- 2) Use positive displacement to launch plugs, (i.e. do not rely on gravity or falling fluid levels).
- 3) Use bails long enough to latch elevators below the cement head to allow reciprocation of the casing during displacement of the cement.
- 4) A cementing manifold which is designed for a top drive system is to be used, if applicable.
- 5) If the casing string is to be worked during the cement job, the cementing head / manifold rating must be adequate to support the casing and landing string weight plus 100,000 lbs of overpull.

## **Primary Cementing**

- 1) Casing cement slurries should be designed with a contingency of one hour or 50% of the Estimated Job Time (EJT) whichever is greater while Liner cement slurries should have a contingency of one hour or 100% of EJT whichever is greater unless experience or other extenuating circumstances indicate otherwise. A slurry design should not be accepted until pilot tests have confirmed an acceptable thickening time.
- 2) Cementing and displacement rates should be maximized based on equipment capability and the ECD which the formation will stand. Research shows that the faster the circulating rate, the better the displacement efficiency. Quite often on deep strings and small liners it is not possible to achieve the desired displacement rate due to fragile formations. If in doubt, a good rule-of thumb is to limit displacement rates to the same AV as drilled with. The time that the cement slurry is not moving should be minimized.
- 3) Collect field samples of mix water and cement/additives at the rig site, use to confirm pilot tests results and make final slurry design adjustments.
- 4) Communicate bottom hole logging temperatures, depth, and time since last circulation to the Drilling Engineer as soon as practical. This information will be used to finalize / confirm thickening times. If bottom hole temperatures vary significantly from the cementing program, it will be necessary to adjust the amount of retarder, verify changes with the Drilling Engineer.
- 5) Communicate the caliper log (4-arm if available) information to the Drilling Engineer as soon as practical. The cement volume necessary to provide adequate coverage should be calculated using the actual caliper log and checked against the estimated cement volume in the Casing and Cementing Program, verify any changes with the Drilling Engineer.

- 6) Ensure that adequate cement is at the rig along with ample quantities of liquid/dry additives. If practical there should be 50-100% excess cement and 100% excess liquid/dry additives at the rig site.
- 7) Ensure that the transfer facilities from the P-tanks to the cement unit are operating correctly.
- 8) Ensure that air lines contain no water (moisture or water in the supply lines could cause plugging during the cement transfer).
- 9) At least two people will calculate the total cement job volumes, including the required volume to displace the top plug to the float collar.
- 10) The volume of mix water pumped will be used to calculate the actual volume of cement pumped. Never rely on P-tank volumes.
- 11) Circulate at least one casing volume or annulus volume (whichever is greater) and condition the hole prior to cementing. The drilling fluid should be conditioned to ensure that it is virtually free of cuttings, that gas is back down to background levels and that it is of uniform density with acceptable properties. This should also be done on the trip, prior to running casing. Reduce the YP to 10 or as low as practical.
- 12) Ensure that the cementing head/manifold releasing mechanisms are working properly and that personnel are familiar with their operation.
- 13) Witness the cementer load the wiper plugs in the cementing head/manifold.
- 14) Monitor returns versus volume pumped throughout the cement job. Any suspected loss of returns during cementing operations should be reported on the Daily Drilling Report, noting time of loss and pressures and volumes.
- 15) The slurry weight should be kept as consistent as possible to keep from extending or retarding setting times. Liquid additives are more sensitive to weight fluctuations than dry blended.
- 16) The weight of the cement slurry should be checked frequently using a pressurized mud balance to verify the accuracy of density measurement device on the cement unit.
- 17) Several samples, spaced throughout the job, of lead and tail slurries should be taken during cementing. A Styrofoam / paper coffee cup filled three-fourths full is an adequate sample. Also catch samples of drilling cement and mix water during cement jobs. The sample cup should be covered by an impermeable cover (eg. Plastic sheet) before being placed in the oven. If left uncovered, evaporation would result in the surface sample setting too quickly and hence not being representative of downhole conditions.

## **Displacement**

- 1) Cement displacement may be performed with either the cement unit or the rig pumps, depending largely on the displacement volumes, overall job time, desired pump rates and expected pressures. The following are general guidelines:
  - o For inner-string cementing, the cementing pump should be used for the entire operation.
  - o For full casing string cementing either the cement unit or rig pumps may be used for displacement. As a guideline, use the cement unit for displacements < 200 bbls and the rig pumps for displacements > 200 bbls. However; each job should be considered on it's own merit based on conditions at the time of the cement job. If the rig pumps are used for displacement, ensure they have been calibrated prior to the cement job.
  - o For liners, the cementing pump should be used until the top plug is launched, then the rig pump may be used, if desired, to complete the displacement and bump the plug. If high pressures (i.e. > 3000 psi) are anticipated it is probably best to continue displacement with the cementing unit.
- 2) If cement is to be displaced with the rig pumps, the pumps are to be calibrated using the trip tank or slug tank prior to starting the cement job.
- 3) Ensure the cement unit is ready to finish the cement displacement if the rig pumps encounter a problem and vise versa.

- 4) Do not over displace the cement by more than 50% of the volume of the shoe track.
- 5) Two or more independent measurements are to be made on displacement jobs, such as tank counters, stroke counters, observers with tally books, etc.
- 6) After bumping the plug bleed casing pressure to zero and check the floats. Repressure the casing string if flow back occurs and hold until surface samples setup or no backflow occurs.
- 7) Circulate down the choke and kill lines to flush the BOP. Perform this circulation as soon as practical after displacing the cement. If it is necessary to hold pressure on the casing due to a float failure, postponing circulation could allow excess cement to cause problems in the BOP's.

## **Cementing Well Control**

- 1) Test all cementing lines and the cementing manifold to the nominal working pressure or as specified in the Cementing Procedure.
- 2) When using an unweighted spacer, ensure that reduction of hydrostatic pressure is not sufficient enough to allow an influx to enter the wellbore.
- 3) Ensure circulating swedges (Casing x Drill Pipe and Casing x male half of Chiksan Union) are available on the floor for the appropriate size casing.

## **Slurry Design**

### **Cement Design Requirements**

The cementing design is a part of the detailed well design phase. The cementing programme developed is required to take into account well trajectory, temperature, drilling fluid type, isolation and abandonment requirements.

The DE should determine from the preliminary casing design, offset well review and other available data sources, the requirements for each cement job. These may include, but are not limited to:

#### Surface Casing:

- o Structural Support (min approx 1500 – 2000 psi long term compressive strength)
- o Rapid setting time to minimise WOC
- o Requirement for cement to surface
- o Surface water flow shut off
- o Losses isolation

#### Intermediate and production casings:

- o Provide good shoe
- o Isolation / zonal isolation
- o Cementing off of permeable zones to minimise abandonment requirements
- o Strength requirements
- o Gas blocking agents (if necessary)

#### Plugs and Squeezes:

- o Purpose of plug or squeeze (abandonment or kickoff Sidetrack Contingency Planning)
- o Isolation / zonal isolation requirements

#### Abandonment:

- o Appropriate isolation of permeable zones
- o Long term integrity

#### All Slurries:

- o Density
- o Thickening time
- o Temperature requirements (at time of setting and long term)
- o Free water

- Spacer (type, volume, density)
- Contact time of spacer and mud removal
- Centralisation

### **Spacer / Washer**

Spacers are effective buffers for avoiding contact between the cement slurry and the drilling mud. The best mud removal is obtained if the density of the spacer is higher than the density of the drilling mud, but lower than that of the cement slurry. The viscosity should be as low as possible to allow turbulent flow regime at reasonable pump rates. Alternatively the yield point must be adequately high to suspend the weighting agent. In many cases, the pumping rates necessary for turbulent flow cannot be applied, because of limitations imposed by the available pumping equipment, or when the resulting friction pressure would be higher than the fracturing pressure of the formation. Therefore laminar flow spacer should be used. The best results are obtained, if the density and the rheological properties of the spacer lie between those of the mud and the cement slurry.

Washers are fluids with a density and a viscosity very close to that of water. They act by thinning and dispersing the mud. The viscosity should also be very low to allow turbulent flow. The simplest form of a washer is fresh water.

Spacers and washers can also be used in combination. If pumped in order mud-washer-spacer-cement, the washer can thin the mud to make it easier for the spacer to displace.

*Recommendations:*

- Spacers and/or washers have to be used on all cement jobs.

### **Gel Cement**

Bentonite (gel) in concentrations from 0-25% (BWOC) is widely used to reduce cement slurry density and increase slurry volume, either by dry blending with the cement or prehydrating in the mix water. The high water requirements of bentonite allows the use of a relatively high water-to-solids ratio without increasing free water breakout. However, the addition of bentonite to cement slurries increases the viscosity, decreases the compressive strength, and increases the thickening time.

**Use only high quality Bentonite (Wyoming - Sodium Montmorillonite).** The bentonite used in drilling mud normally has been beneficiated (or peptized) with an organic polymer to meet API specifications for drilling muds and is undesirable for use in cement slurries as it will increase the viscosity of the slurry while tying-up less free water.

- Concentration: Up to 25% (BWOC) bentonite can be used; however, because of loss of compressive strength and increase in thickening time, 16% (BWOC) is the practical limit. Gel cements used normally fall in the 4-12% (BWOC) range.
- Prehydration: Hydrated Bentonite for gel cement with fresh water. Allow the gel / water suspension to stand for 2 - 6 hours and then add the other slurry components.
- Temperature: Gel cement should not be used above 230°F as bentonite promotes strength retrogression.
- Attapulgite: Attapulgite clay or salt gel has the same water requirements as bentonite and thus can be used with seawater or salt cements to achieve density reductions equivalent to those of bentonite slurries. There is a foaming problem however.

### **Fluid Loss**

The purpose of this guideline is to give recommendations for the use of Fluid Loss additives for routine cementing operations. The cost of Fluid Loss agents can be several thousand dollars per job. In many cases they are not necessary.

*Recommendations:*

No fluid loss control is required when the following conditions are met:

- normal/routine cement job envisaged;
- casing size 13 3/8" and larger;
- permeable sands are absent over cemented zone;
- absence of potential reservoir zones;

- hole is near vertical (<15 deg).

Fluid loss control is required when one or more of the above conditions are not met, vis:

- 7" liner – control fluid loss to <50 ml/30 mins;
- 9 5/8" & 13 3/8" casing – control fluid loss to <100 ml/30 mins;
- squeezing cement through perforations or similar – a high degree of fluid loss control is required;

*Rationale for Above:*

Excessive fluid loss can cause

- premature dehydration leading possible bridging across small holes or in tight annuluses;
- loss of too much water leaving insufficient water for chemical reactions, so cement does not set properly;
- if water is lost to a potential reservoir, significant formation damage can arise;
- in a deviated well, water can form a channel on high side of hole.

### **Accelerators / Retarders**

It is undesirable to have a slurry that sets up too fast or too slow. Examples where either of these have occurred are:

- Too much retarder in P&A plugs that take too long to set and cost time waiting on a tag.
- Not enough accelerator in conductor cementing jobs where WOC impacts critical path.
- Flash setting from too much accelerator in the slurry.

It is imperative that job times be calculated and slurries are designed to fit into the output range. This is our best protection against major cementing errors and also wasting time through being over conservative.

### **High Temperature Cement Applications (Silica Flour)**

At temperatures in excess of 110° C, standard class G cement can experience strength retrogression and increase in permeability. To minimise the effect of this, a silica flour additive is generally included in the cement. This is routinely provided as a pre-blended mix of Class G cement and 35% BWOC silica flour.

*Recommendation:*

In general, silica blend cement should be used where the bottom hole static temperature (BHST) at the deepest cemented depth exceeds 110°C. Special cases where silica blend should be used in particular to minimise both strength retrogression and increased permeability are:

- In production wells where the section of cemented casing will experience life cycle temperatures greater than the BHST experienced at placement due to well production
- In abandonment plugs where BHST exceeds 110°C and hydrocarbon was encountered
- In wells where no hydrocarbons have been encountered, consideration should be given for the use of unblended Class G cement where the BHST is estimated to be up to 121°C.

*It is clear that 110°C is the lowest temperature at which strength retrogression occurs. The cement will take several weeks to reach full compressive strength and the retrogression that will follow will be minimal. At 121°C retrogression will still take several weeks and will not be excessive. In order to avoid the unnecessary addition cost of silica blend cement and the logistical problems of separation and storage it seems that 121°C is the lowest temperature at which silica blend cement should be considered where increased permeability will not cause additional problem. Silica blend cement for abandonment plugs particularly where a hydrocarbon zone is to be cemented off should still be used at temperatures above 110°C as if strength retrogression or permeability increase occur at the cement plug, hydrocarbons could migrate into sands or weak zones further up the wellbore.*

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## Ausrüstung der Produktionsrohrtour Non-Rotating Standardausrüstung

Die geeignete Anordnung der Verrohrungsausrüstung (Zentrierkörbe, Kratzer und Stoppringe), in Verbindung mit dem Bewegen der Rohre (Auf- und Abfahren von ca. 12 m) während der Zementation, ist eine wesentliche Voraussetzung für eine erfolgreiche Primärzementation.

Um die Anordnung der Verrohrungsausrüstung geeignet festzulegen, sind aus Sicht von EP-I/PT folgende Kriterien für Bohrungen im Inland zu berücksichtigen:

### 1. Zentrierkörbe

Zentrierkörbe sind unbedingt vom Rohrschuh<sup>1</sup> bis zum Zementkopf<sup>2</sup> zu verwenden. Die Anzahl der Körbe in KW-führenden Bereichen<sup>3</sup> sollte so ausgewählt werden, daß ein Standoff von mindestens 80% gewährleistet ist, jedoch ist mindestens 1 Korb pro Rohr zu verwenden. Zwischen KW-führenden Bereichen sollte ein Korb auf jedem zweiten Rohr platziert werden. In kritischen Bereichen<sup>4</sup> sind 2 Körbe pro Rohr zu verwenden, wobei eine Überdeckung von jeweils einem Rohr ober- und unterhalb des kritischen Bereichs garantiert sein soll.

Wenn das Bewegen der Rohre während der Zementation, z.B. aufgrund einer hohen Bohrlochsneigung, als nicht durchführbar erscheint<sup>5</sup>, soll das Standoff und damit die Anzahl der Körbe pro Rohr erhöht werden, sodaß die Rohre zumindest ein- und ausgebaut werden können.

Oberhalb des Zementkopfs sind die Zentrierkörbe so anzuordnen, daß Ein-, Ausbau und Bewegen der Rohre während der Zementation erleichtert werden, z.B. ein Korb auf jedem dritten Rohr.

<sup>1</sup> Der Rohrschuh sollte ca. 50 m Meßteufe unterhalb des tiefsten, abbauwürdigen KW-Horizonts sein. Technische Gründe können diese Regel natürlich aufheben (Wasserhorizonte, Verlusthorizonte etc.).

<sup>2</sup> Der Zement wird 150 m - 200 m Meßteufe über die oberste KW-Führung gesteigert.

<sup>3</sup> Ein KW-führender Bereich ist das Intervall von 50 m Meßteufe unterhalb bis 50 m Meßteufe oberhalb eines KW-führenden Horizonts.

<sup>4</sup> Kritische Bereiche sind Strecken, innerhalb derer auf kürzester Distanz signifikante Druckunterschiede im Laufe der Produktion erwartet werden, z.B. GÖK, ÖWK oder permeable, wasserführende Lagen in unmittelbarer Nähe eines abbauwürdigen KW-Horizonts.

<sup>5</sup> Basis ist die Berechnung der minimalen und maximalen Hakenlasten mit geeigneter Software, z.B. CentraPro Plus™ von Weatherford.



Ist die Zementsteigerung bis in die nächst größere Rohrtour geplant, so sind im Bereich Rohr in Rohr Positive Centralizer die bevorzugte Ausrüstung.

## **2. Kratzer**

Im Bereich eines abbauwürdigen KW-Horizonts werden 3 Kratzer pro Rohr (Post Plug) und in kritischen Bereichen 12 Kratzer pro Rohr (Cleavage Barrier) verwendet. Bei beiden Anordnungen soll eine Überdeckung von jeweils einem Rohr ober- und unterhalb des entsprechenden Bereichs gewährleistet sein.

## **3. Stoppringe**

Die Anzahl und Anordnung der Stoppringe richtet sich nach der Anordnung der Zentrierkörbe und Kratzer. Ob ein Zentrierkorb durch Platzierung über einem Stoppring oder zwischen zwei Stoppringen fixiert werden kann, hängt von der Clearance zwischen Rohrtour und Bohrloch ab.

Diese Kriterien sollen bereits bei der Planung von künftigen Bohrungen im Inland beachtet werden.

Die tatsächliche Anordnung der Verrohrungsausrüstung wird nach der vorläufigen Auswertung der Bohrlochmessungen vor Ort den angetroffenen Gegebenheiten unter Berücksichtigung des Bohrlochzustands angepaßt.

Glück Auf!

B. Schlager

H. Gager

# Übernahme/Liquidation einer Neubohrung durch PRT

1. Kontakt mit Bohrung (Sat.-Tel.23991) und Geologen (W. Siedl, R. Korinek...) halten. Wichtige Punkte: Verlustzonen? Wann wird Endteufe erreicht? Wann liegt das erste Log vor (GR, Widerstände, Porositäten)?  
Bei LWD liegt das erste Log bei Erreichen der Endteufe vor (wird nach Ausbau der Garnitur und einlesen der Speicherdaten nur mehr unwesentlich abgeändert), bei Wireline Logging nach Befahren des Bohrloches.
2. Sobald die Messdaten vorliegen, wertet der zuständige Geologe vor Ort aus. Der Produktionstechniker sollte ebenfalls bereits vor Ort sein und in sein Log-Exemplar die Schichtgrenzen und KW-Horizonte eintragen.
3. Entsprechend der Preliminary Log Evaluation (KW-Horizontmächtigkeiten, Porositäten und Ölsättigungen) lassen sich die Ölpermeabilitäten abschätzen (Schlumberger-Chart K3, K4). Anhand der Faustformel

$$q = k \times h \times \Delta p / (\mu \times 20 \times 20)$$

läßt sich die Langzeitrategie des Depletion Modes errechnen. Die Anfangsrate (z.B. beim Swab-PV) kann doppelt so hoch sein.

q	Rate in m <sup>3</sup> /d
h	vertikale Sandmächtigkeit
$\Delta p$	Depression in bar (50 bar als erste Annahme)
$\mu$	Viskosität in cp (A-Öl: 3,74, P-Öl: 1,5 – 2)
20	$\ln(r_E/r_W - 0,75 + S + Dq + \text{Lagerstättenformfaktor})$ im Depletion Mode
20	Beinhaltet Konstante und Umrechnungsfaktor für die verwendeten Einheiten

4. Lassen sich wirtschaftliche Raten erwarten, so ist in Abstimmung mit dem Geologen zu klären, ob genügend Reserven (>15.000 t) durch die Bohrung gefördert werden können.
5. Bei möglicher Wirtschaftlichkeit ist die Bohrung zu verrohren.
6. In Absprache mit Weatherford ist die Bestückung mit Centralizern festzulegen. In KW-Bereichen (50 m über und unter den KW-Sanden) ist ein Standoff von  $\geq 80\%$  zu gewährleisten (Berechnung durch Weatherford).
7. Die Ausrüstung des Casings in den KW-Bereichen mit Kratzern ist vorzunehmen. Hierbei empfiehlt es sich, einen Papierstreifen mit der Unterkante neben einem 1000-er Log (mit den eingetragenen KW-Horizonten) zu platzieren und die mit Kratzern auszurüstenden Rohrintervalle auf dem Papierstreifen zu markieren.
8. Die möglichen Zirkulationsteufen sind so festzulegen, dass ca. 200 m unterhalb des Konduktor-Rohrschuhs beginnend in 200 m Abständen abwärts bis zur Bohrlochsohle in tonigen Bereichen während des Rohreinbaus zirkuliert werden kann.
9. Die Unterkante des Papierstreifens ist, von oben beginnend, an die Zirkulationsteufen anzulegen. Überdecken während des Rohreinbaus Kratzerintervalle mögliche Verlustzonen oder KW-Horizonte, die während des Zirkulierens und späteren Zementierens zu Verlustzonen werden können, so ist die Herausnahme von Kratzern in nicht unbedingt erforderlichen Bereichen zu überlegen (kritische Kratzerbereiche auf dem Papierstreifen ausradieren und durch Anlegen der Papierstreifenunterkante an die Bohrlochsohle überprüfen, ob die verbleibenden Kratzerbereiche hinreichend die später zu fördernden KW-Horizonte überdecken). Lassen sich kritische Kratzerintervalle

- nicht verkleinern, ist eine Zirkulation ohne Bewegen der Rohrtour eine Möglichkeit, die Schaffung von Verlustzonen zu vermeiden.
10. Ein oder zwei Kurzrohre sind etwa 5 – 10 m oberhalb interessierender KW-Lagen einzubauen, um später anhand des CCL die Perforationskanone positionieren zu können.
  11. Nachdem für alle Zirkulationsteufen die Kratzerbestückung überprüft wurde, sind die für die Verrohrung erforderlichen Angaben niederzuschreiben und dem Bohrmeister zu übergeben:

Beispiel:

### **Angaben für den Bohrmeister – Spa S 9a**

- Rohrausrüstung  
Zentrierkorbanordnung gemäß Weatherford-Aufstellung  
2 Kratzer x 1 Kratzer auf je 2 Rohren in folgenden Intervallen:  
1780 – 1820 m  
1835 – 1855 m  
1875 – 1925 m  
1970 – 2105 m  
2150 – 2180 m
- Oberste KW-Führung  
8. Sarmat, 1295 m --> Zementkopf 1100 m
- Mögliche Zirkulationsteufen (RS Conduktor 690 m)  
900 – 950 m  
1225 – 1275 m  
1465 – 1490 m  
1610 – 1620 m  
1960 – 1970 m  
2140 – 2150 m  
2278 m = Rohrschuh/Bohrlochsohle
- Kurzrohr
  1. Kurzrohr bei ca. 2150 m
  2. Kurzrohr bei ca. 2070 m

Unterschrift



**AFFIDAVIT**

I declare in lieu of oath, that I wrote this thesis and performed the associated research myself, using only literature cited in this volume.

Datum 08.06.2011

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Signature Author  
Andreas, Csar  
Matriculation Number: 0535214

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Unterschrift Betreuer/in / Beurteiler/in