Optimization of Cement Plug Design in RAG Wells in Austria

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Affidavit

I declare in lieu of oath, that I wrote this thesis myself, using only literature cited in this volume.

Eidesstattliche Erklärung

Ich erkläre hiermit an Eides statt, dass ich die vorliegende Arbeit eigenhändig angefertigt habe, lediglich unter Verwendung der zitierten Literatur.

Date	Signature

Acknowledgement

First of all I want to thank **DI Heimo Heinzle** from RAG Rohöl-Aufsuchungs AG for offering me the chance to write this interesting thesis about a real problem occurring during the life of a well. I also want to thank **DI Oliver Tausch**, **DI Micheal Brunneder** and **DI Karin Hofstätter** and all the engineers at RAG that supported and provided me with needed data for time of my thesis.

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Abstract (English)

The reason for this Master Thesis was that RAG Rohoel-Aufsuchungs AG experienced an unsatisfying success rate in cement plug jobs in their wells in Austria in the past few years. So far, no reason could be identified why some plug jobs went well and others didn't. The goal was to analyze previous plug jobs and identify possible error sources.

The thesis gives a brief introduction on cement plugs, what they are used for and drilling problems that could be solved with such operation. Further on a cement plug operation is described from the planning, the cementation program and the activities on the rigs site.

The main part of this work is the case study about the cement plug jobs from the last 6 years and a preparation of statistical data. Accordingly the critical parameters for such a job were identified and discussed in detail. The parameters are separated in two groups: unchangeable parameters (formation, inclination…) and changeable parameters (plug length, pump speeds…). To analyze the parameters in detail the available real time data from the rig site was processed.

Together with cementing business unit of Schlumberger (SLB) simulations with their software Plug Advisor were performed to find possible sources of error. The results of these simulations were discussed in this work. Further more, this thesis gives an insight in the testing procedures and testing devises used in the cementing laboratory of Schlumberger.

In addition to the general case study a detailed analysis of the last 5 cement plug jobs of RAG was done. A discussion of all critical parameters and possible causes for not satisfying results are part of this thesis.

At the end recommendation for an improvement of the plug success rate were discussed including alternative methods that are used in the industry.

Abstract (German)

Der Grund für diese Diplomarbeit war eine unzufriedenstellende Erfolgsrate bei Zementbrücken der Firma RAG Rohöl-Aufsuchungs AG der letzten 6 Jahre. Bis heute wurde keine Erklärung gefunden, warum manche Zementbrücken zufriedenstellende Ergebnisse bringen und andere nicht. Das Ziel dieser Arbeit war die Erstellung einer Analyse der bisherigen Zementbrücken, um möglich Fehlerquellen zu identifizieren.

Die Arbeit beschreibt die Anwendung von Zementbrücken und die Probleme, die mit Hilfe dieser gelöst werden können. Des Weiteren wird eine Verfüllungsoperation beschrieben, von der Planung bis zu den Aktivitäten an der Bohranlage.

Der Hauptteil dieser Arbeit beschäftigt sich mit einer Fallstudie, die Zementbrücken der letzten 6 Jahre analysiert und statistisch aufarbeitet. Im Zusammenhang mit dieser Fallstudie werden die kritischen Parameter solch einer Operation identifiziert und diskutiert. Die Parameter sind in 2 Gruppen aufgeteilt: Die unveränderbaren Parameter (Formation, Neigung…) und die veränderbaren Parameter (Brückenlänge, Pumprate…). Um eine genaue Analyse zu gewährleisten wurden Echtzeitdaten der Bohranlagen verarbeitet.

Zusammen mit der Zementiersparte von Schlumberger wurden Simulationen mit der Software Plug Advisor erstellt um mögliche Fehlerquellen zu identifizieren. Die Ergebnisse dieser Simulationen werden in dieser Arbeit im Detail behandelt. Weiters gibt diese Arbeit einen Einblick in die Versuche und die dazugehörigen Gerätschaften, die im Zementlabor bei Schlumberger angewendet bzw. verwendet werden.

Als Zusatz der Fallstudie wurden die letzten 5 gesetzten Zementbrücken im Detail analysiert um die genauen Ursachen eines Erfolges oder Misserfolges zu identifizieren.

Am Ende gibt diese Arbeit noch Verbesserungsvorschläge für das Setzen von Zementbrücken sowie Empfehlungen für alternative Methoden die weltweit in der Öl- und Gasindustrie angewandt werden.

Contents

1. Introduction

1.1. Problem statement

The drilling department of the Rohöl Aufsuchungs- Gesellschaft (RAG) had experienced an unsatisfying success rate in cement plug jobs at their wells in Austria and Germany over the past few years. So far, no reason could be identified why some cement plug jobs went well and others didn't.

The oil and gas industry's average rate of 2.4[1] attempts to set one successful plug shows that this phenomenon is not unique. Over the last decades a lot of research was conducted to develop operational techniques to gain better results. Therefore service companies, like Schlumberger or Halliburton, developed software specialized in simulating the placement of cement plugs to optimize the parameter like pumped volume amount as well as different physical properties of the used fluids and their interactions. Different tools such as diverter tool or Cement Support Tool (CST) were developed to improve the plug operations. This leads to an increased success rate of cement plug operations but so far there is no ultimate solution for this problem.

In case that a cement plug is not successfully placed, the job has to be repeated in order to meet either the function (e.g. kick-off plug) or the legal requirement (e.g. plug and abandonment regulations). This setting procedure is time consuming because the cement needs 12 hours to harden and to provide a certain compressive strength. A repetition of such jobs includes the time for Waiting on Cement (WOC) and time for a new cement placement. All this increases the total costs of the well depending on the rig rate, and the costs for a second.

Fall seeing to that problem RAG is interested to investigate the previously performed cement plug jobs to identify "negative" trends in operations, and to reduce the number of unsatisfying plugs to a minimum.

1.2. Thesis objectives and scope of work

The main objective of this thesis is to identify possible sources of error in order to optimize the cement plug design in the future.

A detailed data analysis and investigation of each executed cement plug jobs of the past 6 years are conducted to identify possible reasons for the functioning or malfunctioning of cement plugs. Most of the data to be analysed needs to be taken out of RAG's Drilling Monitoring System DMS. When doing this analysis the focus lies on the following points:

- mud-cement interaction (usually a K2CO3 mud system is used)
- viscosity and density differences of mud and cement
- influence of inclination / inclined wellbores
- influence of pumping speed / pulling speed / stinger used
- operations before and after the cement plug job (and their duration)
- other parameters and observations (e.g. cuttings discharge, porosity of surrounding layers at plug setting depth, mud properties …)
- planned vs. actual cementing programs & output (lessons learned and implemented improvements)

Further on literature research at Schlumberger (SLB) should give a general overview of cement plugs, cement support tools and cement plugs for high density mud to integrate the gained knowledge in the cement job operations and to update RAG's "Best Practice für Verfüllungen".

The author of this thesis used Schlumberger's simulation software called 'Cement Plug Advisor' used to compare past and current cement programs. Therefore, all cement plug jobs carried out in the past (which weren't planned with simulator software back then) are re-planned with the current software and the output is compared to the program that was used in the past. The difference between the programs is analysed in order to find out if the software would be capable to improve the jobs.

Laboratory experiments with different cements, potassium carbonate and bentonite mud systems were made in Schlumberger's lab in Vechta, Lower Saxony. In order to investigate the interaction between mud and cement influences the rheological behavior of the fluids. Special attention is given to the influence of the mud on the cement hardening time.

2. Cementing in general

Cementing in the oil industry is nearly as old as the industry itself. The first cement job was performed in 1903 in order to guarantee a zonal isolation in oil, gas and water wells[2]. Since then, where the only function of cement was to provide a hydraulic seal between casing and formation (primary cementing), the industry used cement other problems (remedial cementing) that occur during the drilling process. Nowadays cementing, in all its variations, is a major part of a well’s lifecycle from drilling until the abandonment (cement plugs).

Although cementing has a long history in the oil and gas industry, it’s still no standard procedure due to numerous factors (formation geology, temperature, pressure…) that influence a successful cement job. Over the last years the industry developed new additives to adjust the cement slurries for the different in-situ conditions. Software was developed to simulate the placement process and is capable to optimize the rheology, the pump rate and the volumes of the different fluids that are used. Many experiments and simulations where performed to create a better understanding of the process during a cement job to improve the cement plug procedures.

2.1. Cement plug

Plug cementing is a form of remedial cementing that is used to solve the following challenges that occur during drilling[3].

- To sidetrack above a fish or to initiate directional drilling
- To plug back a zone or a well (abandonment)
- To solve a lost-circulation problem during drilling operation
- To provide an anchor for an openhole test
- For other remedial work

2.1.1 Cement plug for sidetrack operation

Sidetrack operations are performed if the original hole is dry and other near targets should be drilled from the same wellbore or if a fish blocks the original hole and fishing operations are not successful or not economic.

In order to exit the original hole, a kickoff plug (or whip-stock plug) has to be placed at the desired depth.

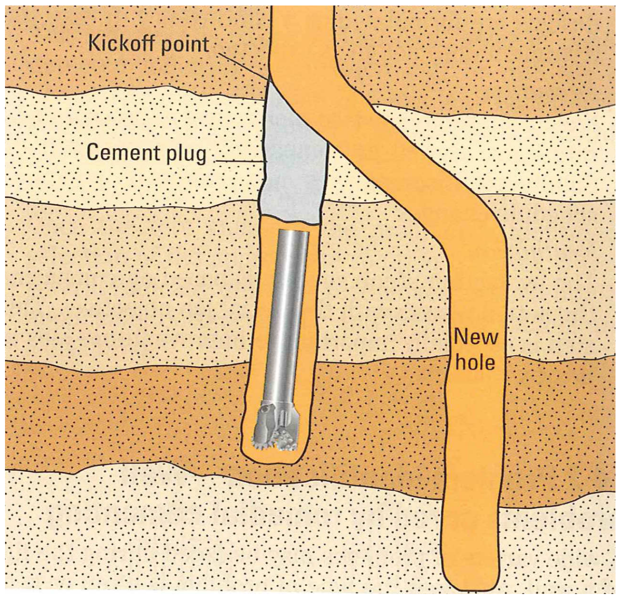

Figure 2.1 - Kickoff Plug [2]

The compressive strength of the cement plug has to be higher than the formation (5,000 – 7,000 psi)[2]. If this is not possible, material that reinforces the cement matrix has to be added. Materials like polymer fibers (Loveland and Bond 1996) and metallic micro ribbons (Al-Suwaldi et al 2001 Chapter 3) are used[2].

2.1.2 Plug back a zone or a well

2.1.2.1 Production depletion

In this case the plug is used to induce a hydraulic barrier between different zones. If, for example, a lower zone is depleted and a production from a higher reservoir layer is planned, it has to be guaranteed that there is no cross flow. Such cross flow would affect the production of the upper layer. Normally the initial pressure of the upper production layer is higher than the pressure of the depleted reservoir layer below. This would cause a flow from the upper layer to the lower one. The described plug is shown in Figure 2.2. The task of this plug is to separate the two zone.

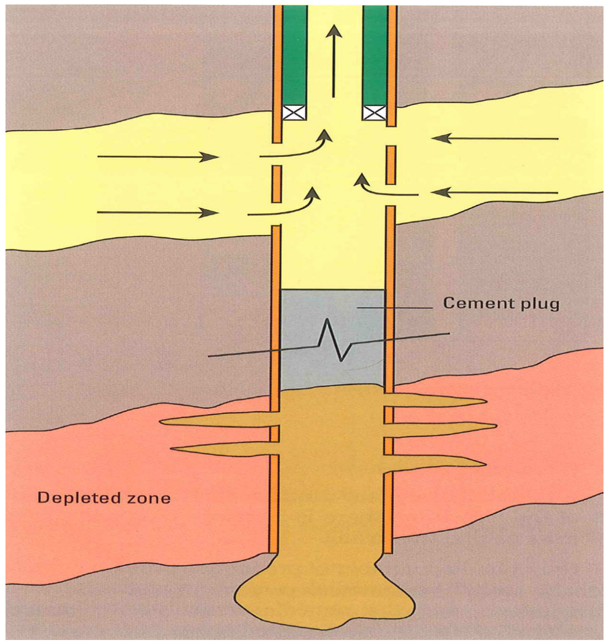

Figure 2.2 - Plugging a depleted zone [2]

2.1.2.2 Well abandonment

A well is abandoned when the well is dry. This means when the well is drilled and there are no hydrocarbons in place or the amount is not commercial. In most countries where oil and gas is produced there are rules for well abandonment operations. In Austria these rules are written down in the Bohrlochbergbau-Verordnung. The main objective of the cementation plug is to avoid that any formation fluids migrate to the surface or into other layers that contain ground water. The second objective is to restore natural integrity of the formation that was interrupted while drilling[2]. Figure 2.3 shows such abandonment with three plugs in place.

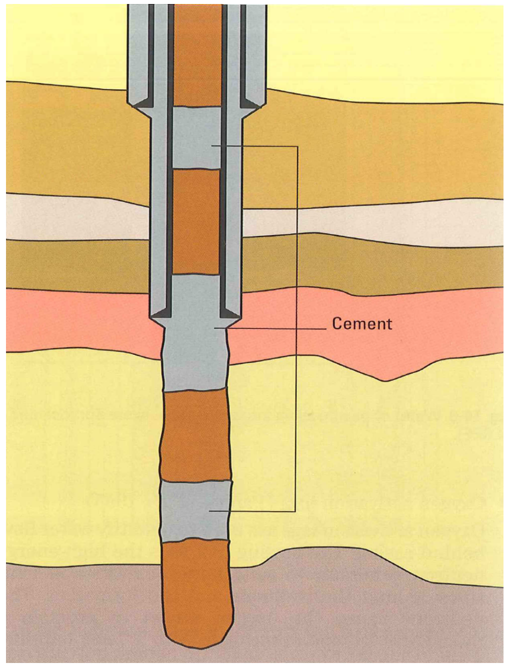

Figure 2.3 - Abandonment Plug [2]

2.1.3 Solve a lost-circulation problem during drilling operation

An indication for a lost circulation problem is, when the returns are smaller than the volume that is pumped into the hole. For that reason the tank level in the mud tanks is observed. If such a problem occurs, the first option is to add some lost circulation materials. “Commonly used lost-circulation materials include are fibrous (cedar bark, shredded cane stalks, mineral fiber and hair), flaky (mica flakes and pieces of plastic or cellophane sheeting) or granular (ground and sized limestone or marble, wood, nut hulls, Formica, corncobs and cotton hulls). Laymen has suggested lost-circulation materials to the "fix-a-flat" materials for repair of automobile tires”[4].

If such actions do not help to stop the loss, a cement plug is an option to deal with that challenge. To be able to set a plug successfully two questions have to be answered[2].

- What is the nature of the leak: permeable formation (sandstone), natural fissures, induced fractures or caverns (carbonate rocks)?
- At which depths are the loss zones located?

Figure 2.4 shows a plug set over a zone where the fluid loss occurred called thief zone. After the cement has developed sufficient compressive strength, the drilling operation can be continued with drilling through the plug.

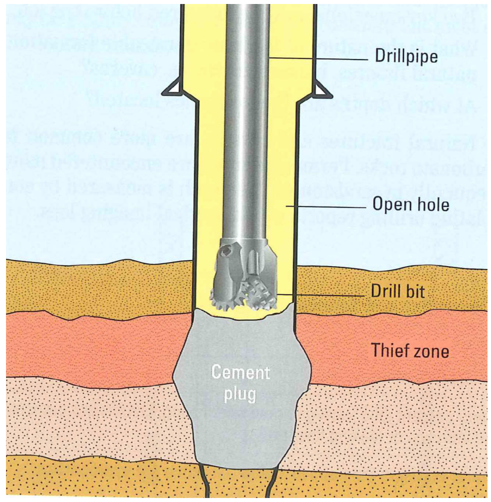

Figure 2.4 - Lost Circulation Plug [2]

2.1.4 Provide an anchor for an openhole test

This plug can also be referred to a temporary or protective plug[2]. As shown in Figure 2.5, the function of this plug is to protect a weaker formation if a "stronger" formation is tested above. This plug is an alternative to an openhole packer if there are setting problems.

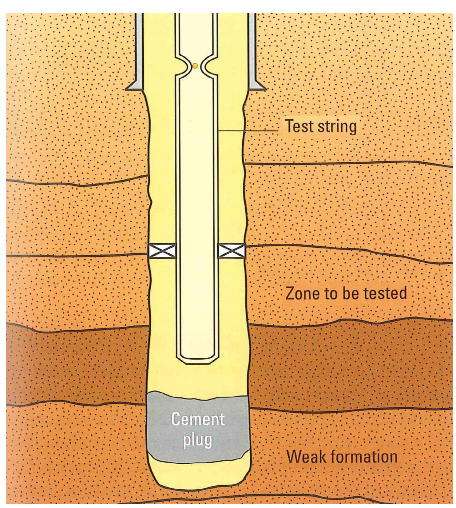

Figure 2.5 - Plug set as anchor for a test [2]

2.1.5 Other remedial work

Squeeze cementing is a possibility to solve failed primary cement jobs or production induced tasks like closing perforations. Operations, like squeeze operations, belong to the same group as cement plugs, the group of remedial cementing. For the purpose of completeness it should be mentioned that there is no further detailed discussion about that topic in this thesis.

2.2. Cement job operation

2.2.1 Pre-planning

To be able to discuss the critical parameters that could lead to plug failure it is necessary to get an overview about the cement plug jobs in general.

The reasons for a plug operation are discussed in the Chapter 2.1. The following Chapter starts from the decision that a plug will be placed to the part where the plug is tested.

Depending on the kind of plug which is set, the position of the plug differentiates between abandonment plug and kick off plug. For an abandonment plug it is necessary to fulfill the governmental regulations. These regulations are stated in the Bohrlochbergbau-Verordnung. The regulations define the number, the position and the interval where plugs have to be set. Beyond that it is allowed to set more plugs than required by law.

A kick off plug is not regulated by law. It has to be placed over the interval where it is planned to exit the actual wellbore. A safety margin below and above (+/- 50 meters) should be considered in the planning to ensure a successful kick off.

In general the preparation of the job starts with contacting the service company, which is specialized on cementing. Commonly, it is the same company that is hired for the casing cementation.

The cementing company is provided with the following material.

- Plug length (stage intervals)
- Pipe list
- Cement stinger configuration
- Caliber log
- Fluid loss limits
- Layers with gas influence

2.2.2 Cementing Program

According to the provided data, the service company develops a cementation program. An example attached in APPENDIX A. Subsequently this program is checked by the responsible engineer of the operator and the company man. All relevant data for the job is included in the program. The pump schedule defines how mud push, cement slurry and mud are pumped. The volumes for the different fluids used are defined as well as the desired pump rate. According to the schedule, the time need for the job is calculated and a safety factor of 120 min is added. The result is the required thickening time. The thickening time is defined as the time that the cement slurry requires to reach 100 Bearden units of consistency[5]. The maximum pumpable viscosity is defined with 70 Bearden units of consistency.

The cement slurry hardening time is designed for the pumping time that is needed and other requirements. The other requirements could be fluid loss agents or gas block components. Table 2.1 shows a list of fluid additives that are used to design the cement slurry or the mud push.

SLB-Code	Name	Description
D013	Retarder	Retarder for medium Temperatures
D020	Bentonite	Viscosifier
D028	HT Retarder	High temperature Retarder
D031	Barite	Weighting agent
D076	Hematite	Weighting agent
D080A	Dispersant	Liquefier
D095	CemNET	Lost circulation material
D145A	Dispersant	Liquefier
D155	Micro Silica	Fine grained material for gas block
D167	UNIFLAC-S	Fluid loss agent
D182	MUDPUSH II	Spacer-Basis
D193	Fluid Loss	Fluid loss agent
D197	ACCUSET	Temperature independent retarder
D206	Antifoam	Antifoam
D500	GASBLOK	Low Temperature gas-migration control.
D600G	GASBLOK	Medium Temperature gas-migration control.

Table 2.1 - Cement/ Mudpush Additives

The cementation program includes also the test results of the cement slurry from their lab (discussed in Chapter 7). These results can either be from a test that is performed with the exact recipe of the pumped cement slurry or from reference values of similar slurry that were tested under similar temperature conditions. The test includes on the one hand a rheology test at room temperature and on the other hand a simulation at the simulated bottom hole circulating temperature. The test with the down hole pressure is done to get a realistic simulation and to assure a safe pumping process. Due to that fact the bottom hole circulating temperature is used rater than the bottom hole static temperature that API recommends. The definition for the bottom hole circulating temperature is:

“The temperature at the bottom of a well while fluid is being circulated, abbreviated BHCT. This is the temperature used for most tests of cement slurry in a liquid state (such as thickening time and fluid loss). In most cases, the BHCT is lower than the bottom hole static temperature (BHST), but in some cases, such as in deep water or in the arctic, the BHCT may be higher than the BHST.”[6]

Those laboratory tests also include a fluid loss test according to API and the thickening time test to check if the slurry meets the time requirements for a safe job.

The cementing program includes the simulation outputs from their software CEMCADE, which simulates the placement of the cement slurry. The software includes all the transferred information (e.g. Caliber, DP dimensions …) and is capable to simulate the annular pressure, to check it against the limits of pore- and fracture pressure. Another simulation is performed to compare the pump pressure with the well head pressure to generate knowledge about the pressure that will encounter. This is done to check if the pressure does not exceed the limits of the used equipment. Schlumberger simulates as well the flow rate and compares in-flow and out-flow.

2.2.3 Job operations on the rig site

The safety meeting is scheduled on the beginning of each job. In this meeting all important safety aspects are discussed and the schedule is explained to everybody who is involved in the job. At that time the cementing string is already positioned in the hole at the desired depth of the first plug stage. The cementing string consist of a cement stinger with a smaller diameter (2 7/8" or 3 1/2") than the drill pipe, the drill pipe and a cement head located on the rig floor.

Following to the safety meeting the circulation performed by the rig pumps stops and the lines are switched to the pump truck of the cementing company. Once the lines are mounted, they are pressure tested to avoid any leakage during the cement job. Subsequently the mud push is pumped according to the pump schedule. Shortly after the water is pumped, the pre-loaded drill pipe dart is released. The drill pipe dart avoids a mixture between the fluids while they are pumped through the string. According to the schedule the cement is pumped before the mud push post flush. While the cementing company pumps the fluids, the rig pumps regular drilling mud in the tank system of the cementing company. After the mud push has been pumped, the cement company pumps a defined volume of mud to set up the conditions for a proper u-tube effect (discussed in Chapter 4.2.5). A under displacement is needed for a proper hydrostatic equilibrium while pulling out the cementing string. A side effect of this is that the pipe is not pulled out wet. During the pumping the drill string should be rotated for a better mud displacement. After the cementing company has pumped the fluids, the valves of the cement head are closed and the cement lines are disconnected. The aim of closing the valves, before the lines are disconnected, is to avoid sucking air into the cementing string which could have a negative influence on the u-tube effect.

After the cement head is led down, the cementing string is pulled out of hole. This process should not be done too fast whether too slow to get stuck in the hardening cement (discussed in Chapter 4.2.7). The length of pipe that is pulled out depends on the plug length. The lower end of the string should be pulled out until it is approximately 10 meters above the desired top of cement.

When reaching this point the annular blowout preventer (BOP) is closed and the rig pumps circulate indirect (reverse). This means that the pumps pump into the annulus under the closed BOP and the mud push and the spare cement are circulated out over the string. This avoids that the cement and the mud push get in contact with the formation. Important limits during the indirect circulation are the Maximum Allowable Annular Shut-In Pressure (MAASP) and the Equivalent Circulating Density (ECD).

2.2.3.1 MAASP

"The Maximum Allowable Annular Surface Pressure (MAASP) equals the formation breakdown pressure at the point under consideration minus the hydrostatic head of the mud/or influence in the casing. During well control operations the critical point to consider is the casing shoe.

MAASP = Formation Break Down Pressure - Head of mud in use   Equation 2.1

or

MAASP = (E.M.W - MWMUD) x 0.052 x Shoe Depth (TVD)   Equation 2.2

Where

E.M.W = Equivalent mud weight at which formation breaks at shoe

MWMUD = Mud Weight

During the process of controlling and circulating out an influence, several stages can be distinguished in calculating the MAASP. However, the MAASP is only significant while the casing is full of fluid. For pre-kick calculation purposes, the value of the MAASP shall be revised whenever the hydrostatic head of mud in the hole changes." [7]

2.2.3.2 ECD

“The effective density exerted by a circulating fluid against the formation that takes into account the pressure drop in the annulus above the point being considered. The ECD is calculated as:

$$ECD = d + P/0.052*D \qquad \text{Equation 2.3}$$

d = mud weight (ppg)

P = pressure drop in the annulus between depth D and surface (psi)

D = true vertical depth (feet)

The ECD is an important parameter in avoiding kicks and losses, particularly in wells that have a narrow window between the fracture gradient and pore-pressure gradient.” [8]

During the reverse circulation the pH value is measured to identify the different fluid phases. The difference of the pH value between mud and cement helps to separate the fluids and to dispose the spare cement. Sugar as a retarder is added to keep the cement liquid for the transport to the waste dump. When the liquids are separated the plug or the stage (if the plug has more stages) is completed.

After the separation there are two possibilities to continue either wait on cement and test the plug or set the next stage the same way as described. The wait on cement time is normally set with 12 hours. Afterwards the cement plug is tested, either by tagging it and applying load on it or by applying pressure.

3. Case study

One of the major parts of this thesis was to analyse all available data of the cement plug jobs that RAG performed over the last six years. The first observed plugs were set in May 2006. In this year a huge number of wells were plugged and abandoned. Over the years there were seven rigs that worked for RAG, which placed cement plugs wherever it was necessary.

The main part of the data was found in RAG's internal software called the Drilling Monitoring System (DMS), an Oracle based database. The company man normally enters the required data directly on the rig site. Additional data was gathered from the Bohrungsprojekt-Management System (BMS) and from the End Of Job Reports (EOJR) from Schlumberger.

The data gathering was the first step in order to create a general statistic of the plug success rate that RAG has placed over the last years. To measure the success following ranges were set by the author to quantify if the plug was a success or a failure.

- Excellent stage +/- 0-15 meters away from planned Top Of Cement (TOC)
- Satisfying stage +/- 15-25 meters away from planned Top Of Cement (TOC)
- Failed stage more than +/- 25 meters away from planned Top Of Cement (TOC)

Altogether 208 stages, of 54 cement plug jobs, were analysed and evaluated.

3.1. Problems with data gathering

One of the problems that rose during the data gathering was that normally not every stage was tested. Common practice is to place three stages and then test the last stage for its success. This saves a lot of time because there is no need to wait 12 hours on cement after each stage. This procedure does not allow identifying a failed plug right away. The usual way to test the TOC of the stage is to set a string on the cement and load it with 3 to 8 tons. This method by itself is no guarantee that the plug stage is tight. This could be if the cement is not properly placed over the length of the plug (cross section of the hole is nor fully filled with cement) (Figure 3.1).

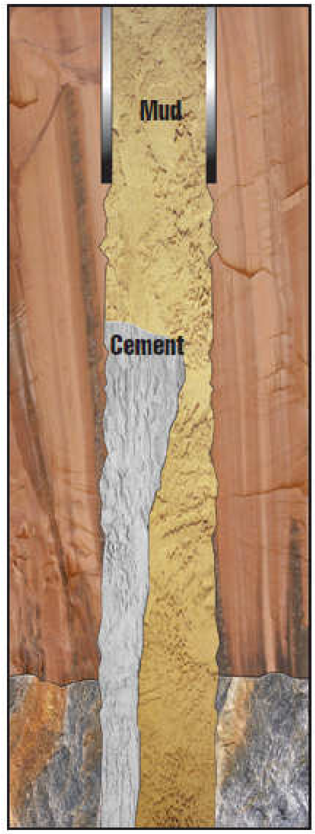

Figure 3.1- improper cement plug[9]

A proper test for the integrity is to pressure test the plug and look for a pressure decrease. This practice makes it also hard to repeat a job properly because there is no clear indication, which stage failed and where exactly the TOC is. The common practice of not testing every stage is based on the Austrian law for plug and abandonment. There are countries where the law forces the operator to test every stage for integrity.

3.2. Success ratio – in general

In Figure 3.2 an overall rate of the plugs can be seen. The biggest part is the "untested stages" shows that the majorities (over 60 %) of plugs were not tested. To create a better understanding of a success rate for the plugs placed by RAG the untested stages are not shown in Figure 3.3. It is shown that the 33% of the plugs are more than 25 meters away from the planned TOC and are therefore in the category failed. If this number is compared with the worldwide statistic of 2.4 plugs that have to be set to have one successful kick-off plug[1] , which indicates a 70% chance of a plug failure (the failure criteria is not defined) , RAG's success rate is not bad overall. Another survey from the North Sea[10] shows that 30% of the plugs that were set without a mechanical barrier below failed completely, wherever 70 % of the set plug had the top of cement within +/- 30 meters from the planned top of cement. This survey show similar success rates compared with RAG. An important assumption is that top jobs (plugs that are cemented to surface) are assumed as excellent stage even they are not tested. These jobs are just visually checked if the cement reaches surface.

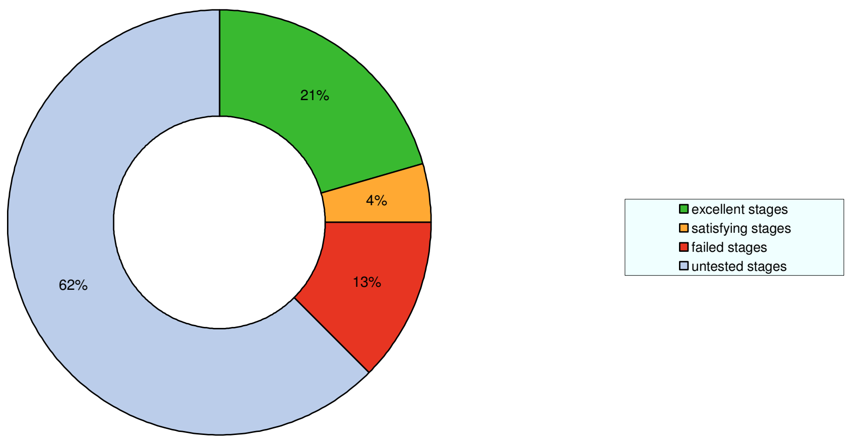

Figure 3.2 - Plug success rate

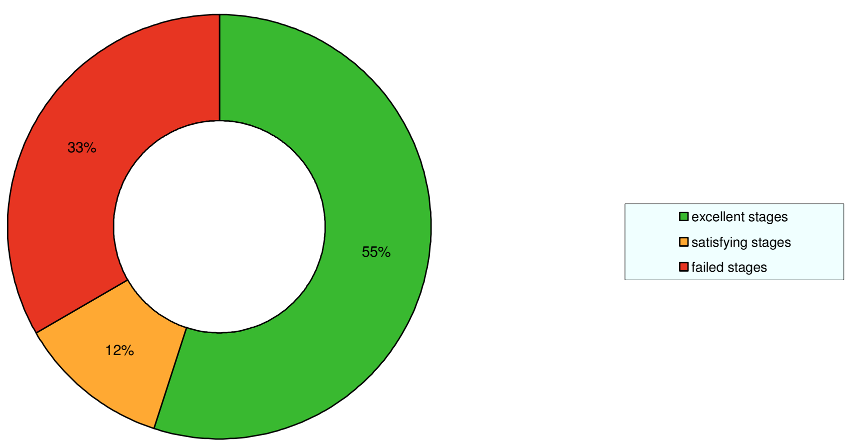

Figure 3.3 - Plug success rate - untested stages not included

In Figure 3.4 it was assumed that the untested stages have the same result as the tested stage above. If the 3rd stage is excellent the 1st and the 2nd stage are excellent as well and the same way for a failed 3rd stage. This assumption is no guarantee that the lower stages have the same result as the tested stage.

One example was found where the tested stage was a total failure but the TOC was found exactly at the TOC height of the lower stage, which leads to the assumption that just the upper stage was a total failure and the lower stage was perfect in place.

The result of this assumption is very similar to the result of the statistic where just the real tested stages are taken into account. Although a discussion with RAG's engineers in charge leads to the fact that statistics using only the real results without any assumption are better[11].

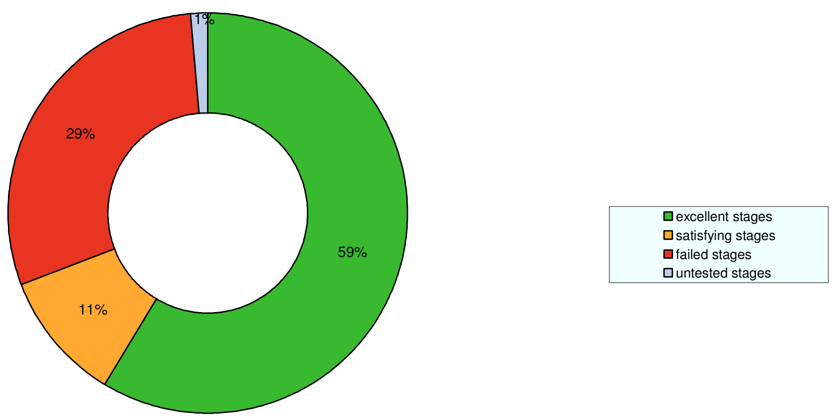

Figure 3.4 - Plug success rate - untested stages assumed with same result as tested

3.3. Success ratio - rig depended

An interesting statistic for RAG was the performance of the different rigs that are working for them. The first rig depended statistic (Figure 3.5) shows the plug results split up for each rig. This figure indicates that the number of placed plugs for each rig is quite different and some of the rigs performed a high number of plug jobs than others.

W 9 was RAG's own rig that operated until 2008 since then the rigs E 200 and E 202 are operated by RAG.

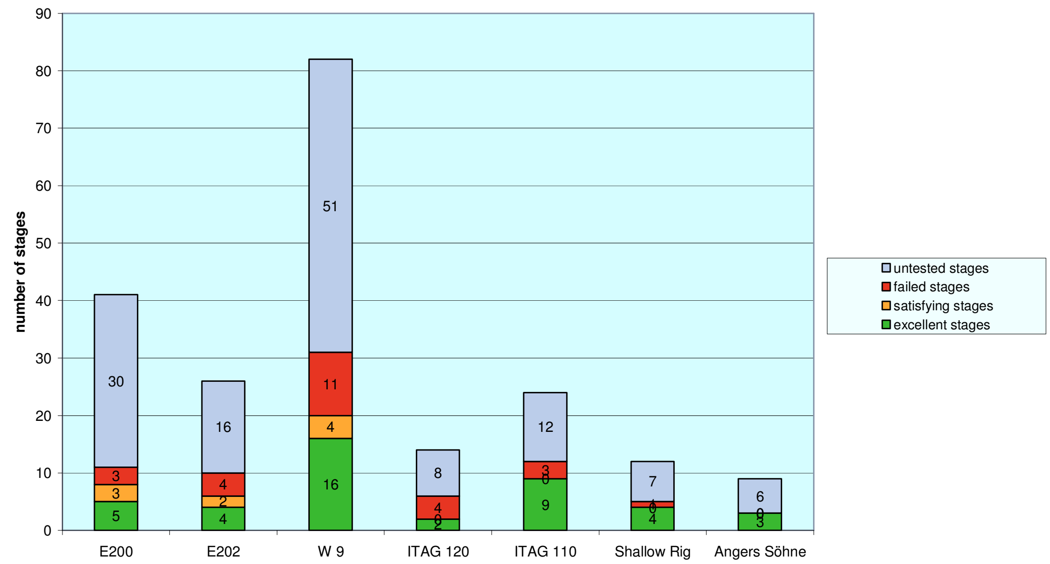

Figure 3.5 - Plug success - rig dependent

For better visualization and comparison between the rigs, the number of each rig was given 100% in the Figure 3.6. This comparison shows that each rigs operated by RAG have a quite similar success rate between 60% and 73% (excellent stages + satisfying stages). The results of the contractor rigs show a higher success rate than their own rigs, but the relatively low number of performed plugs should be considered for any kind of conclusion. According to that low number of plugs and the fact that the rigs of Shallow Rig and Angers Söhne only performed top plugs rather than plugs that are placed and tested in a certain depth, it is not applicable for an easy comparison between the rigs. It can be asserted that the all rigs, except ITAG 110, perform better than the worldwide average[1, 10](discussed in Chapter 3.2).

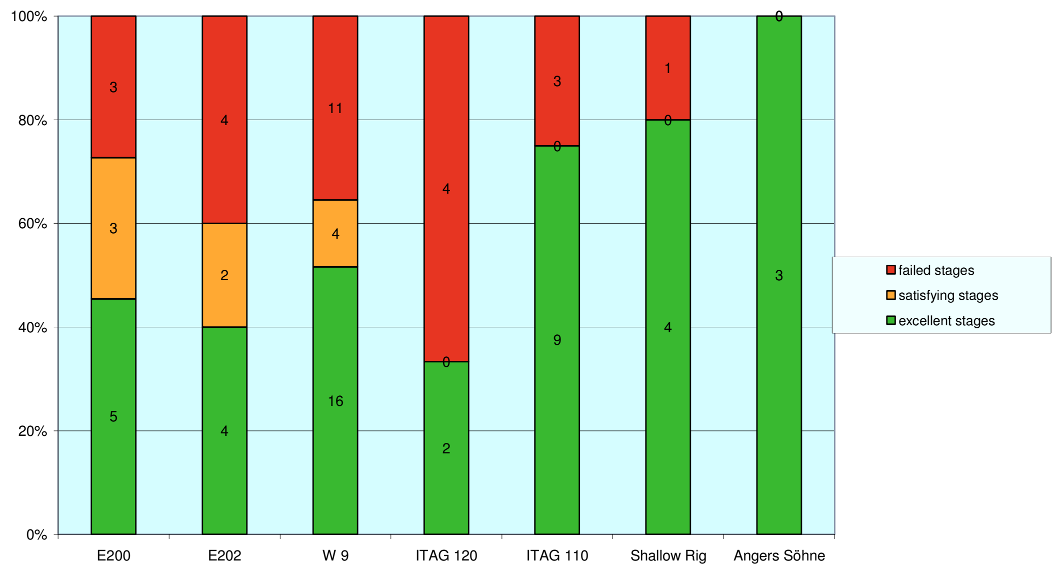

Figure 3.6 - Plug success (100%) - rig dependent

3.4. Success ratio – chronological

Another general statistic was produced which shows the success rate separated for each year from 2006 until 2011. In Figure 3.7 the untested stages are included and it can be seen that up to 73% of the stages per year have not been tested.

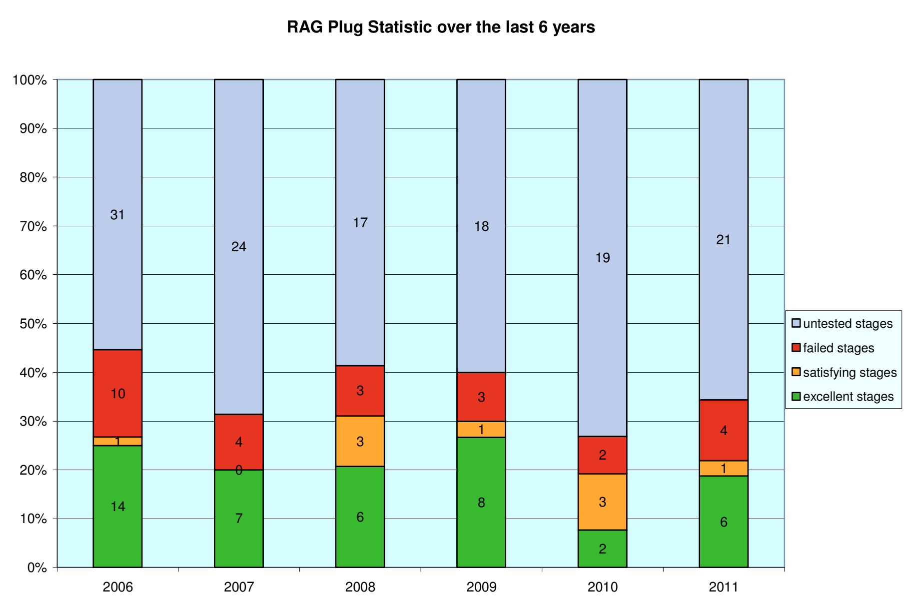

Figure 3.7 - Chronological plug success

To have a clearer indication of the success rate, the untested stages are not included in Figure 3.8. Again the statistics shows no clear trend of improvement or aggravation of the plug success over the years.

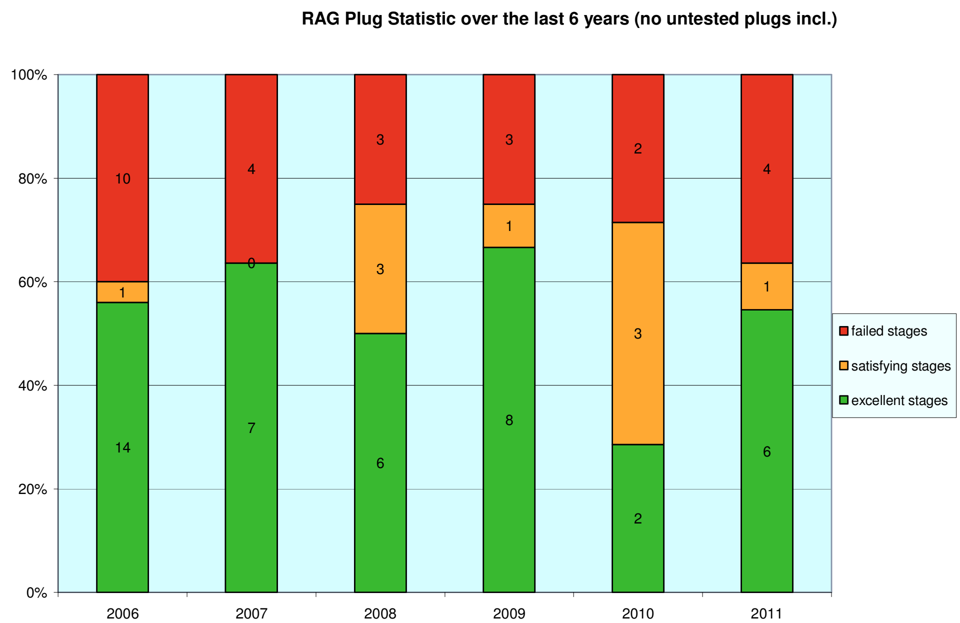

Figure 3.8 - Chronological plug success - untested stages not included

4. Critical parameter

Subsequently the general case study, which indicates how many cement plug jobs were satisfying and how many did not bring the desired result, it is the goal to identify a probable trend for critical parameters that could influence the result of a cement job. During the research, for parameters that could have an influence, two big groups of parameters were identified. Firstly the group of parameters that could have an influence on the plug and can't be changed, such as formation geology, or inclination of the wellbore and the group of operational parameters that could be changed such as pulling speed or pumped volume.

4.1. Un-changeable parameters

4.1.1 Inclination

The inclination of a wellbore can have a big influence on the plug success. The higher the borehole is inclined the higher is the chance of a problem during the placement[1, 2]. The cause of an unstable interface between the fluids is the higher specific gravity of the cement slurry in comparison with the mud or high viscous pill that is placed as a base for the cement plug. Figure 4.1 shows how the cement slurry behaves when placed on a viscous pill in a high inclined well. The cement slurry has the tendency to slump under the viscous pill and reduces the effective length of the cement plug. This scenario could be even worse when the cement starts to interchange with the viscous pill and flows completely under the original planned base of the plug. This is known as Boycott Effect[12].

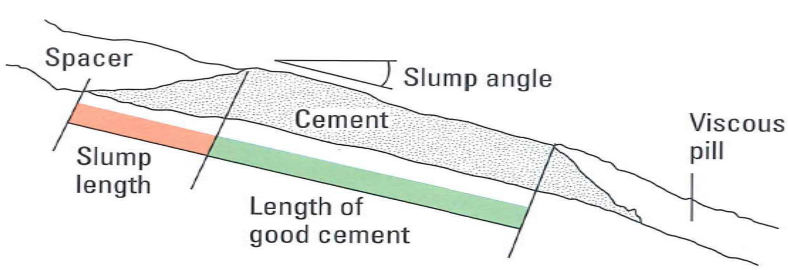

Figure 4.1 - Cement Slurry flow in an inclined well[2]

To generate a proper statistic four groups with different inclination angles intervals were set up. The first indication that can be seen in Figure 4.2 is that more than 50% of the tested plugs were set at an inclination between 0 ° and 15 °.

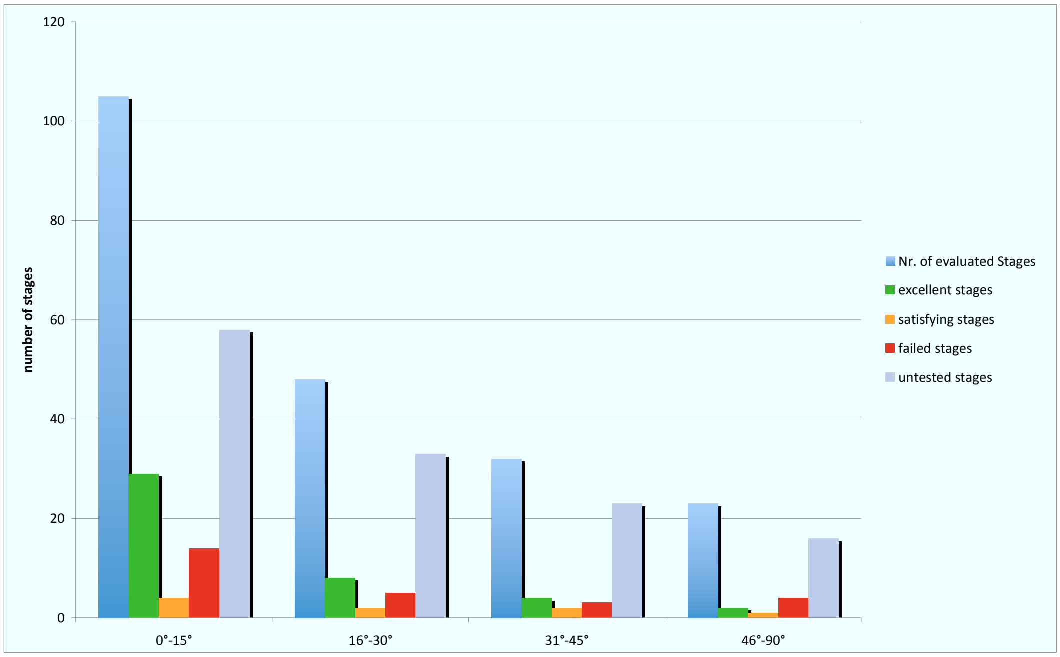

Figure 4.2 Plug success ratio - inclination depended

In order to create a clearer indication Figure 4.3 was generated. It is shown that with higher inclination the number of successful plugs decreases. This proves the theory that highly inclined wellbores are harder to plug than vertical wells.

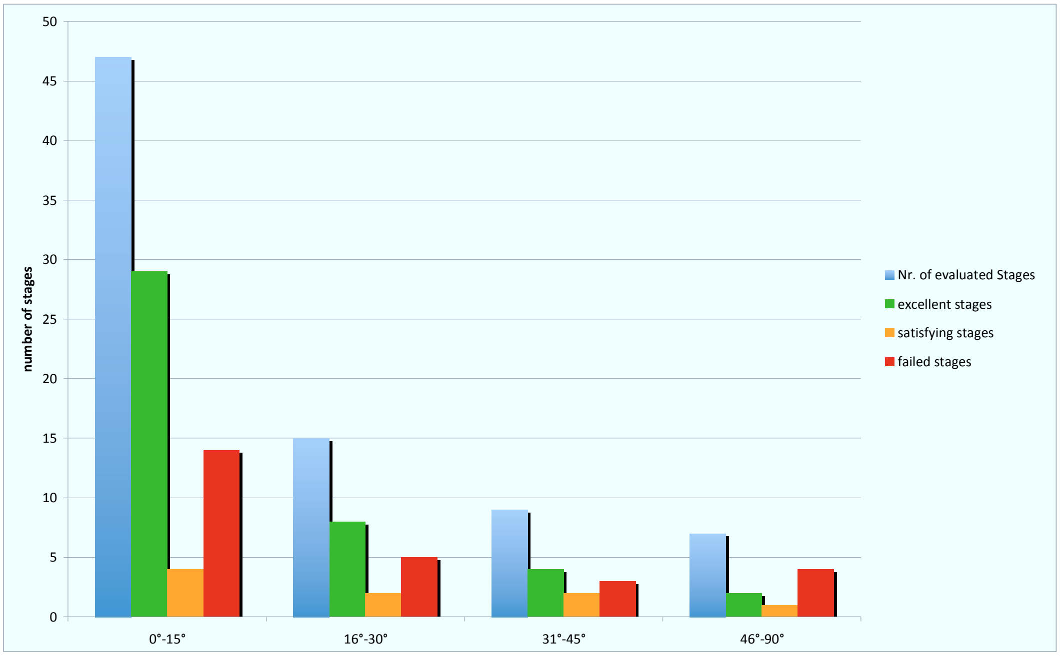

Figure 4.3 - Plug success - inclination depended (untested stages not included)

4.1.2 Geology

In context with this thesis the geology as an influence parameter on the plug result was investigated. Together with the geology department of RAG the completion logs of the wells, where a plug have been set were observed. For all depth intervals where plugs were set the parameters were gathered.

4.1.2.1 Permeable layer

It was investigated how thick the layers were and what kind of formation fluid they contain. The analysed formation fluids are discussed in Chapter 4.1.2.4.

4.1.2.2 Lithology

This was the first step to get an idea about the rock that is encountered in the area where the plugs were set. Most of the time there was sandstone, marl clay and conglomerate in place[13].

4.1.2.3 Porosity

According to the layers and the knowledge about the rock it was possible to identify the porosity. The porosity range was between 10 and 22%[13].

4.1.2.4 Formation water

As a parameter of the formation water the salinity was observed. It ranges from 15,000 to 25,000 ppm and was considered as not being a problem for the cement. Another parameter was the pH value, which is around 7 (e.g. Eozän 7.15)[13].

4.1.2.5 Literature research – influence of geology

A literature research on minerals that influence the cement was done. It seems that until now there is no big interest in that topic. Schlumberger did a few internal tests for certain formations where they had concerns that the produced cuttings may have an influence. These tests show that there is no influence at all and supports the assumption that the formation material has no big influence on the cement.

The standard "Betonaggresivität nach DIN 4030" describes how the ground water reacts with the concrete. It describes different materials that could be dissolved in the water and could lead to corrosion of the concrete. The observed materials are listed in Table 4.1. Each of those has a specified range and are subdivided in three classes.

- "schwach angreifend" – not very aggressive just small reaction with the concrete
- "stark angreifend" – aggressive and reaction with the concrete
- "sehr stark angreifened" – very aggressive and has a high impact on concrete.

Betonaggressivität von Wässern nach DIN 4030

Untersuchungsparameter	schwach angreifend	stark angreifend	sehr stark angreifend
pH-Wert	6,5–5,5	5,5–4,5	unter 4,5
kalklösende Kohlensäure (CO_2) in mg/l	15–30	30–60	über 60
Ammonium (NH_4) in mg/l	15–30	30–60	über 60
Magnesium (Mg) in mg/l	100–300	300–1500	über 1500
Sulfat (SO_4) in mg/l	200–600	600–3000	über 3000

Table 4.1 - Concrete aggressiveness[14]

Based on the statement of RAG's petro physicist these substances are not occurring in a concentration that is relevant[13]. Therefore, the formation water should not have a big influence on the placed cement plugs.

Based on the investigation of those parameter (porosity, permeable layers…) the stages where sorted in three different groups.

- No no influence of the geology
- Possible influence of the geology possible
- Yes geology has an influence

Figure 4.4 shows that in 68 % of the observed plugs are not influenced by the geology. In 22% the geology can have an influence on the plug and 10% of the plugs are influenced by the geology.

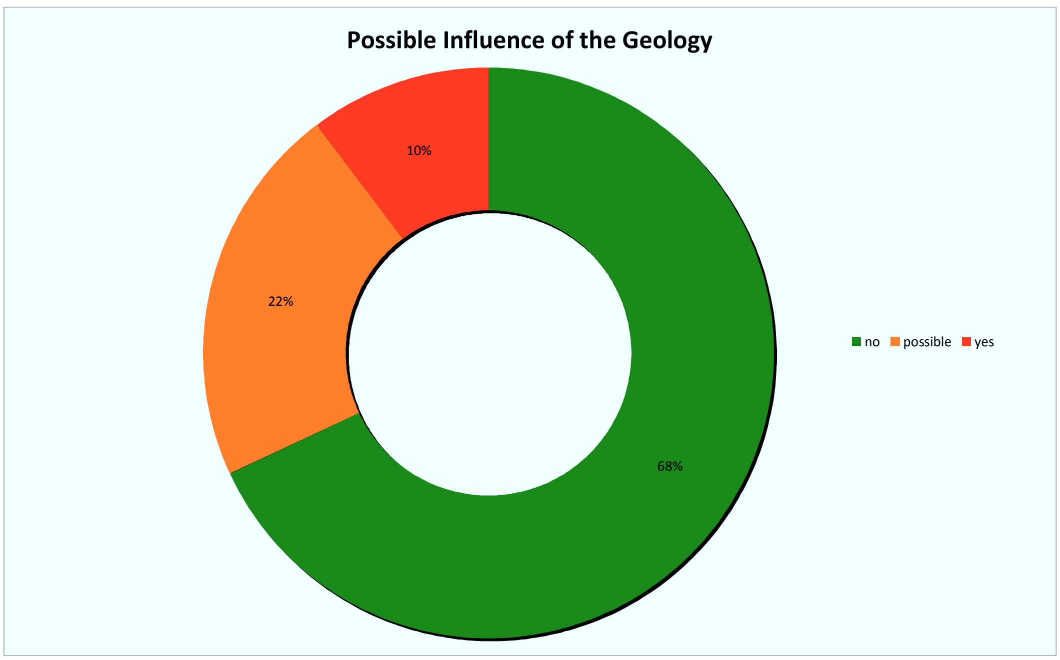

Figure 4.4 - Geology influence

For further investigation, the cases, where the geology might have an influence, are linked with the results of the plugs. Figure 4.5 shows that there is a plug failure of 43% if the geology can have an influence (22% possible + 10% yes). These results show no clear indication if there is a problem with the geology because the plug result is linked to many other parameters. The issue with observing only the 10% where the geology has a definite influx is that only 2 of the 12 plug stages have been tested.

Stated this geology can have an influence, but the number of associated plug failures is minor.

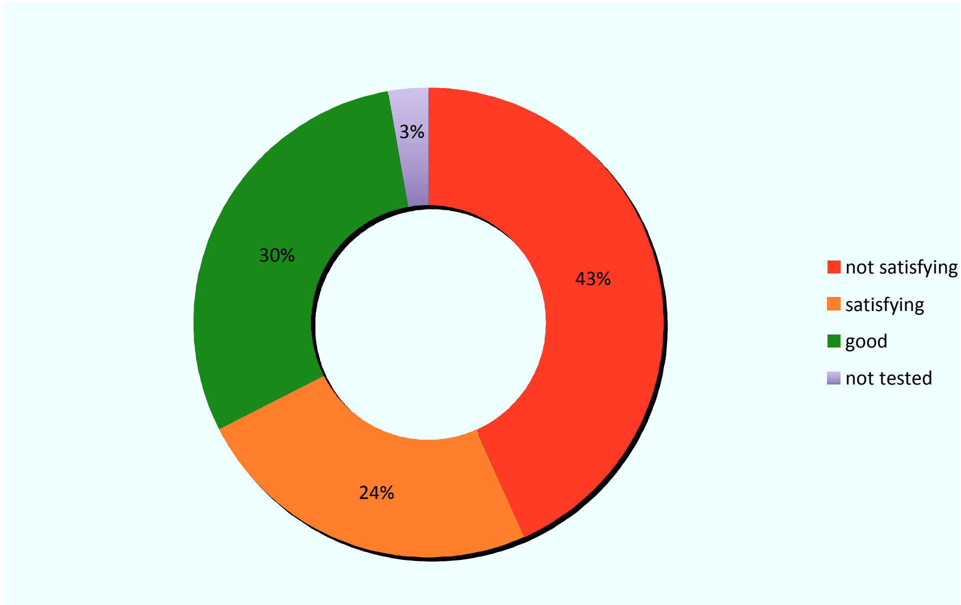

Figure 4.5 - Plug success with possible geology influence

4.2. Changeable parameters

In order to get an idea on the critical operational parameters which have an influence on the placement of plugs, a comparison of the “Best Practices” of RAG, Schlumberger and Halliburton was created. The main parameters were identified and the different recommendations for each parameter are shown in Table 4.2.

Critical Parameters

Topic	RAG	Schlumberger	Halliburton
Plug base	Viscous pill min. 100m in the hole CST tool for inclinations higher 30°	mechanical base or viscous pill or reactive pill or sand plug	hole size <= 12 1/4 CST hole size > 12 1/4 Viscous Reactive pill
Stinger	3 1/2" for 5"DP 2 7/8" for 4"DP	>= 9 5/8Casing ->5"DP + 3 1/2" Stinger 7" Casing -> 3 1/2" DP + 2.75" Stinger	>= 8 1/2" use 3 1/2" stinger < 8 1/2" use 2 7/8" stinger
Stinger length	stinger longer than the plug	1.5 x length of the plug	1.5 x length of the plug
Plug length	min. 100m	152.4m - 274.32m if longer then risk assessment	150m - 180m
Spacer annular fill	after cementing same height in DP and annulus	152.5m - 244m	150m - 300m or 10 min contact
Spacer pump speed			the last 0.8 - 1.6m³ with 160-320l/min
Under displacement	min 500l	Based on the Plug Advisor	800 - 1600l
Rotating Pipe (during cement placement)	15 - 20 rpm	rotate (not specified how fast)	15 - 30 rpm
Pull out of Hole	0.155 m/sec	< 0.15 m/sec especially for inclined wells	0.16 - 0.25 m/sec
Circulation	10m above TOC circulate indirect max. 1000 l/min	30.5m - 46m above expected TOC	no recommendation
Wait on Cement	after WOC test plug with load on op (not defined) or pressure test with liquid	Wait until compressive strength: 5-100psi as base for the next cement plug 5000-7000psi for Kick off Plugs	Wait until compressive strength 500psi 3000 psi for Kick off Plugs
High Viscosity Pill	min. length: 100m	min. length: 92m highest yield and gel strength (barely pumpable) density between mud and cement slurry	

Table 4.2 - Critical Parameters defined

4.2.1 Plug base

The plug base is specified as the fluid, formation or mechanical device where the plug is placed. RAG's best practice recommends either a hard base (bottom of the wellbore or mechanical device) or if a fluid is used a high viscous pill with a minimum length of 100m. In addition to the pill a Cement Support Tool (CST) (discussed in **Fehler! Verweisquelle konnte nicht gefunden werden.**) is recommended. Schlumberger also suggests a mechanical base, a high viscous pill or a reactive pill for the best results (Discussed in 9.2.2). Halliburton recommends nearly the same as the others do but differentiates between different hole sizes. For diameters smaller than 12 ¼ inches a CST is suggested, for bigger diameters a viscous reactive pill should be used. Schlumberger as well as Halliburton do not give any recommendations based on the inclination.

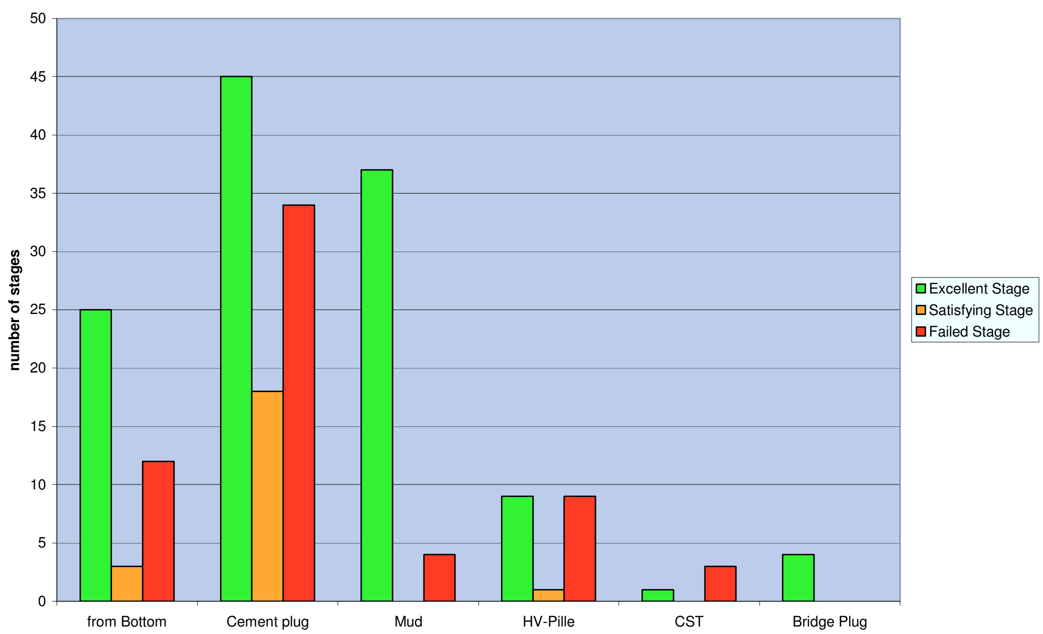

Figure 4.6 - Plug success - base dependent

In Figure 4.6 it is possible to see the result of the plugs depending on their base. The values for this figure assume that the plugs below the tested plug have the same result as the tested one, because the same figure just for tested plugs would not have much sense due to the fact that normally each tested plug has a previous cement plug as base underneath it.

Taking this assumption in consideration the figure has to be read carefully. For example the results for plug failure for plugs placed on the bottom can't be true because there is no better base for a plug than at the bottom of a well. This relatively high number is based on the result of the 3rd plug of the bottom. If the wrong volume is pumped or too much cement slurry is circulated out the TOC could be deeper than planned, which leads to a plug failure. The high number of failures for the high viscosity pill and the CST should not be taken as an argument that these tools are not working properly. Figure 4.6 shows that these options where not used very often. Therefore the handling is not a standard operation and further test runs should be performed to develop a proper learning curve.

4.2.2 Stinger

Every company has quite the same desired stinger diameter. Two different diameters depending on the hole size are recommended. A 2 7/8" stinger in combination with a 4" drill pipe for diameters smaller than 6 1/8" and a 3 1/2 " stinger in combination with a 5" drill pipe for hole sizes bigger than 8 ½".

According to the best practice from RAG the stinger selection has been done properly for wells of the last 3 years. There are a few older jobs where 3 ½" stinger was used in a 6 1/8" hole but there is no clear indication that this would lead to a plug failure.

The second observed parameter for the stinger is the length. RAG recommends a minimum length that the TOC is within the stinger when the cement slurry is pumped. This should avoid that the bigger drill pipe (smaller clearance in the annulus) induces turbulences in the cement and could influence the interface between cement and mud. The standard stinger length of RAG is around 375 meters. Schlumberger and Halliburton recommend a stinger length of 1.5 times the plug length to be on the safe side (cement never reaches the level of the drill pipe). In order to fulfill that requirement, the used standard string with a maximum plug length would be 250 meters. As discussed in the next point, this maximum length is exceeded.

4.2.3 Plug length

Recommendations for the plug length are quite different between the companies. RAG just defines a minimum plug length of 100 meters. Schlumberger is requesting a length between 152.4 and 274.32 meters and Halliburton between 150 and 180 meters. The limit for the minimum length is in place, if a mixing zone occurs that there is still enough cement slurry length to set a proper plug. The maximum length limit is in place to guarantee a safe pull out of the stinger before the cement starts hardening.

As shown in Figure 4.7 the set plugs normally exceed the length limit of Schlumberger. The length limit is based on the worldwide worst-case values for pulling out pipe. An internal audit at RAG proved that the used rigs combined with the crews are capable to POOH (pull out of hole) quicker and therefore a maximum length of 300 meters (in exceptional cases 330 meters) was defined as a safe value[11].

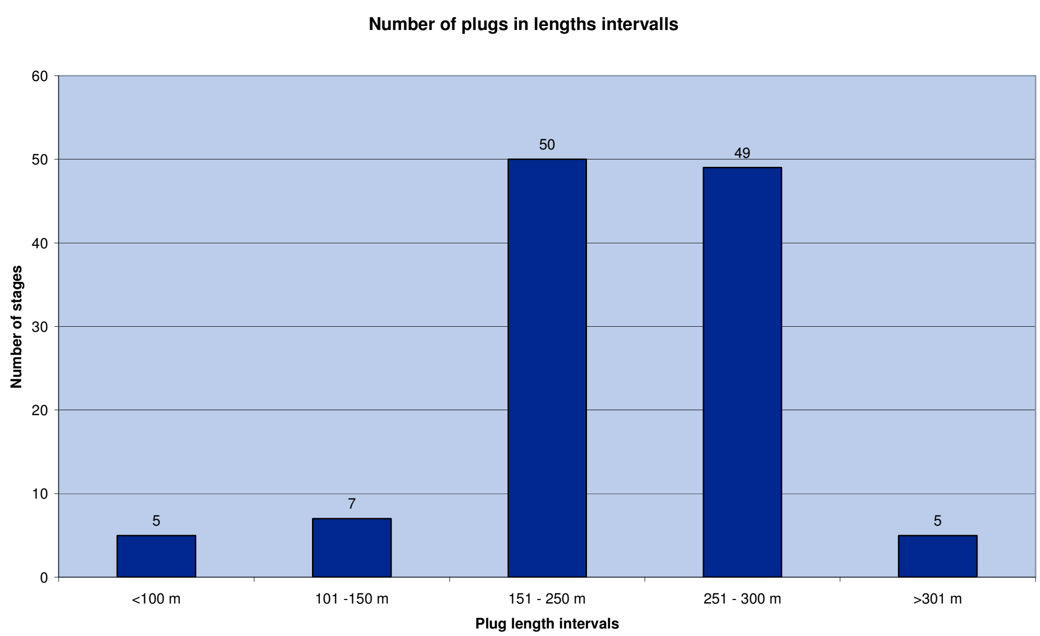

Figure 4.7 - Plug length

The plugs that are below 100 meters are normally longer than 95 meters. These plugs normally reach the surface, therefore these plugs should not be considered as under the limit.

4.2.4 Spacer

4.2.4.1 Spacer annular fill

RAG's recommendation for the spacer says that it should have the same "height" in the annulus and in the drill pipe. SLB and Halliburton define nearly the same height for the annular fill (150 – 300 m). Halliburton even defines a minimum of 10 min contact time to ensure optimal mud removal.

All these values are set for a mud push as spacer. RAG's common way is to use water as a spacer which showed better results in the past. During this thesis a simulation together with Schlumberger was performed to prove this assumption (discussed in Chapter 6.2.2). Therefore the ranges are not really applicable. The only valid requirement is the one from RAG to ensure a hydrostatic equilibrium according to the U-tube effect.

4.2.4.2 Spacer pump speed

The only recommendation for the pump speed is defined by Halliburton. It is only stated that the pump rate should be reduced for the last 0.8 – 1.6 m^3. This is also a good way to ensure that the exact volume is pumped. Although this is not written down in the RAG's best practice it is normally handled that way.

4.2.5 Under displacement

The reason to under displace while circulate the cement slurry in is to avoid a mud flow back and to ensure that the fluids can find a hydrostatic balance. A flow back on the rig floor leads to a trip out operation that is "wet" which slows down the pull out of hole because the crew has to wait until the pulled out stand is free of mud.

Another reason for under displacement is that while pulling out of hole the ratio between annuls and cementing string changes. This is caused by the different pipe diameters used (e.g. 5"DP and 3 ½"Stinger). An example for this difference is shown in Figure 4.8 and Figure 4.9. It is shown that the under displacement brings a better result.

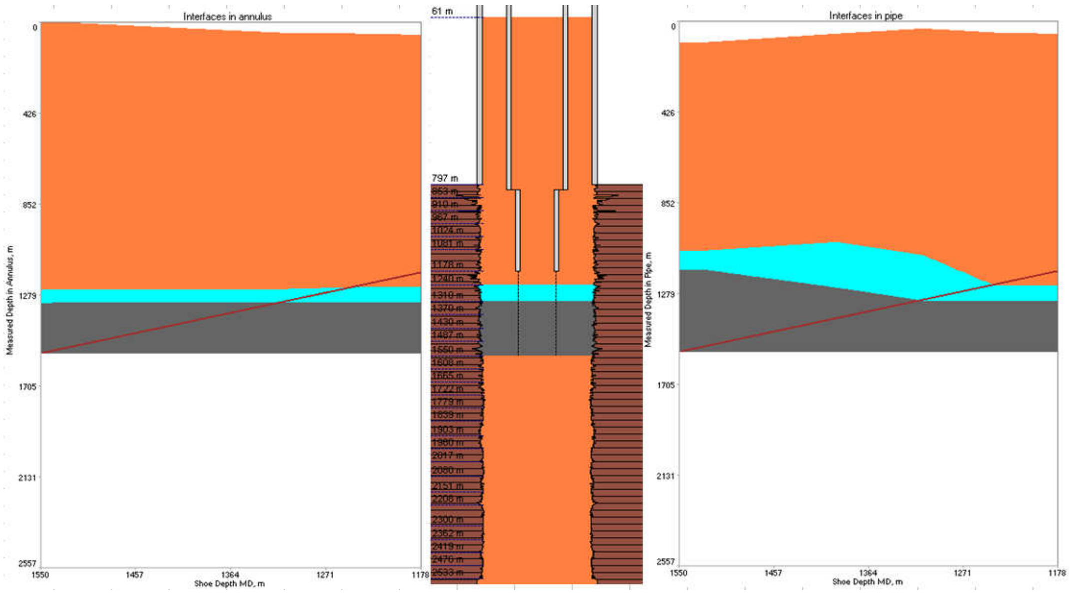

Figure 4.8 - Volumes as suggested from Plug Advisor - underbalanced

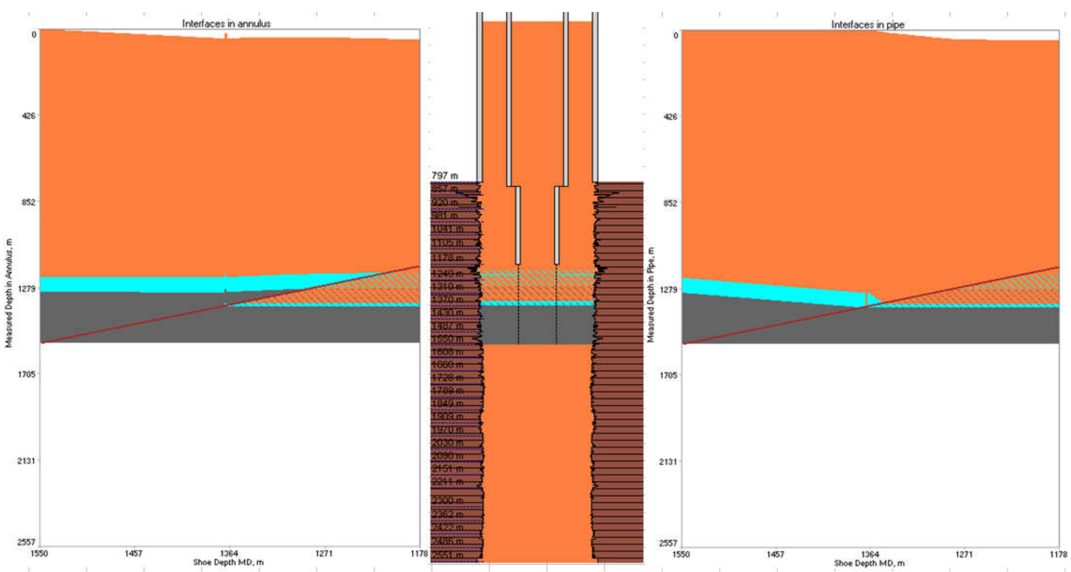

Figure 4.9 - Volumes as calculated for a balanced plug

RAG recommends an under displaced volume of minimum 500 liters or a suggestion of the cementing company. Schlumberger has no limitations for that parameter and takes the values from their Plug Advisor software (discussed in Chapter 6.1.3). Halliburton suggests a significant higher volume (800 – 1600l) than the others.

The simulation result of the Plug Advisor software often suggests an under displacement volume that is smaller than the 500 liters that RAG uses as a minimum.

This could lead to different results, between Schlumberger and RAG, for the mud volume that is pumped after the cement slurry.

4.2.6 Rotating pipe

The reason for rotating the pipe is to improve the displacement of the mud by the cement. All observed best practices agree that a rotation during setting is required. A rotation speed range between 15 -30 rpm is written down in all best practices.

Based on bad experience with rotating the pipe that RAG had in the past, the rotating speed was reduced to 15 -20 rpm[11].

Real time data was required to get the data for the rotation parameters. According to the fact that real time data is only available for the plugs set by the new rigs of RAG, only a fraction of all observed plugs can be analysed.

How the real-time data is generated is discussed in Chapter 5.

When the data is ready it is possible to process the data in MS Excel. Theoretical there would be two possibilities to rotate the string.

4.2.6.1 Rotating the string via the top drive

Rotating the string via the top drive is the common way to rotate the string during drilling. To mange this task the most upper part of the string is connected with the top drive. This connection enables the string to rotate and circulate at the same time without having a Kelly plus Kelly-bushing in place. This saves a lot of time and makes it as well easier to circulate while tripping out if necessary.

It is not ideal using this option to rotate during the cement slurry is pumped. First of all, it is not practicable to install a cement head under the top drive. This option is only used for a liner cementation. In this case a ball has to be dropped to release a plug down hole. The second disadvantage for cementing over the top drive is that it is possible that cement remains in the system and it is difficult to clean out the leftovers.

4.2.6.2 Rotating the string via the rotary table

The rotation of the string, while the cement slurry is pumped, caused by the rotary table is the better option. It is easier to handle the wiper darts at the cementing head.

The separate cement lines make additional cleaning unnecessary. To rotating the string, slips are placed to connect the string with the rotary table. The contact creates huge friction forces that allow rotating the string. The cement head has bearings to ensure that the lower part can be rotated against the upper part. Further more the cement head is held in place to ensure that only the lower part with the string is rotated and not the upper part where the flow lines for the cement are mounted. This is done with the cat line, which runs through the cement head and is then attached to the rig floor.

For the investigation of the plugs the real-time data of the top drive and the rotary table were processed. Two channels are taken into account:

- Rotation [rpm]
- Torque [Nm]

The data for these to channels were plotted. Figure 4.10 is an example of the rotation while pumping the cement slurry (compared with the EOJR of Schlumberger). The rotating before pulling out of hole at stage 5 and stage 6 can be seen. This case shows a rotation of 14.5 rpm at stage 5 and 15.2 rpm at stage 6. Those are optimal values according to the best practices. The change of the torque values is discussed later on in this chapter.

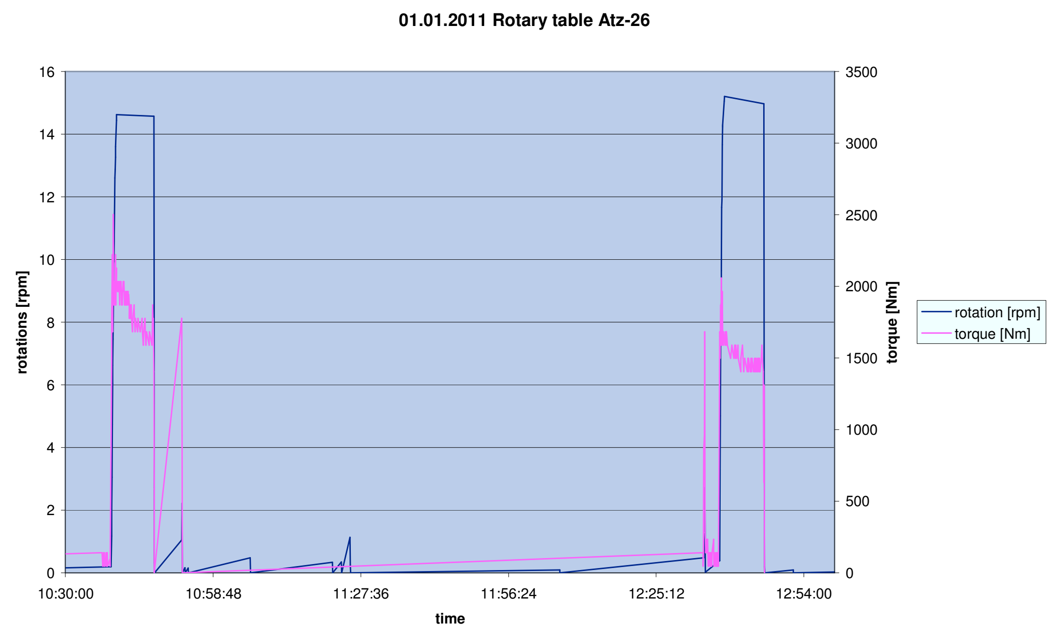

Figure 4.10 - String rotation

The executed analysis shows if the used rpm's meet the described requirements, three categories with different value ranges have initially been set by the author.

- Good (between 15 – 20 rpm)
- Satisfying (between 10 -14 rpm and 21- 30 rpm)
- Not satisfying (under 10 rpm and over 30rpm)

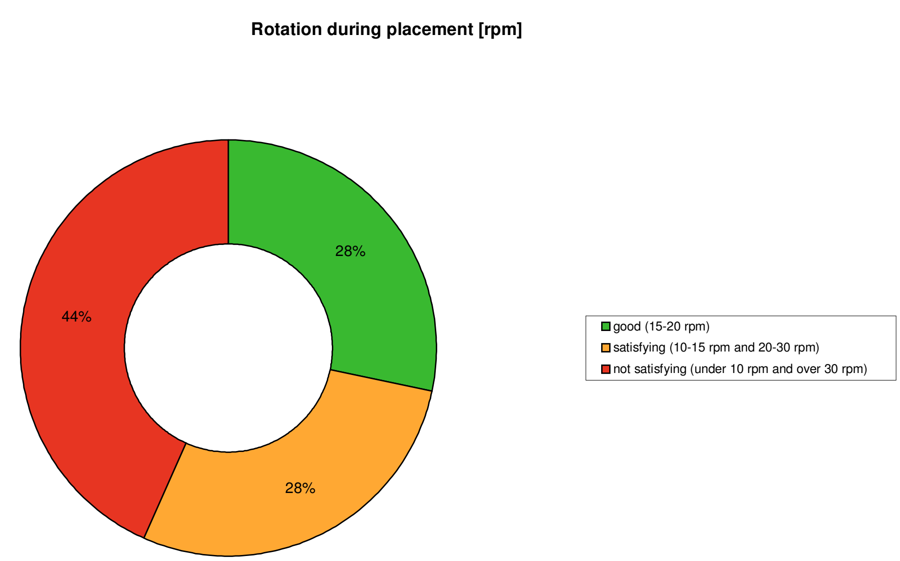

Figure 4.11 - String rotation during placement

The outcome is shown in Figure 4.11. Of the not satisfying category more than 50% of the stages were not rotated at all. For further investigation the categories were compared with the plug results in two different ways, either all stages or only the tested stages. Figure 4.12 shows the results if all stages are considered, tested or assumed with the result from the tested stage above (Note: This is just an assumption and needs to be compared with the values of the statistic that uses only the tested plugs). It is shown that there is a slight indication for a relation between the rotations per minute and the plug result.

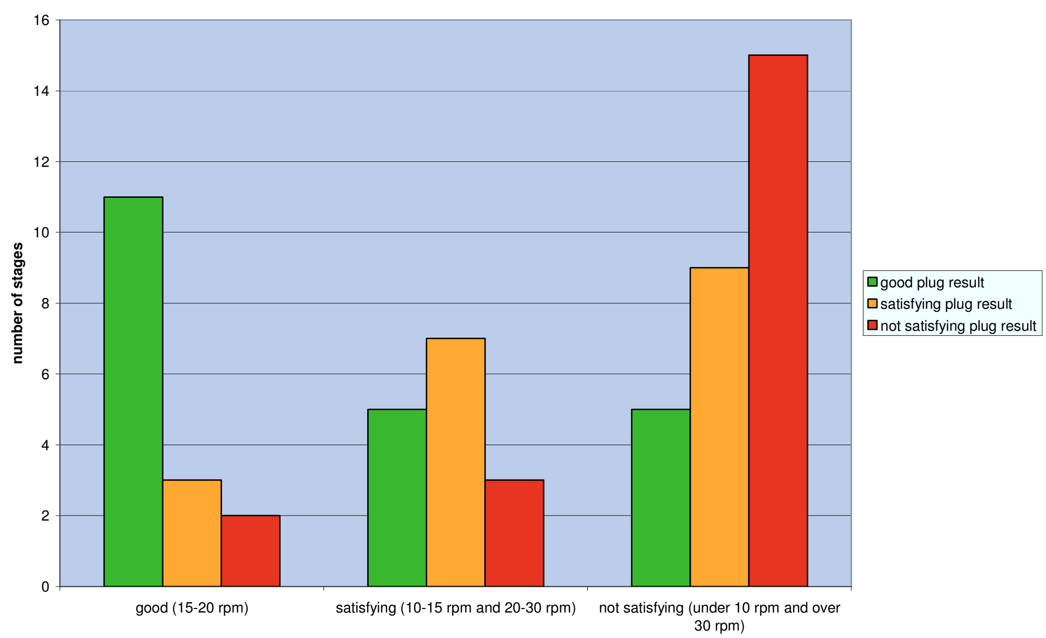

Figure 4.12 - plug success - rotation depended

The same analysis is done in Figure 4.13 but only the tested plugs are taken into consideration. Figure 4.12 shows that there is an indication for relation between rotations per minute and plug success. According to that statistic the rpm could have an effect on plug failure.

The number of plugs that are observed is limited due to the fact that the real time data is only available for 60 stages. Therefore the result is an indication for a trend, but it is not full-scale significant.

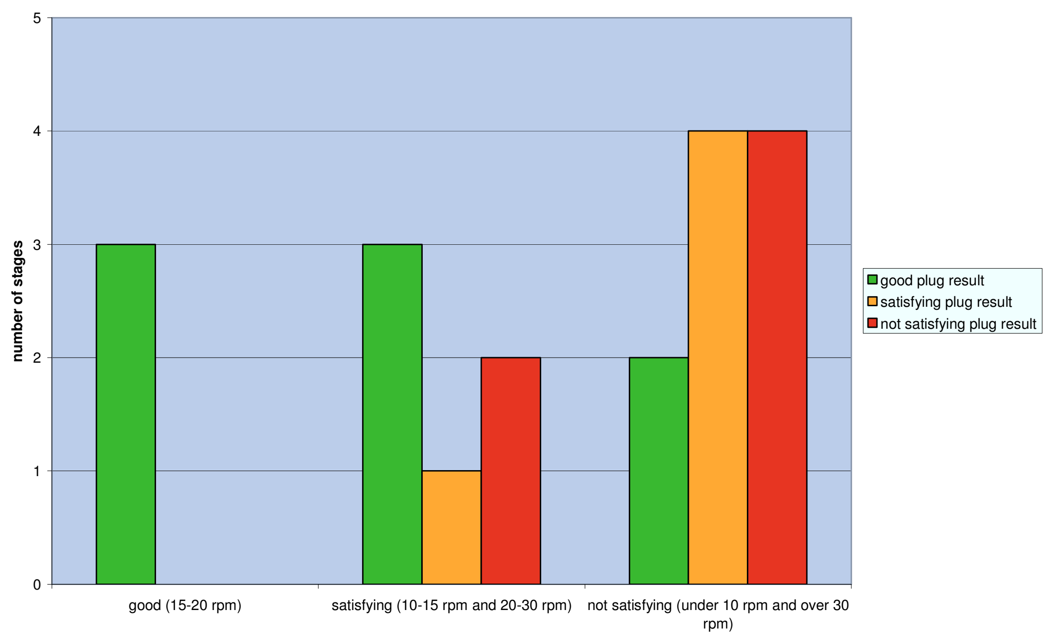

Figure 4.13 - plug success - rotation depended (untested stages not included)

The torque values in this example ranges from 1500 -2500 Nm. So far there are no indication values known from any best practice. The investigation of the torque values show, that there is no similar behavior of the torque values when comparing different plugs. According to the different well paths with different friction environments it gets clear that a comparison is not practicable and will produce no result. Further more the investigation shows that torque values and there difference between start and end values differentiate a lot. In some cases the torque declines with rotation in other cases it is vice versa. No indication between a certain value range and the plug success or plug fail could be found.

4.2.7 Pull out of hole speed

There are different values for the pull out of hole (POOH) speed given in several best practices. In general a rather slow speed of around 0.15 m/sec is suggested. The reason behind is to avoid that the mud or the high viscosity pill that is underneath the cement slurry is not “sucked” in, in order to establish a rather clear interface between the cement slurry and the fluid below. This helps to keep the mixing zone as low as possible.

In the literature no calculations or simulations can be found to prove the given value of 0.15 m/sec. This fact is supported by the statement of the SLB Expert Desk (Gerard D'Accord):

“This value has been here for decades. I am pretty sure there is no demonstration that this is a safe POOH velocity, either theoretical or experimental. I think that, as often, this is a reasonable "common sense" compromise, no more.

This being said, there are a few old engineering results available that could be used to justify this threshold value; in order to properly calculate the impact of the POOH on fluid movement, you would need to know many parameters including the low-shear rate rheology of the fluids and the centralization of the pipe among others. The benefit/cost of such a calculation would be marginal.”[15]

Further investigation could not be taken into account, as the mentioned old engineering results were not available.

To investigate this operational parameter it was again necessary to get the real-time data and process it. To create a chart, two parameters were plotted:

- POOH speed [m/sec]
- Block movement [m]

Figure 4.14 shows a complete interval from the stinger being in place until it is pulled out to the upper end of the plug. After that the reverse circulation starts.

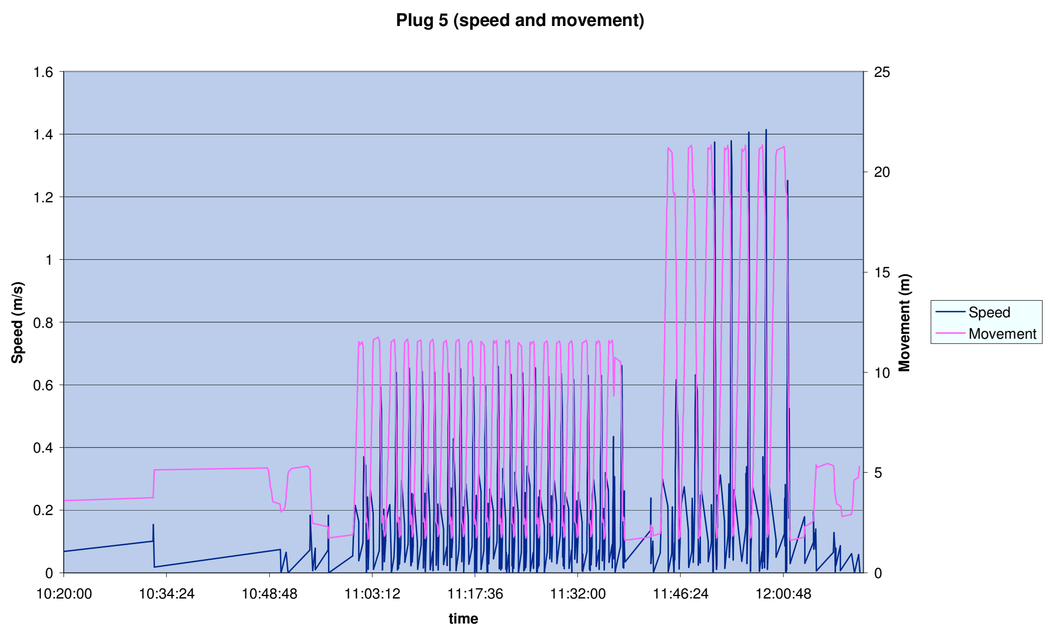

Figure 4.14 - Pulling speed and block movement

To investigate the POOH speed a detailed plot of the POOH section is created to look at the first three stands in detail. This analysis is done because they have the biggest influence on a possible "suction" that leads to a mixing of the fluids. Two values have been recorded during the investigation. The highest speed (highest peak), that occurs during the first three stands, and the average speed of the stand where the highest speed happens have been observed.

The real time data is not recorded in a fixed time interval. It is recorded if a certain change of the recorded parameter occurs. Therefore the time interval was split into 1 second steps. The time stamps that had no direct values were allocated with the value of the last time stamp that had a value until there is a time stamp that had a recorded value.

To visualise the results of this investigation the author initially categorised the average speed in three categories:

- Good (under or equal 0.15 m/s)
- Satisfying (between 0.16 and 0.2 m/s)
- Not satisfying (over 0.21 m/s)

As shown in Figure 4.15 in more than 50% of the observed stages the average speed was higher than the stated limit in the best practice.

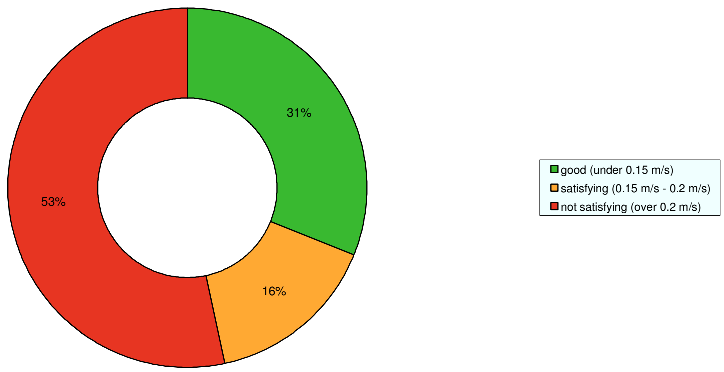

Figure 4.15 - Pull out of hole average speed

Further on the values of the different categories were compared with the plug result in two different ways, either all stages or the tested stages only. Figure 4.16 shows three categories linked with the results of the tested plugs (assumed the result from the tested stage above) (Note: This is just an assumption and needs to be compared with the values of the statistic that uses only the tested plugs). It is shown that there is a trend that a speed between 0.15 – 0.2 m/sec would bring the best results.

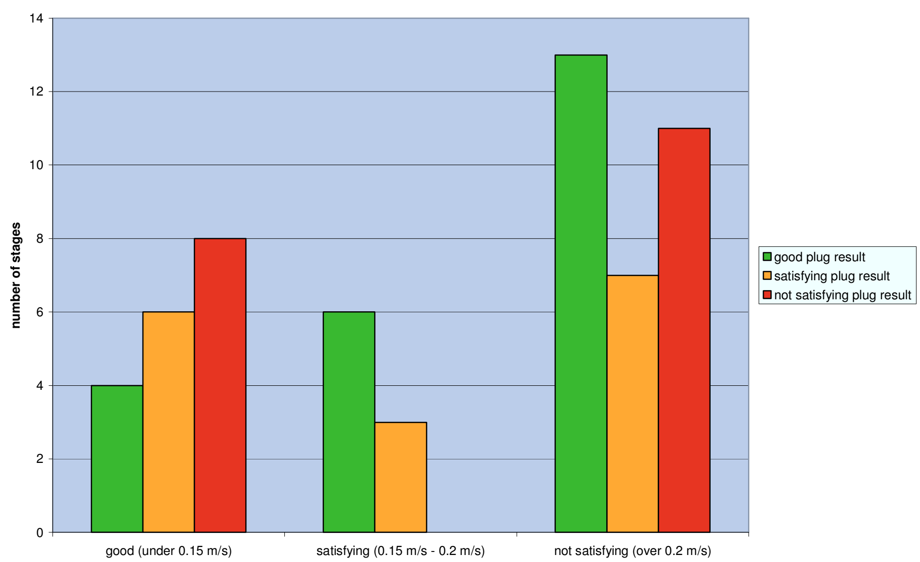

Figure 4.16 - Plug success - POOH depended

The same analysis is done in Figure 4.17 but only the tested stages are taken into consideration. As in Figure 4.16 there is an indication for a trend.

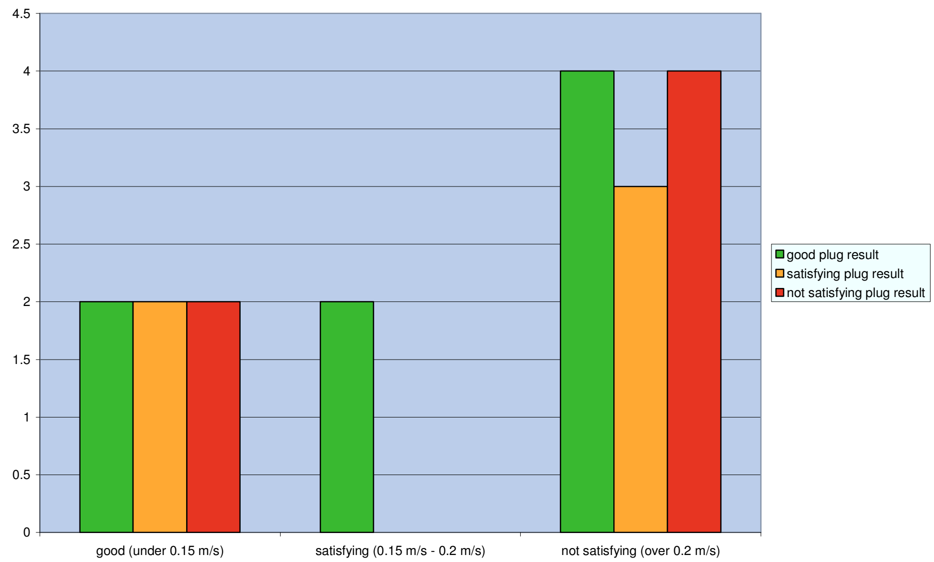

Figure 4.17 - Plug success - POOH depended (only tested stages)

The issue with the statistic is that the number of observed plugs is limited due to the fact that the real time data is only available for 60 stages. Therefore the result is an indication for a trend, but it is not full-scale significant.

4.2.8 Circulation

After the cement slurry and the spacer have been pumped, a calculated volume of mud is pumped to generate a proper “u-tube” effect and fulfill the under displacement requirements. Following, the stinger is pulled out and the circulation starts.

The best practices recommend an indirect circulation. If there is cement slurry or spacer circulated out it is better to have minor contact to the formation. Therefore it is better to circulate from the annulus into the string.

Halliburton’s recommendation refers to clean the cement string and not the circulation process.

RAG's limits are a 10 m gap between the TOC and the end of the stinger. Schlumberger suggests a 30.5 m to 46 m gap for the indirect circulation. Those values are not proven by any calculation. As well as for the pull out of hole speed (Chapter 4.2.7) those values are based on experience that is generated over the years. The higher values of Schlumberger include additional safety margins. RAG is the only one that sets a maximum pump rate of 1000 l/min. These limits were set according to the pumps that were used.

4.2.9 Wait on cement

RAG's has no recommendation for the waiting time. The only requirement is that the plug is tested either by putting load on the top of cement (not defined – in general 3 to 8 tons) or apply a pressure test with liquid and observe the pressure changes (not defined – in general 20 to 40 bars). This is normally done after 3 stages were placed.

Schlumberger and Halliburton advise limits for the compressive strength that are related to the waiting time. The limits for compressive strength as a base for the next plug are 5 – 100 psi regarding to Schlumberger and 500 psi to Halliburton. In case a kick off plug is planned Schlumberger requires 5000 -7000 psi and Halliburton sets a limit of 3000 psi for the compressive strength. These values were tested in the laboratory. Such tests were performed, to get information about the time the cement slurry needs to develop the required strength (discussed in Chapter 7.2.5).

4.2.10 High viscosity pill

All three best practices agree on the requirement of a high viscosity pill in certain environments. This is discussed in Chapter 4.2.1. RAG suggests also a minimum length of 100 m similar to Schlumberger's 92 m. Schlumberger describes the parameters of the high viscosity pill as follows:

The high viscosity pill should have the highest possible yield and gel strength that is barely pump able. The density of the pill should be between the densities of mud and cement slurry enabling a cementation hierarchy.

5. Getting the real time data

After defining the time intervals when the plugs were set, the next step was to define the channels that are necessary for the observed parameter. The time interval was set either by data gathered from the Drilling Monitoring System (DMS) of RAG or if available from the end of job (EOJ) report from the cementing company which is time wise more accurate than the data from the DMS. The reason behind that is that in the DMS the work is scheduled in hours (sometimes half an hour) and summarizes three single cement stages to one operation. This makes it relatively hard to define the different operations (pull out of hole, rotations) and the exact time. For example: Is the string rotated during movement or just while the cement is pumped?

5.1. Real-time data generation

Nowadays every new rig that is manufactured is equipped with sensors to monitor and control the operations that are going on. Figure 5.1 shows a schematic of the rigs bus and sensor system. The sensors are indicated at the bottom (top drive, draw works…) that generate the real-time data. Over the bus system the data are delivered to the process server. The process server saves the generated data and displays it. The driller's cabin is connected to the process server and the driller is capable to operate the rig. The network is protected by a firewall because it is connected to RAG's internal network in order to allow the engineers in charge to have a look at the operations that are going on.

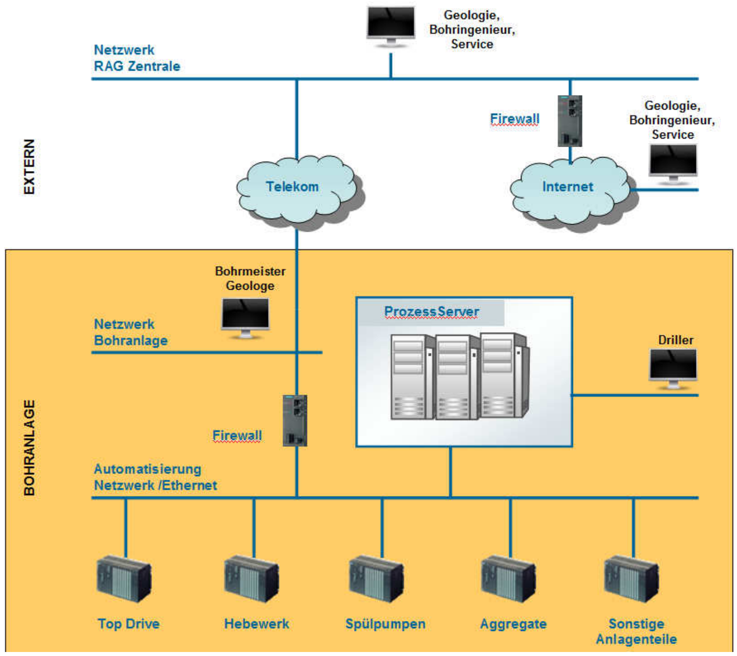

Figure 5.1 - Schematic sketch of the network[16]

5.1.1 Sensors

The generated data of the sensors is not saved on a fixed time interval. The sensors provide the server with continuous data these are only saved if there is a significant change (pre-defined with a certain value depending on the signal measured e.g. Block speed is saved if there is a change of 0.01 m/s) of the value.

The real-time data used for this thesis, plus the sensors that are used to measure them, are listed below.

- Block Speed: two redundant rotary pulse generators are mounted on the main shaft of the draw work and measure the position of the drum and calculate the speed
- Block Position: is calculated from the block speed sensors
- Rotations of the rotary table: a rotary pulse generator uses the same measurement principle as the block speed
- Torque of the rotary table: an electronic frequency converter calculates the actual value over the current power consumption

- Rotations of the top drive: a rotary pulse generator uses the same measurement principle as the block speed (sensor is an integral part of the top drive)
- Torque of the top drive: an electronic frequency converter calculates the actual value over the current power consumption (sensor is an integral part of the top drive)
- Hook load: on the basis of the dead line anchor a pressure sensor is mounted and measures the pressure from 0 to 100 bars (100 bars equates 618 tons) (Guaranteed accuracy of the sensor is +/- 2 tons).
- Trip tank level: is measured by an ultrasonic distance sensor, with the measured level the volume can be calculated by the known geometry of the tank
- Pumps: in this thesis the interest was, if the pump is running or not. 1is recorded when the pump is running, 0 while the pump is off.

5.2. Process real time data

After receiving the data in comma-separated values (*.csv) format a change with notepad has to be made to get the data in an optimal format to use it in Microsoft Excel.

5.2.1 Microsoft Excel problems

The reason for using Microsoft Excel is that the software is very easy to handle and the nearly every company has a license for it.

A few restrictions of Microsoft Excel are shown here. One of the problems was the limits that Microsoft Excel has. There is the limit of 65,536 rows[17]. This limit is exceeded when a cement job that takes longer than a day. The solution for this situation was to split the data in the *.csv file and create two Excel spread sheets. The second limitation problem is that only 32,000 data points can be displayed in 2D point chart. This limit forces the author to just display one stage of the cement job.

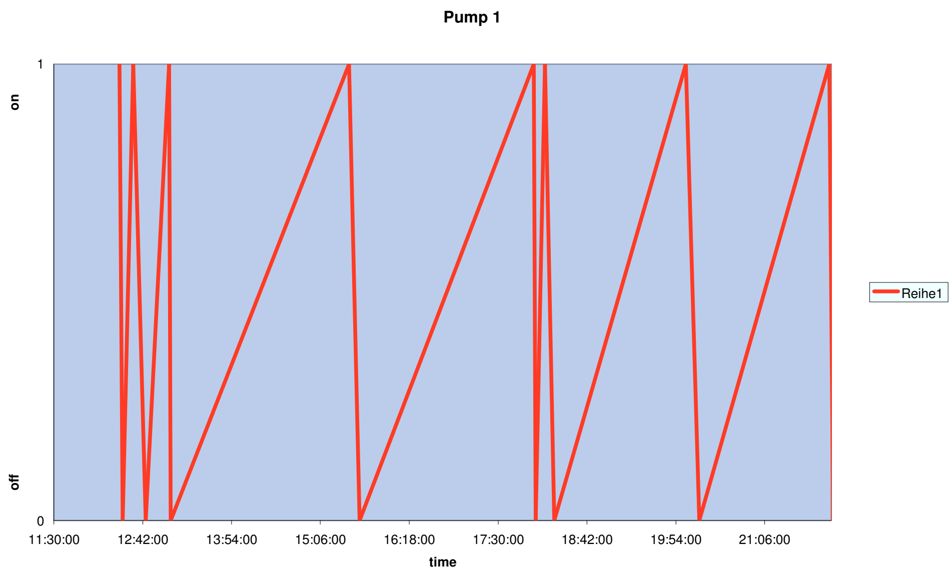

Figure 5.2 - Data output before applying the Macro

Microsoft Excel is only capable to connect data points with a direct line. This was especially inapplicable for the visualisation of the pump operations. If the pump is switched on "1" signal is recorded, if the pump is switched of again "0" is logged. The Figure 5.2 above shows how it was displayed without any further processing. In this plot it is very hard to identify whether the pump is switched on or not. In order to display the data properly a macro was generated that duplicates the values from the previous row and the time stamp from the next row is taken (shown in Figure 5.3).

```
Sub test()
Dim i As Integer

On Error Resume Next

Range("b2").Select
i = CInt(InputBox("Enter number of rows to insert"))
If i <= 0 Then
MsgBox ("Invalid Number Entered")
Exit Sub
End If

Do Until i = "1"

    ActiveCell.EntireRow.Select
    Selection.Insert Shift:=xlDown

    ActiveCell.Offset(1, 1).Select
    ActiveCell.Copy
    ActiveCell.Offset(-1, 0).Select
    ActiveCell.Offset.PasteSpecial
    ActiveCell.Offset(-1, 1).Select
    ActiveCell.Copy
    ActiveCell.Offset(1, 0).Select
    ActiveCell.Offset.PasteSpecial

    ActiveCell.Offset(2, 0).Select
    i = i - 1

Loop

End Sub
```

Figure 5.3 - Macro

Figure 5.4 shows a proper visualization of the data after applying the mentioned macro.

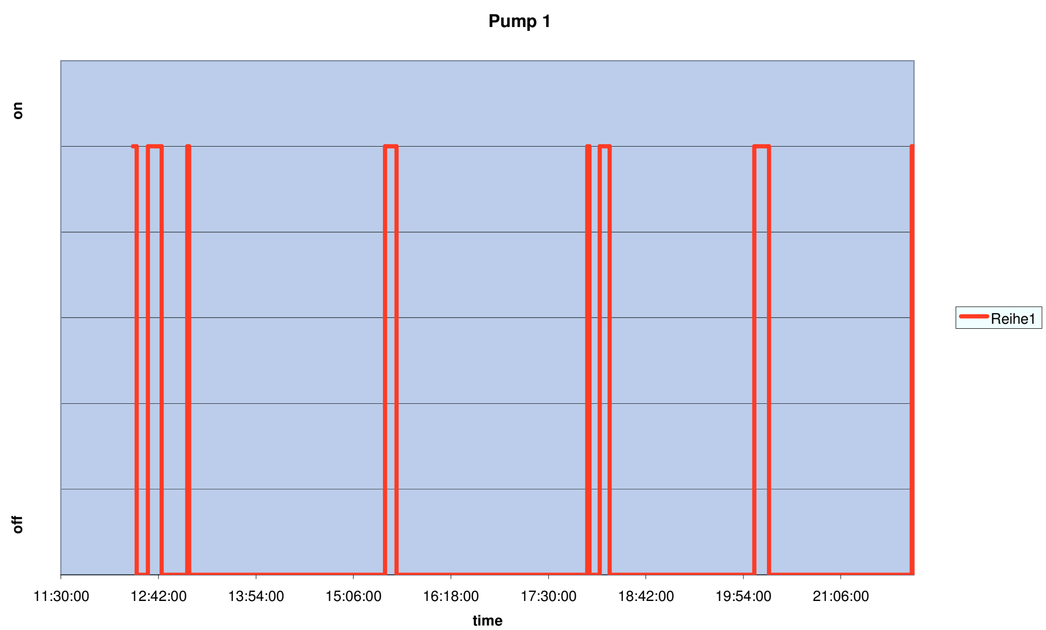

Figure 5.4 - Pump operations after applying the macro

6. Simulation at Schlumberger

6.1. General

In context of this thesis an insight into Schlumberger's planning software in Ampfing, Bavaria, Germany was gained. This chapter shows what the software is capable of. Schlumberger has three software packages, they use there is CemCAT, CemCADE and especially for plugs the Plug Advisor.

6.1.1 CemCAT

This software package is used on the rig site to record all relevant job data. The software is capable to record the real-time data such as pump rate, pressure, flow rate and the density of the pumped fluids. This recorded data allows post evaluating the job and comparing it with the planned parameters.

6.1.2 CemCADE

CemCADE is the biggest software package. It is used for all kind of cement jobs (casing-, plug- and squeeze-cementations). The input for this software is data that is delivered by the operator.

- Plug length (stage intervals)
- Pipe list
- Cement stinger configuration
- Caliber log
- Fluid loss limits
- Layers with gas influence

A reference list with fluids used for previous jobs in the designated area helps to identify a proper fluid (mud push, cement slurry). These fluids are optimised if necessary. The software simulates the complete pump schedule, as well as the wellhead pressure and the annular pressure.

Part of this software package is WELLCLEAN, which is used to simulate the mud removal behind the casing. This add-on will be discussed in Chapter 6.2.2.

6.1.3 Plug Advisor

This software is especially designed to simulate cement plugs. There are two possibilities to generate a plug placement simulation. The first option is to insert the relevant data manually to the software (stinger length, cement slurry volume…). The second and more practicable option is to load the file generated by the CemCADE software. This file includes already all the relevant data because they were already inserted manually.

The software is able to optimise the fluid volume. It is also possible to insert the pumped volumes manually which is necessary for a post evaluation of a plug stage or to simulate individual planned plug stages.

There are two simulations performed by this software, one is the pull out of hole simulation, the other one is the placement simulation that simulates the pumping process.

6.2. Simulations

6.2.1 Plug Advisor simulations

In the past the Plug Advisor software was not used to simulate plugs on a regular basis. The common way was to simulate the cement job with CemCADE and Plug Advisor was only used to create a playback if a job was not satisfying.

For this thesis 70 stages from 17 wells were simulated with the planned values from CemCADE and are compared to the simulation using the real values.

6.2.1.1 Pull out of hole (POOH) simulation

The pull out of hole simulation computes three different values: the length of uncontaminated cement after POOH , the length of contaminated cement after POOH and the uncontaminated static top of cement. During the simulation a discussion with the responsible engineers of Schlumberger brought up the question if the annulus is filled up while the string is pulled out. The following simulation shows that there is a significant change in the plug stability between a POOH with filling up the annulus and a POOH without filling up the annulus. The first simulation was computed with a constant fill up of the annulus. It shows that there is a clear interface between cement, mud and mud push (water).

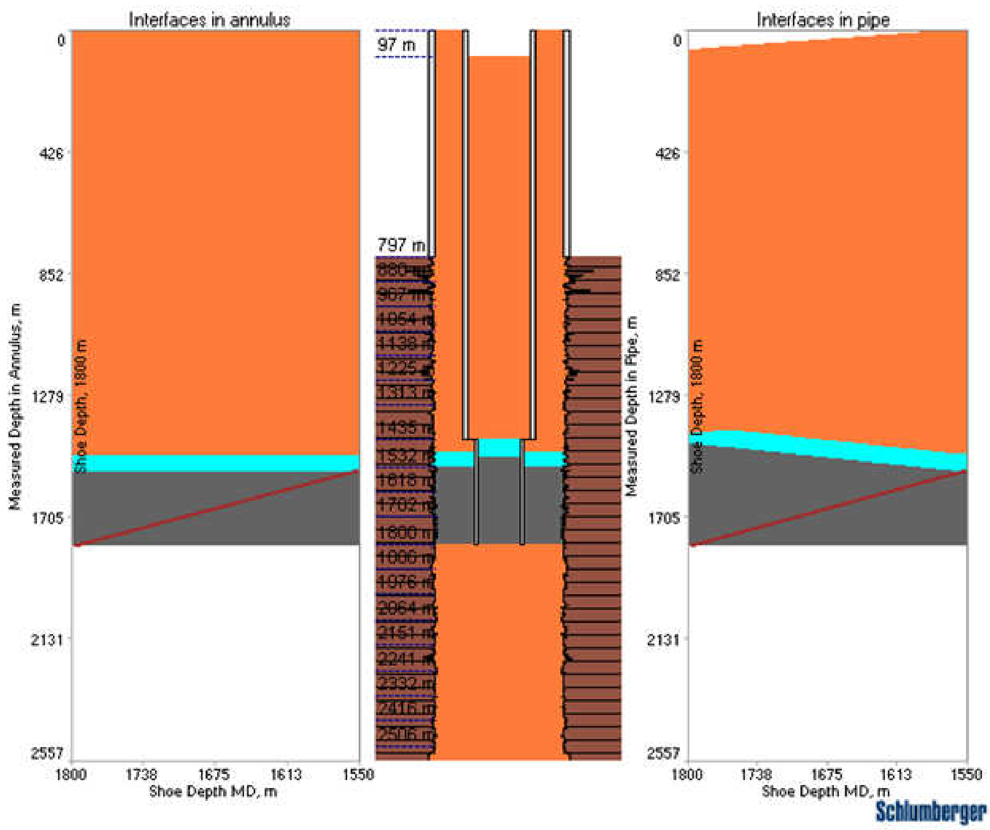

Figure 6.1 - Rag55 plug 4 – annulus filled up

The second simulation for this plug was performed using the same volumes pumped but the annulus was not filled. The result shows a mixture between the fluids. It is shown that there is no clear interface between the fluids.

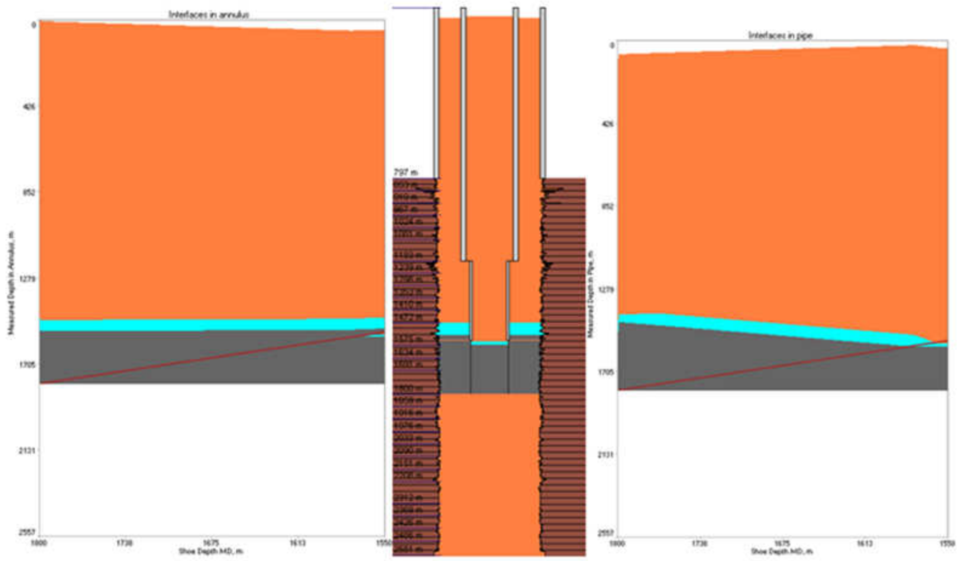

Figure 6.2 - Rag 55 plug 4 - no fill up

In some cases the simulation shows no mud push at the end of the POOH sequence. The reason is that at the end of the POOH the hydrostatic pressure in the annulus is higher than in the cementing string, this forces the mud push and a part of the cement to flow back into the stinger. This phenomenon is seen a few times and is linked to the fact of using water as a mud push. As no mixing zone is generated this should not induce a problem.

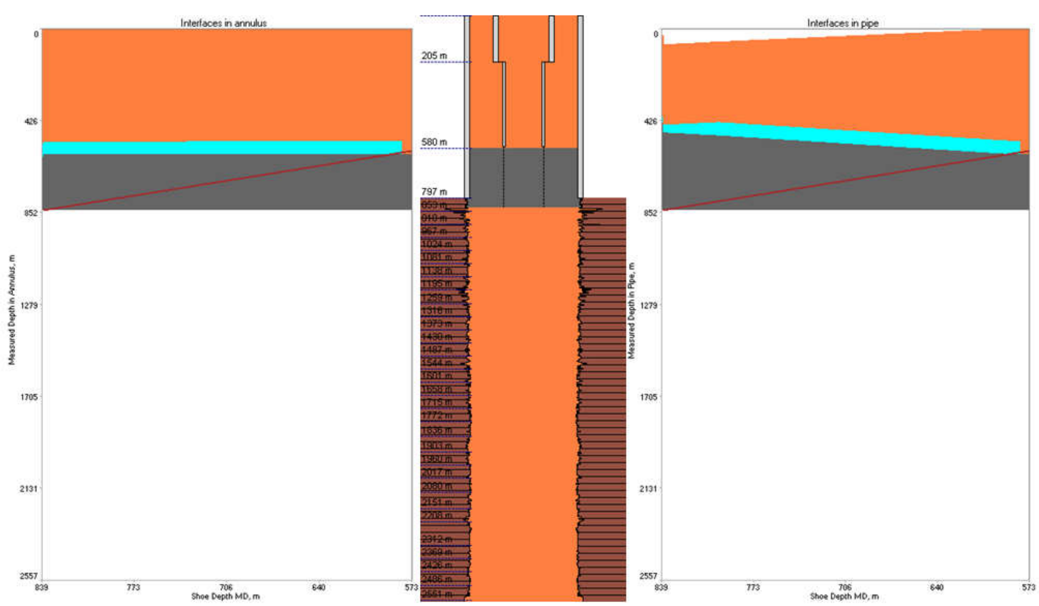

Figure 6.3 - RAG 55 plug 8 - no mud push

Another case that was simulated shows extreme washouts underneath the casing shoe. In this simulation the annulus was not filled up. The circumstances, that the annulus was not filled (rather than planned), combined with the washouts leads, to a plug result that is not satisfying. A mixing between mud and water and between water and cement slurry is induced by the pull out.

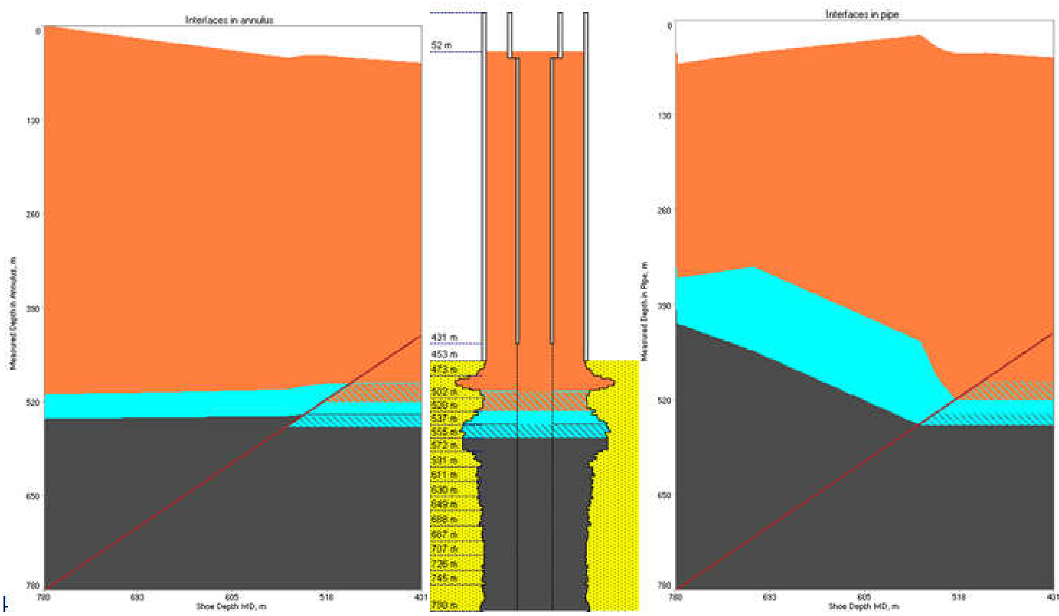

Figure 6.4 - Frido 1 - washout

After running the pull out simulation for the plugs, the value of the uncontaminated top of cement was compared with the planned value from each stage of the cement-program. The author grouped the results into 3 categories

- Excellent +/- 10 meters away from planned top of cement (TOC)
- Satisfying +/- 15-25 meters away from planned top of cement (TOC)
- Not satisfying more than +/- 25 meters away from planned top of cement (TOC)

While simulating it was not clear if the annulus was filled up or not. For that reason each plug was simulated four times.

- With planned values
    - Annulus filled up during POOH
    - Annulus not filled during POOH
- With the real values from the job
    - Annulus filled up during POOH
    - Annulus not filled during POOH

The results of the simulation with an annulus not filled during POOH show that the success rate of the simulation using the planned values is higher than the success rate of the simulation using the actual (e.g. real pumped volume) values.

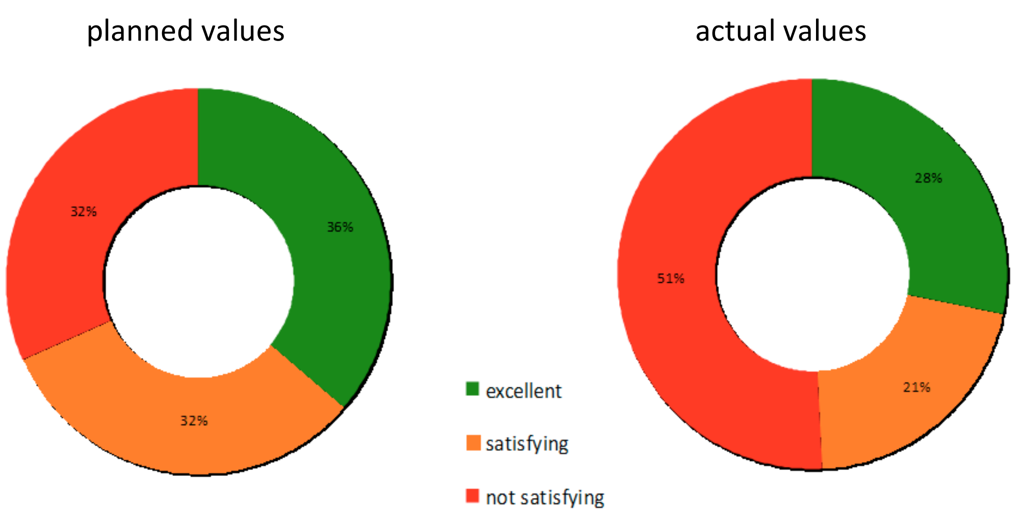

Figure 6.5 - Simulation results - annulus not filled

The results for the plugs that were simulated with an annulus filled during POOH show that the simulation with the planned values has again a higher success rate than the simulation results using the actual values.

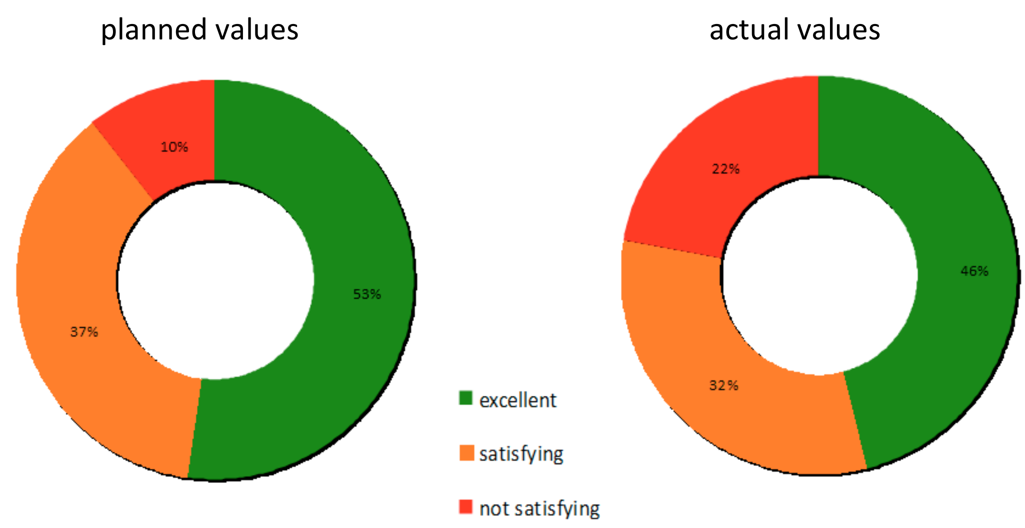

Figure 6.6 - Simulation results - annulus filled

The number of not satisfying results occurring when simulating with the planned values can be linked to a lot of reasons. One reason is that the plugs were planned with an annulus filled but during the operation it was not filled. In some cases there is no big difference between the plugs if the annulus is filled or not. Another problem that was already mentioned is that the use of water as spacer made it sometimes not possible for the program to find a hydrostatic equilibrium. As mentioned before not every plug was simulated with the Plug Advisor software.

Indicating that particular problem during the simulation, the data in the Drilling Monitoring System (DMS) was investigated in order to find out if the annulus was filled up during the POOH or not. No statement or data was found that gives prove. The company man on the rig site stated that the common way is to fill up the hole during the pull out. In order to prove the statement the real time data was analysed.

On the rig there are many ways to fill up the annulus. Four real time parameters were identified to prove if the annulus is filled or not:

- Rig pump 1
- Rig pump 2
- Trip tank volume
- Trip tank pump

After data processing and applying the macro described in Chapter 5.2, the data for rig pump was plotted (shown in Figure 5.4). The data was manually compared with the pull out of hole operations. This observation shows that the pump was not running during the pull out of hole operation.

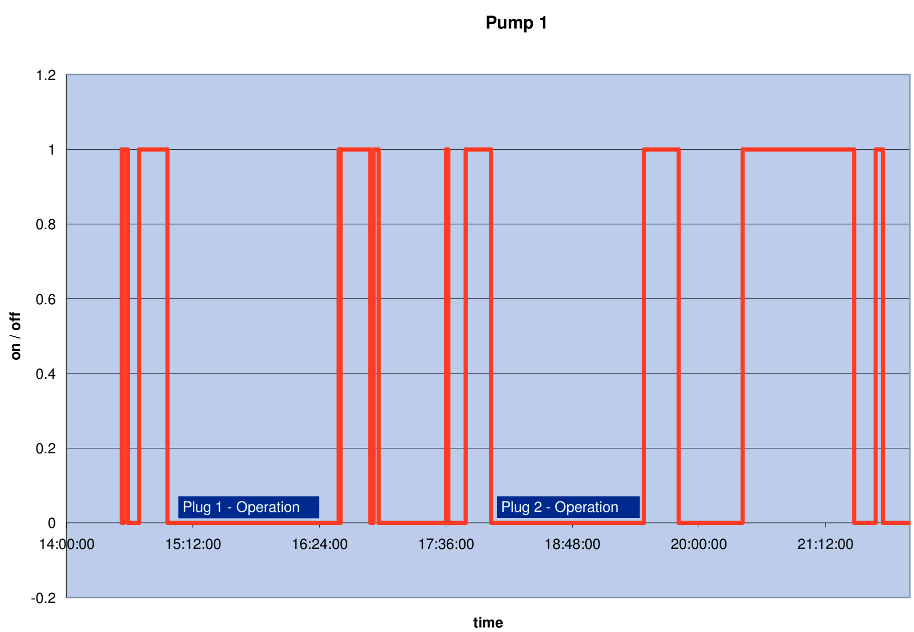

Figure 6.7 - Plug operations plus pump activity

It shows that the pump is running before and after the stinger is pulled out. The reason for running the pump before the pull out starts is to ensure the hydrostatic equilibrium. This pumping is already done by the cementing truck that's why the rig pumps pump the mud over to the tanks of the cementing truck. After the pull out of hole operation, a reverse circulation is done to bring out the spare cement. This circulation is operated by the rig and its pumps.

The next parameter that was observed was the trip tank pump. In every observed operation the trip tank pump was not used. That does not mean that the trip tank is not used because there are other ways to fill up the tank.

The last parameter that was observed was the trip tank volume. This parameter was plotted together with the block movement of the rig to identify the exact volume changes depending on the pipe movement. The example below shows a very small change of the trip tank volume during pull out of hole. The difference between the maximum and the minimum peak are 17 liter. Therefore it seems reasonable that the annulus was not filled up during the stinger was pulled out.

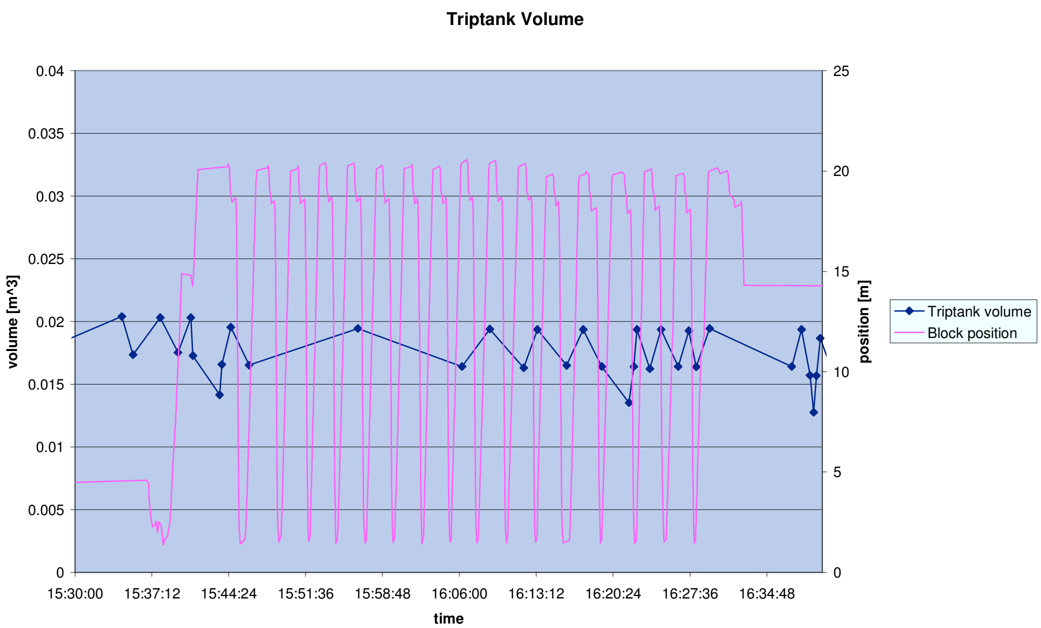

Figure 6.8 - Trip tank volume plus block movement

Another example for the trip tank volume is shown in Figure 6.9. The trip tank volume decreases during the pipe is pulled out of hole. This is an indicator for a filled up annulus during tripping. In this case the indicator is proven to be true because the annulus was filled up during the operation. This was done as a special request of the cementing company and the author as a result of the simulation.

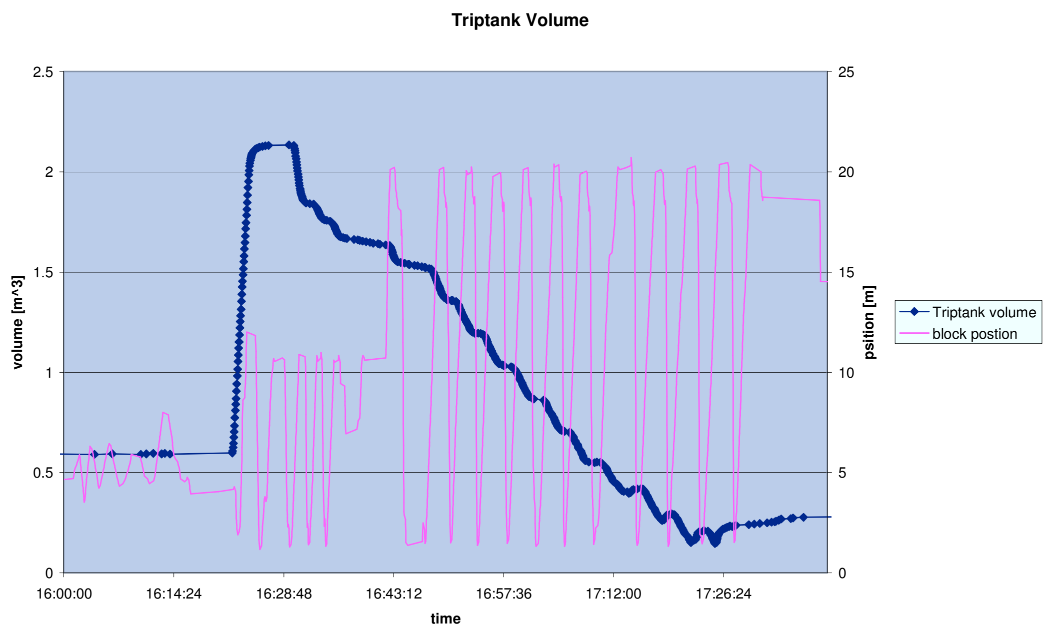

Figure 6.9 – Trip tank volume decreases

Other plots show trip tanks that were filled during the pull out of hole operation, this is also an indication that the annulus was filled up.

6.2.1.2 Placement simulation

The Plug Advisor software is capable to simulate the placement of the fluids during the pumping phase. It simulates the expected length of the mixed zones that can occur in the pipe and in the annulus.

The input mask of the simulation software is shown below. It is possible to simulate a cementing plug (=mechanical barrier) as well as to adjust the pump rate and the pumped volume for each fluid. The first simulation that has to be done before carrying on, is a simulation of the pressure regimes (static and dynamic). This is done to be sure that the pore and fracture limits of the formation are not exceeded. In this case the simulation shows that the placement is easily within all limits. If the result of this simulation would not be satisfying some changes in the program have to be done. This could be a decrease of the stage length or if it is possible a change of the fluid density to reduce the pressure on the formation.

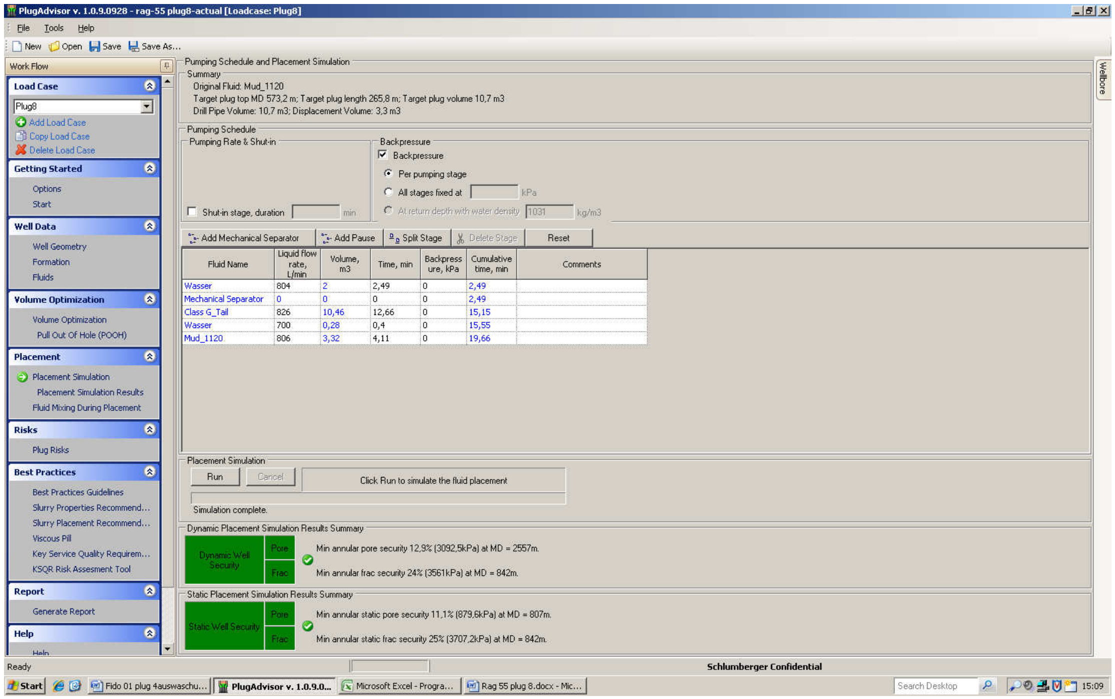

Figure 6.10 - Screen shot of the simulation input

The Plug Advisor software generates different slurry contamination risk values for the inside of the pipe and the annulus for each minute of the pumping stage.

- High risk – high chance for a contamination of the slurry
- Medium risk – medium chance for contamination of the slurry
- Low risk – low chance for contamination of the slurry

In general, the high risk interval should be smaller than the low risk interval. This simulation should give an idea about the contamination that can occur during pumping the slurry down. This placement simulation does only take contaminations into account that are induced while pumping the slurry down. These mixtures as well as the mixtures that are induced while pulling out the cement stinger could influence the hardening time of the cement slurry.

The mixing of the fluids in the pipe can be reduced by using cementing plugs as a barrier between the fluids. This barrier, especially the one before the cement slurry, helps to separate the fluids, but also helps to get the mud out of the pipe before the cement slurry is pumped down.

Besides the contamination risk for each minute of the pumping stage, the placement simulation generates an interval where the top of cement should be at the end of the placement.

The screenshot below shows the simulation after the pumping phase has ended. The two columns on the left side show the mixture in the annulus and the related risk of contamination. The columns on the right side show the mixture and the related risk of contamination for the cement stinger.

The following color coding applies: orange for the mud, blue for the water and grey for the cement slurry - for the mixing zones; green for low risk, yellow for medium risk and red for high risk - for the contamination risk.

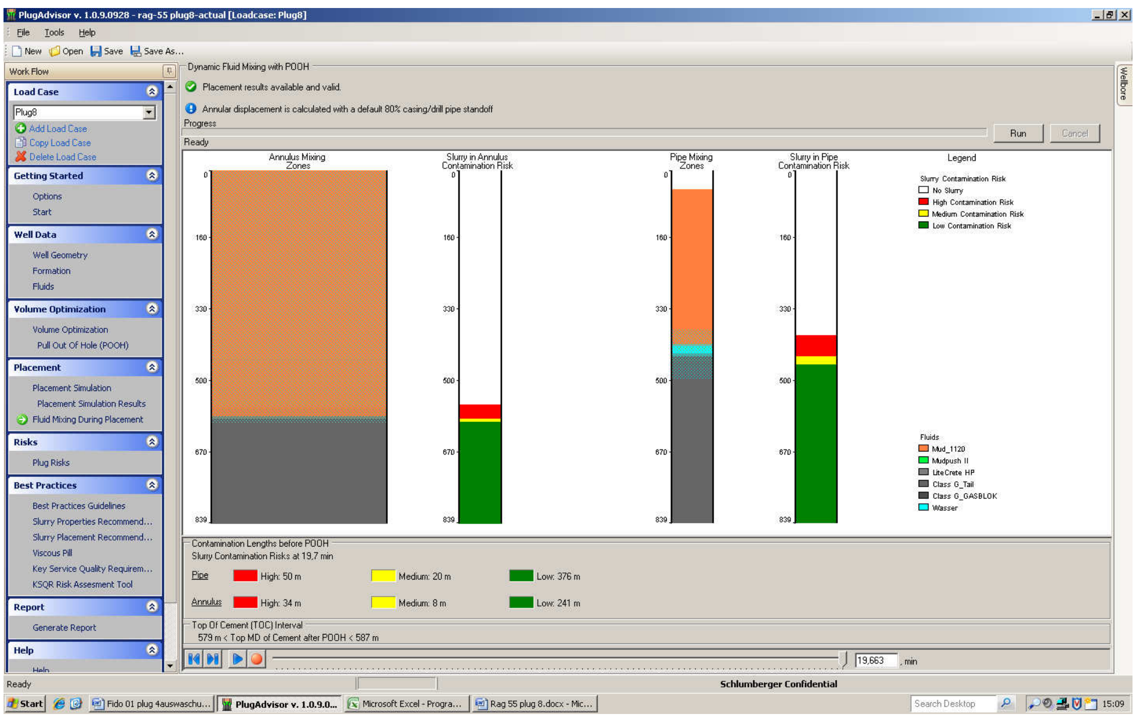

Figure 6.11 - Output of the placement simulation

The simulation was performed with the planned values from the cementing program and with the values that were recorded during the actual job.

Further on the results of the simulation were compared to the planned top of cement of the cementing program. The result of this comparison is shown in the picture below.

The result of the simulation with the planned values and the simulation with the actual values are very similar. The number of simulations were the desired top of cement is not within the interval is higher than the number where the interval and the desired top of cement fits. This statistic result shows that a more careful planning and simulating of the plugs should be induced in the future.

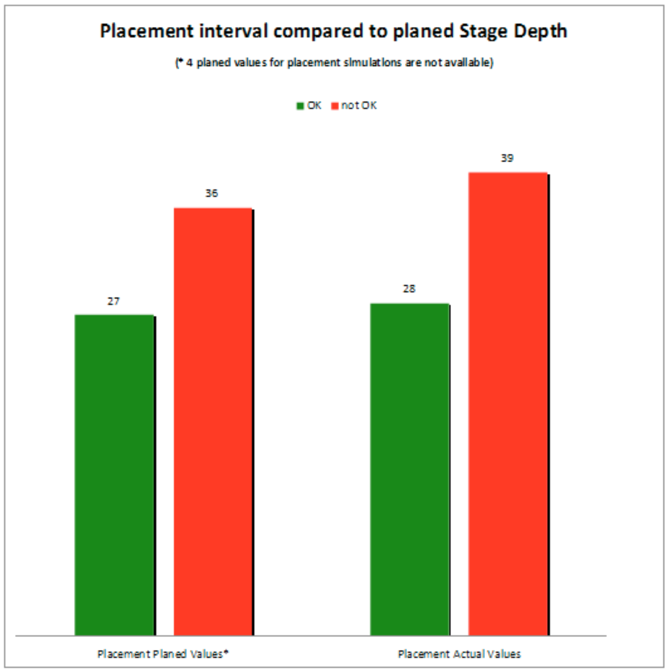

Figure 6.12 - Result of the placement simulation

6.2.1.3 Weakness of simulation

During the simulation that compares water versus mud push as spacer it was found out that the standoff is low due to the fact that there are no centralizers in place and the stinger is small compared to the hole diameter. This low standoff occurs especially in inclined wells. This simulation is discussed in detail in Chapter 6.2.2.

One of the default values in this simulation is an 80% standoff which is proven in the other simulation not to be true. This standard value is not adjustable so the contamination risk and the mixing simulation are not perfect especially for the annulus that is influenced by the standoff. According to that fact it could be questioned if the results are completely wrong or if the results still can be used somehow.

6.2.2 Mud push vs. water simulation

During the literature research for this thesis it turned out that using water as a mud push for plug operation is not the common way. However RAG made good experience with using water as spacer for plug jobs over the last years. In order to confirm the decision that is based on experience, a simulation was performed.

For this simulation the package WELLCLEAN from CemCADE was used. This software package is normally used to simulate the mud removal behind the casing during a normal cement job. Adjustments and assumptions were done to be able to use the software for a cement plug job. The WELLCLEAN package deals with the mud removal. This is related to the fluids used and to the standoff of the casing. For a casing cementation centralizers are used to get a sufficient standoff for a prober mud removal.

When setting a cement plug no centralizers are used on the stinger. If so, it would guarantee a good standoff but while pulling the stinger out the centralizers would induce turbulences and would force a mixture between mud, spacer and cement slurry. Therefore centralizers are not practicable to use on a cementing stinger.

This simulation was performed for a plug set at well RAG 55. The joint length and diameter were inserted as centralizer data to implement a standoff. The result of the standoff simulation is shown below. It shows that the standoff ranges from 10% between the joints to 25% at the joints (marked as centralizers). The standoff is just interesting for the lower part of the string, because the cement stinger is the only part that is in contact with the cement slurry. The result of this simulation shows that the placement simulation with a default standoff of 80% has a weakness (discussed in Chapter 6.2.1.3).

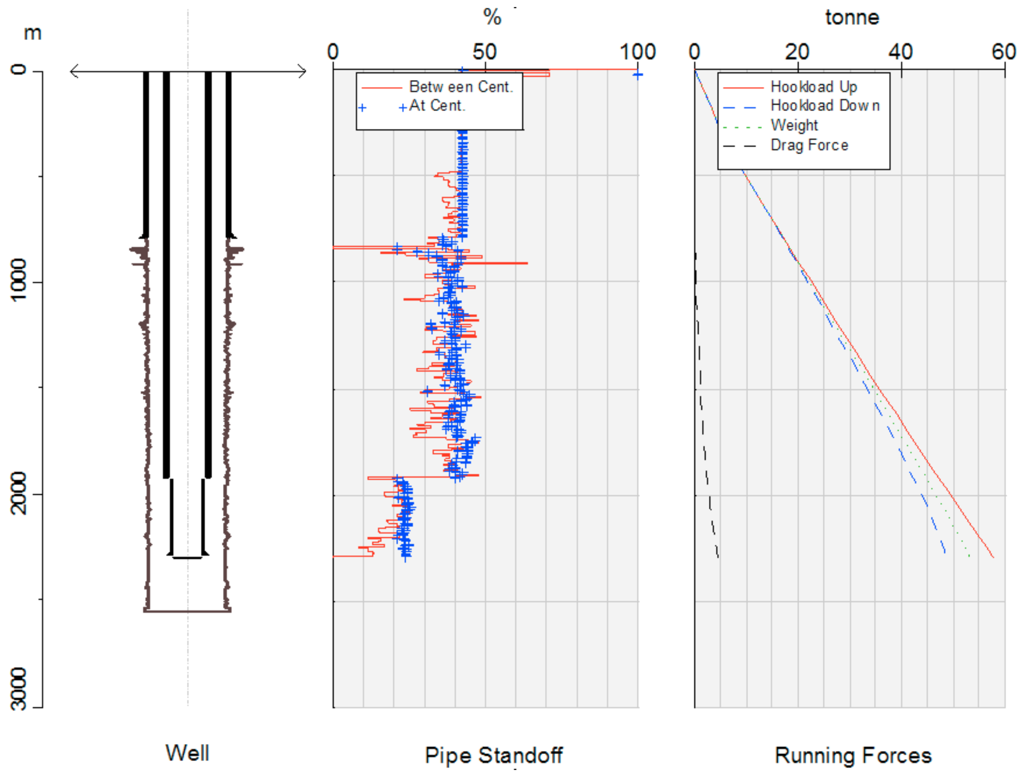

Figure 6.13 - Standoff simulation

The main part of this simulation was to show the differences between the water and mud push as spacer. The simulation inputs (volumes, rates...) were the same in both simulations, accept the original water phase was changed to a mud push with a density of 1.25 kg/l. The comparison is shown in Figure 6.14. The simulation shows that the water is nearly completely mixed with the mud and the cement. The simulation with mud push as spacer shows a clearer separation of the different fluid phases. In the interval of the cement plug the risk of mud on the wall using water show similar results as the simulation with mud push. For a proper placement only the mud removal over the plug is necessary and it is even better to keep the mud above to guarantee a good filter cake.

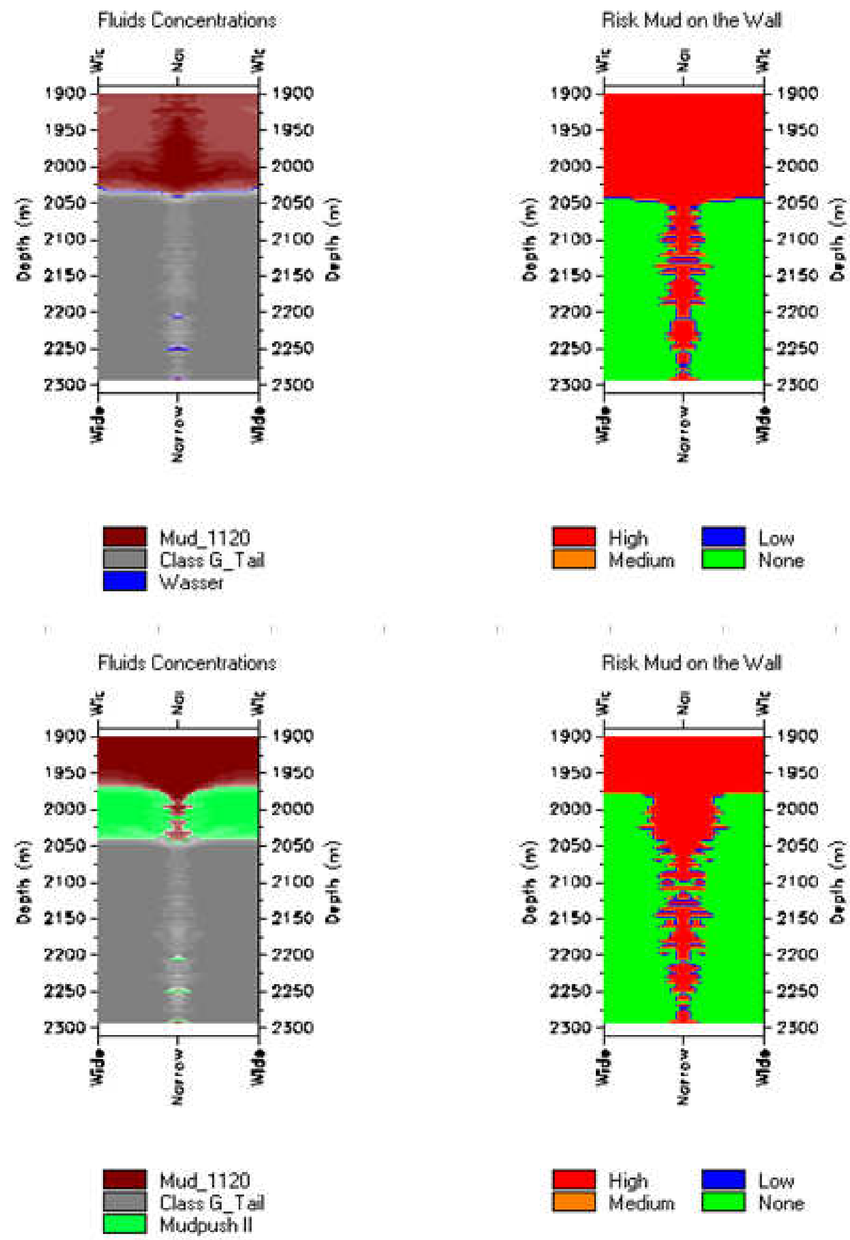

Figure 6.14 - Mud displacement - water vs. mud push

The fluid concentration plots show that either water or mud push is trapped behind the pipe inducing fluid pockets. A discussion with Schlumberger pointed out that it is better to have water mixed with the cement rather than a mud push, because mud push works like a retarder for the cement. Water, on the other side, is a component of the cement and it just dilutes the cement a little bit. Regarding to this simulation and the good experience in the past water is still preferred as spacer for cement plug jobs.

One aspect of the discussion was the scenario of deep wells with higher temperature. In this case water with retarder should be used to avoid early hardening. This could happen if the normal water dilutes the cement slurry and reduces the hardening time that is extended by retarders due to the higher temperatures. This could lead to different hardening time for the cement slurry and could cause problems while pumping the cement in place.

7. Schlumberger's cement laboratory in Vechta

7.1. General

One objective of this thesis was to give an insight about the tests that the cement runs through before it is used in the field. These tests were run at the Schlumberger lab in Vechta, Germany. If a new cement job is pending the requirements for the cement are communicated from the responsible field engineer. These requirements include the subsurface temperature regimes, the required time for pumping and if special additives, like gas block, are needed. After setting the requirements the reference database is searched for similar cements. The common practice is to use the recipe from the database or adjust it a little bit and test it. In some cases it is not possible to test the cement in time. Therefore the recipe from the similar cement slurry is used for the job. Setting a cement plug is an operation that is normally not planned in advanced for that reason a previous recipe or the recipe for the tail cement of the planned casing job is used.

7.2. Testing Procedure

7.2.1 Mixing

The testing procedure starts with mixing the cement according to the planned recipe. In order to guarantee a test sample that is close to the cement slurry used in the field the cement and all the other additives are taken from the same lot as used in the field. Additional to material that is provided from Schlumberger, also the material that is provided by the client is tested with samples that are used in the field. An important part of the testing procedure is the used water. In general a water sample from the rig site is used to mix the cement. This is important if the rig uses ground water that is stored at the rig site. This water can contain minerals and other organic material that could affect the cement. The cement tests for RAG are done with normal tap water (drinking water) because the rig site is supplied with fresh water from the next water pipeline. The used water is tested and regulated by the government. The prescriptive values for the material in the water are lower than any value that would affect the cement.

7.2.2 Density measurement

The density is tested with a "Tru-wate fluid density balance" scale. (Figure 7.1) The chamber is filled with mud and closed. The rest of the chamber is pressurised with a pump that includes cement. This procedure ensures a result that is more accurate than the result with a normal scale that is used for the mud on the rig site.

Figure 7.1 - Density measurement device

7.2.3 Rheology

The rheology is measured with a chandler rheometer. The rheology measurements are performed up and down. That means starting with 3 rpm, 6 rpm, 30 rpm, 60 rpm, 100 rpm, 200 rpm, 300 rpm and back again. The average values are taken as results. The value for 600 rpm is not taken because the shear forces would dissolve the cement a bit and the result would not be valid. The gel strength is measured according to American Petroleum Institute (API) at 10 seconds and 10 minutes.

The basic testing is done at a room temperature of around 22°C. Sometimes a second test at the bottom hole circulating pressure is done. This is necessary to see how the cement acts in the borehole at higher temperatures.

Figure 7.2 - Rheometer from Chandler Engineering[18]

7.2.4 Thickening time

The thickening time is important for the pump ability of the cement slurry. The test simulates the pressure and temperature that cement slurry faces during the placement. The measuring device is called a pressurized consitometer (Figure 7.3). This apparatus is capable to apply exact pressure and temperature.

Figure 7.3 - Pressure consitometer

To start the test, a cell with a paddle is filled with cement (Figure 7.4). The prepared cell is then inserted into the pressurized consitometer. After the cell is placed a potentiometer (Figure 7.5) is mounted on top of the cell. Once the potentiometer is set, the cell rotation can be started to check if it is mounted successfully. Before the pressure chamber is closed, the rest of the free space is filled up with synthetic oil. This oil works as transport medium for the temperature and the pressure. After the closure head seals the chamber a thermometer is inserted from the top, the test can be started.

Figure 7.4 - Paddle for the pressure cell

Figure 7.5 - Photometers of the consitometer

The output of such a test is shown in Figure 7.6. This plot shows a right angle set cement. This kind of cement setting is preferable because the cement is pumpable for a long time and the hardening is very fast. An advantage is that the hydrostatic pressure forces of the cement works against the formation fluid. The short time does not allow e.g. gas to migrate upwards.

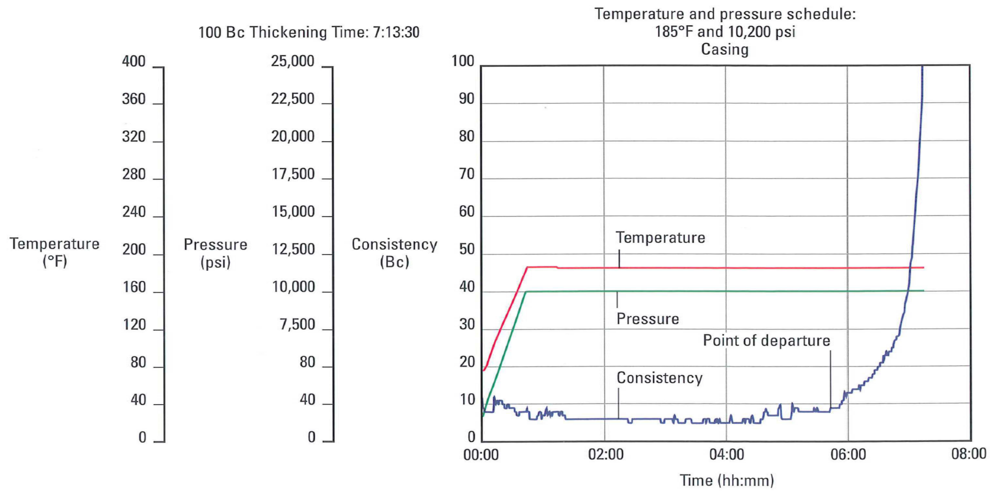

Figure 7.6 - Output of consitometer[2]

The test runs until the consistency reaches a value of 100 units Bearden of consistency. The Bearden units of consistency are defined as:

"The pump ability or consistency of a slurry, measured in Bearden units of consistency (Bc), a dimensionless quantity with no direct conversion factor to more common units of viscosity."[19]

There are three time steps recorded for the report. At 40 Bc the time value is recorded. This time is compared with the time of the point of departure (= when the cement slurry starts to gain compressive strength). This comparison gives an indication how the cement is getting hard (e.g. right angle set). The most important time value is the time when the consistency reaches 70 Bc. This value indicates when the cement slurry is barely pumpable. The time when the cement slurry reaches 70 Bc has to be bigger than the time that is necessary to pump the cement in place (plus a 120 minute safety bonus). The test stops at 100 Bc which was the limit for a still pumpable cement slurry in the past.

After the oil and the cement cooled down, the cell can be taken out and is ready to be dismounted. When the cement is broken off the paddle the breaking structure gives an indication if the cement is homogenous or not.

7.2.5 Compressive strength

An important value for the cement is the compressive strength. The compressive strength can be measured either with a destructive or a non-destructive test.

7.2.5.1 Destructive test

The API standard is the destructive test. To prepare such a test, cement slurry samples are filled in metal cubes (2" x 2") and the cubes are heated and pressurised for a pre - defined time. For exact results only one sample per run can be headed due to the temperature and pressure drop if another sample would be taken out earlier. Such a machine is shown in Figure 7.7.

Figure 7.7 - Pressure/temperature cell (left) and compressive strength tester (right)

After the sample is taken out of the apparatus and dismounted from the metal cube it can be mounted into the compressive strength tester (Figure 7.7). This device applies pressure on the sample until it breaks. The compressive strength is calculated by using the applied pressure and the area (4 in^2). This method is very time consuming if a detailed plot for the development of the compressive strength is needed.

7.2.5.2 Non-destructive test

The non-destructive test is performed with an Ultrasonic Cement Analyzer (UCA). This device makes it is possible to measure the compressive strength continually over the heating process. Figure 7.8 below shows 2 UCA devices. The left one is running a test, the right one is dismounted and the cell that is filled with cement can be seen.

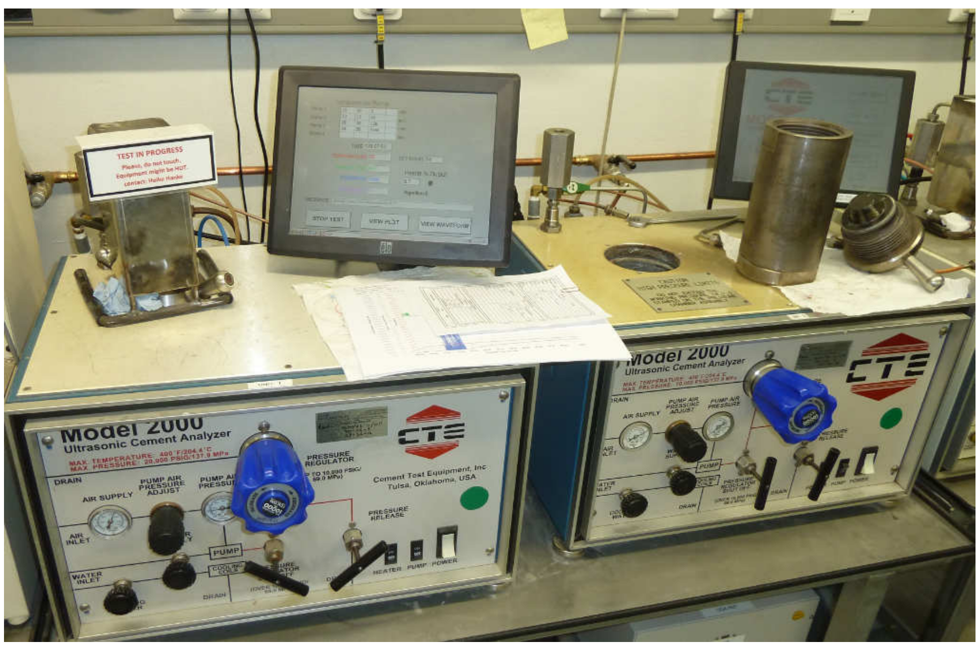

Figure 7.8 - Ultra Sonic Cement Analyzer (UCA)

Beside the compressive strength, this device is also able to measure the transit time of the tested cement sample. The transit time is important when correlating of the Ultra-Sonic Imager Tool (USIT) that is used to evaluate the cement job. This method is used for casing cementing jobs. The tool is running inside the casing. This and similar measurements are not practicable for cement plug evaluation. In Figure 7.9 a typical result of the UCA test is shown. The plot shows the development of the compressive strength and how the transit time changes over time. In Figure 7.10 the corresponding table with the temperature and pressure changes over time is shown.

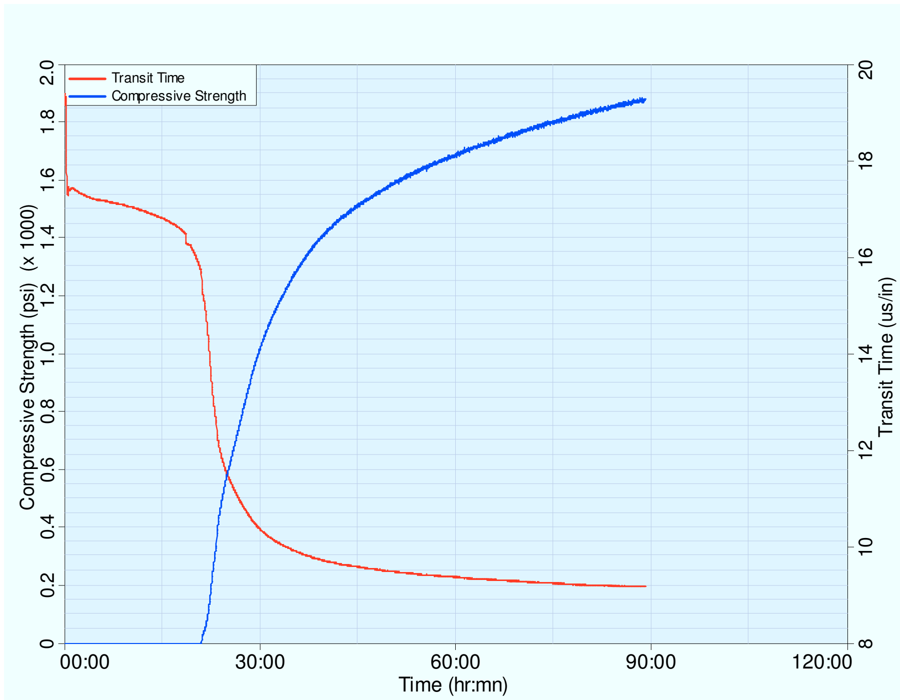

Figure 7.9 - Output of the UCA

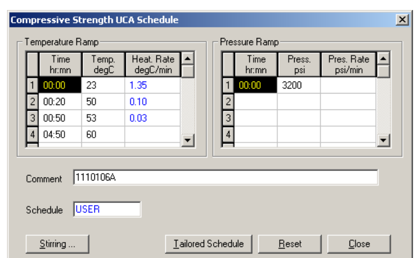

Figure 7.10 - Pressure and temperature schedule of the test

According to the laboratory staff from Schlumberger certain compressive strength values have a special meaning[20]. At 50 psi compressive strength, the cement slurry stops gelling. 500 psi is a sufficient strength to carry on with the next operation steps. If the casing is pulled in tension it is recommended to wait until additional strength is developed. The last time stamp is recorded when the cement developed its final strength. This can be seen when compressive strength does not change a lot over the time, indicated by the line flatting out.

7.3. Mud – contamination

While discussing the problem, that the formation could have an influence on the cement another aspect of contamination was raised (e.g. the mud contamination). In a different project that deals with casing cementation, the interaction between cement slurry and mud was investigated. In context with this investigation compressive strength test have been made. The tests were performed with the Ultra Sonic Cement Analyzer and class G cement with different contaminations materials was observed. The test samples were contaminated with mud or cuttings in two different concentrations. The important tests for this thesis were the tests of the samples with the mud contamination. The maximum contamination concentration of 25 % is limited by the UCA as discussed in Chapter 7.2.5.2. The result of this investigation is shown in Figure 7.11.

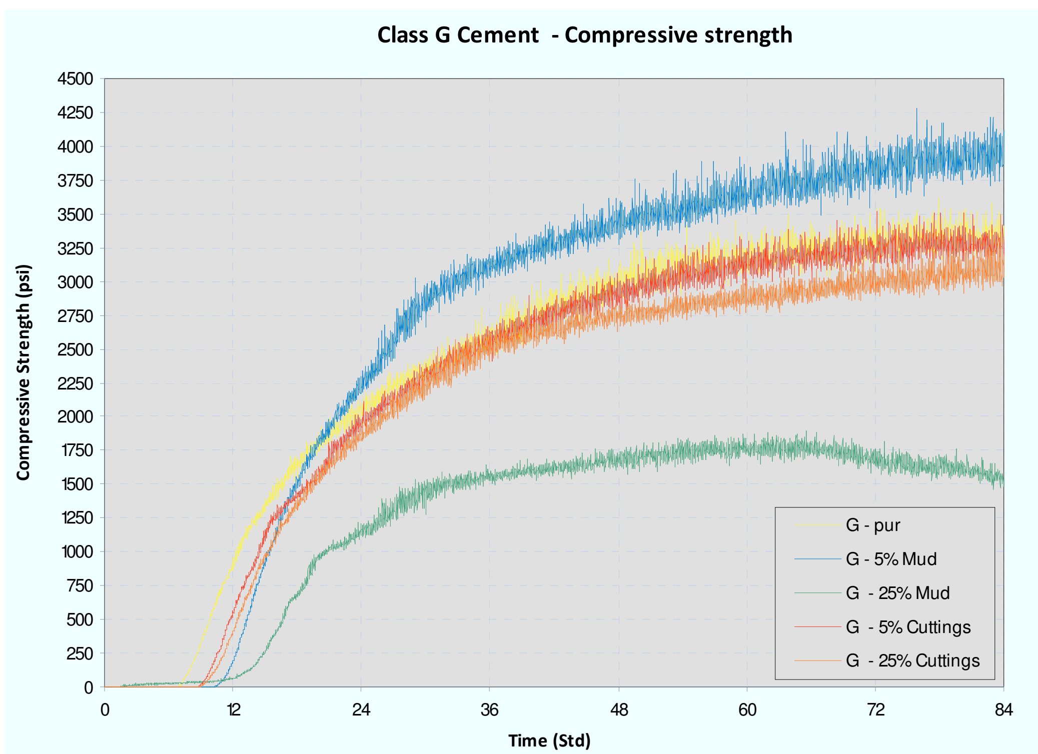

Figure 7.11 - Compressive strength test with contaminated cement

The results show that it takes 7.5 hours before the cement slurry starts to develop a compressive strength. The cement slurry that is contaminated with 5% mud needs 10.5 hours to generate a compressive strength. Although the contaminated cement needs 3 hours more to start getting hard it develops a higher final compressive strength later on.

The cement slurry that is contaminated with 25 % mud starts early to develop a minimum of compressive strength (50 psi mark at the same time as the 5 % contaminated mud) but needs more time to reach the 500 psi level. Additional to the slow development of the compressive strength the final compressive strength is 50 % lower than the one from the uncontaminated cement slurry.

8. Detailed review of the last five plugs

Following the general discussion of critical parameters and tests that can be performed, five plugs are reviewed in detail to point out failure scenarios. This detailed discussion shows plug successes and plug failures and point out probable sources of error. The five plugs were set short before or during this thesis. The data from these five plug jobs were summarized in an Excel sheet (shown in APPENDIX B).

8.1. Bad Hall Nord 4

8.1.1 General

Bad Hall Nord 4 was plugged in 3 stages in January 2011. The purpose of the last stage was to kick-off for Bad Hall Nord 4A. Only stage 3 was tested. The result of the plug was categorised as a fail because the top of cement was found at 715 m MD instead of 680 m MD. Further on while drilling it was shown that the cement was not hard below 745 m MD.

Well	Rig	Cement Stage	planned Interval		
			Lower End [MD]	Upper End [MD]	Stage Length [m]
Bad Hall Nord 4	E202	stage 1	2215	1915	300
Bad Hall Nord 4	E202	stage 2	1915	1615	300
Bad Hall Nord 4	E202	stage 3	980	680	300

Table 8.1 - Bad Hall Nord 4 - General

8.1.2 Base

The first stage was placed from bottom of the well. The second stage was placed directly on top of the first stage. The base for the third stage was a Cement Support Tool placed on the mud underneath.

8.1.3 Geology

The formation, where stage one and two were placed, was identified as possible influence parameter for the plug. This is based on the sandstone layers occurring in that depth (shown in Table 8.2). For stage three no geological influence was found to be relevant.

Nettos [m]	G=gas w=water x=nothing	porosity [%]	Salinity [ppm]	Geology responsible for failure yes/no/possible
9.4	w	15	n/a	Possible
6.5	w	20	n/a	Possible
0	x	0	0	No

Table 8.2 - Bad Hall Nord 4 – Geology

8.1.4 Inclination

The first stage is placed in a 54.14° inclined section of the well. The second stage is placed in the build up section with up to 54.14°. The third section is placed in the vertical section of the well.

8.1.5 Operating parameters

The average Pull Out Of Hole (POOH) speed was way higher than the desired speed of 0.15 m/s. The maximum POOH speeds, considered of minor relevance, exceeded the limits. The rotation was a bit lower than the desired rpm's of 15 to 20 rpm and is therefore categorised as satisfying.

POOH average Speed [m/s]	POOH max. Speed [m/s]	Rotation duration [min]	Rotation [rpm]	Rotation torque [Nm]
0.33	0.35	38.00	12.15	5000.00
0.25	0.37	32.0	11.60	3500.0
0.32	0.34	26.0	13.00	1950.0

Table 8.3 - Bad Hall Nord 4 - Operating parameters

8.1.6 Pumped volumes

The investigation of the pumped volumes shows that these pumped volumes match the planned volumes most of the time. The only exception is the post pumped mud after the first stage. This could have an influence on the hydrostatic equilibrium. The last stage was pumped with Mudpush instead of water.

Pumped Volumes							
Pre Pumped Water plan [m3]	Pre Pumped Water actual [m3]	Cement plan [m3]	Cement actual [m3]	Post Pumped Water plan [m3]	Post Pumped Water actual [m3]	Post Pumped Mud plan [m3]	Post Pumped Mud actual [m3]
3.5	3.56	13	12.89	1	1.06	15	14.46
3.5	3.69	13	13.31	0.9	0.93	12.3	12.34
2.4	2.48	12.5	12.64	0.8	0.77	3.8	3.878

Table 8.4 -Bad Hall Nord 4 - pumped volumes

8.1.7 Simulation results

The simulation with Schlumberger shows better results with an annulus that is filled up. This indicates that the plug was planned with an annulus that is filled up during the POOH process. The simulation with the actual pumped values shows a better result with a filled annulus.

Annulus Not Filled Up: Plug Advisor: Simulation Volume Optimization, Pull Out of Hole		Annulus Filled UP : Plug Advisor: Simulation Volume Optimization, Pull Out of Hole	
simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]	simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]
1908	1974	1908	1927
1653	1608	1622	1615
677	710	677	684

Table 8.5 - Bad Hall Nord 4 - POOH Simulation results

The results of the placement simulation (Table 8.6) show intervals where the top of cement should be. The simulation with the planned values gave excellent results. The simulation with the real volumes shows a little shift of the interval boundaries.

Plug Advisor: Placement Fluid Mixing During Placement			
simulation with planned values: TOC (MD) high	simulation with planned values: TOC (MD) low	simulation with actual values: TOC (MD) high	simulation with actual values: TOC (MD) low
1904	1926	1926	1937
1609	1637	1599	1609
671	681	657	701

Table 8.6 - Bad Hall Nord 4 - Placement Simulation results

8.1.8 Comment

Due to the fact that only the third stage was tested, there is no indication if stage one and two were successfully placed. Stage three was tested and was categorised as a fail. An analysis of the parameters shows that the average POOH speeds were too fast which could lead to a mixture of cement slurry and the mud. This causes cement slurry that takes longer to get hard and can induce mud pockets that weaken the plug especially when mudpush is used (works as a retarder).This assumption is supported by information from the drilling process that the cement was tagged at 715 meters, but from 745 to 781 meters there was no significant cement resistance.

Another reason for the not satisfying result is the CST that is used as base. If there is a malfunction of this tool the cement slurry flows beneath it. A combination of a high viscosity pill and a CST could guarantee a good base.

A cause for unsuccessful plug can also be that the volumes were planned with a filled annulus and investigations indicate that the annulus was not filled up while POOH. As shown in the in the simulation this would not bring the desired results.

8.2. Bad Hall Nord 4A

8.2.1 General

Bad Hall Nord 4A was plugged in tree stages in February 2011. The purpose was to plug and abandon the well. All three stages were tested. The result of the plug was categorised as a success because all the top of cement were found within a deviation of 10 meters from the desired tops.

Well	Rig	Cement Stage	planned Interval		
			Lower End [MD]	Upper End [MD]	Stage Length [m]
Bad Hall Nord 4	E202	stage 1	2215	1915	300
Bad Hall Nord 4	E202	stage 2	1915	1615	300
Bad Hall Nord 4	E202	stage 3	920	620	300

Table 8.7 - Bad Hall Nord 4A - General

8.2.2 Base

The first stage was placed from bottom of the well. The second stage was placed directly on top of the first stage. The base for the third stage was mud with 1.26 kg/l .

8.2.3 Geology

The formation, where stage one and two were placed, was identified as possible influence parameter for the plug. This is based on the sandstone layers occurring in that depth (shown in Table 8.8). For stage three no geological influence was found to be relevant.

Nettos [m]	G=gas w=water x=nothing	porosity [%]	Salinity [ppm]	Geology responsible for failure yes/no/possible
13.3	w	n/a	n/a	possible
10.9	w	n/a	n/a	possible
0	x	n/a	n/a	no

Table 8.8 - Bad Hall Nord 4A – Geology

8.2.4 Inclination

The first stage is placed in a 38.91° inclined section of the well. The second stage is placed in the build up section with up to 38.91°. The third section is placed in kick off section with maximum 15° inclination.

8.2.5 Operating parameters

The average Pull Out Of Hole (POOH) speeds of the first two stages were exactly at the defined limit. The POOH speed for the third stage was way higher than the desired speed of 0.15 m/s. The rotation was a bit lower than the desired rpm's of 15 to 20 rpm and is therefore categorised as satisfying, except stage two where the rotation was very low.

POOH average Speed [m/s]	POOH max. Speed [m/s]	Rotation duration [min]	Rotation [rpm]	Rotation torque [Nm]
0.15	0.22	33	12.34	6500
0.14	0.35	23	4.25	4300
0.53	1.05	17	14.5	1600

Table 8.9 - Bad Hall Nord 4A - Operating parameters

8.2.6 Pumped volumes

The investigation of the pumped volumes shows that these pumped volumes match the planned volumes most of the time. The only exception is the post pumped mud after the first stage and second stage. This could have an influence on the hydrostatic equilibrium.

Pumped Volumes							
Pre Pumped Water plan [m^3]	Pre Pumped Water actual [m^3]	Cement plan [m^3]	Cement actual [m^3]	Post Pumped Water plan [m^3]	Post Pumped Water actual [m^3]	Post Pumped Mud plan [m^3]	Post Pumped Mud actual [m^3]
3.5	3.53	13	13.47	0.5	0.54	15.2	14.6
3.5	3.51	13	13.49	0.9	0.53	12.4	11.81
3	3.01	13	12.96	0.5	0.52	3.3	3.01

Table 8.10 -Bad Hall Nord 4A - pumped volumes

8.2.7 Simulation results

The simulation with Schlumberger shows similar results with a filled or not filled annulus. Also the simulation results with the actual pumped values are similar.

Annulus Not Filled Up: Plug Advisor: Simulation Volume Optimization, Pull Out of Hole		Annulus Filled UP : Plug Advisor: Simulation Volume Optimization, Pull Out of Hole	
simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]	simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]
1931	1894	1901	1901
1604	1596	1607	1596
650	635	0	635

Table 8.11 - Bad Hall Nord 4A - POOH Simulation results

The results of the placement simulation (Table 8.12) show intervals where the top of cement should be. The simulation with the planned values gave similar results compared with the simulation using real volumes.

Plug Advisor: Placement Fluid Mixing During Placement			
simulation with planned values: TOC (MD) high	simulation with planned values: TOC (MD) low	simulation with actual values: TOC (MD) high	simulation with actual values: TOC (MD) low
1904	1926	1893	1915
1580	1647	1599	1618
646	656	623	637

Table 8.12 - Bad Hall Nord 4A - Placement Simulation results

8.2.8 Comment

Although some operating parameters were not optimal, all three stages were categorised as successful. The operation was similar to the one of Bad Hall Nord 4. Only the inclination was not that high and no mudpush and no CST was used.

The slower POOH speed in combination with water as spacer could be a reason why Bad Hall Nord 4A was a success and Bad Hall Nord 4 not.

8.3. Atzbach 30

8.3.1 General

Atzbach 30 was plugged in three stages in April 2011. The purpose of the last stage was to kick-off for Atzbach 30A. Only stage three was tested. The result of the plug was categorised as success because the top of cement was found at 340 m MD and further drilling to 403 m MD shows hard cement.

Well	Rig	Cement Stage	planned Interval		
			Lower End [MD]	Upper End [MD]	Stage Length [m]
Atzbach 30	E200	stage 1	1100	850	250
Atzbach 30	E200	stage 2	850	600	250
Atzbach 30	E200	stage 3	600	350	250

Table 8.13 - Atzbach 30 – General

8.3.2 Base

The first stage was placed on a high viscosity pill (Recipe in chapter 9.2.2). The second and third stage was placed directly on top of each other. The high viscosity pill was placed from 1300 – 1100m MD with a density of 1.5 kg/l.

8.3.3 Geology

For all stages no geological influence was found to be relevant.

Nettos [m]	G=gas w=water x=nothing	porosity [%]	Salinity [ppm]	Geology responsible for failure yes/no/possible
6.9	w	22	n/a	no
0	x	0	0	no
0	x	0	0	no

Table 8.14 - Atzbach 30 – Geology

8.3.4 Inclination

All stages were placed in the vertical section of the well.

8.3.5 Operating parameters

The average Pull Out Of Hole (POOH) speeds of the first two stages were exactly at the set limit. The POOH speed for the third stage was a little higher than the desired speed of 0.15 m/s. The rotations per minute were exact at the desired rpm interval of 15 to 20 rpm and are therefore categorised as excellent.

POOH average Speed [m/s]	POOH max. Speed [m/s]	Rotation duration [min]	Rotation [rpm]	Rotation torque [Nm]
0.14	0.17	12	19.80	3050
0.14	0.19	11	20.00	3000
0.20	0.47	10	20.00	5776

Table 8.15 - Atzbach 30 - Operating parameters

8.3.6 Pumped volumes

The investigation of the pumped volumes shows that these pumped volumes match the planned volumes most of the time.

Pumped Volumes							
Pre Pumped Water plan [m^3]	Pre Pumped Water actual [m^3]	Cement plan [m^3]	Cement actual [m^3]	Post Pumped Water plan [m^3]	Post Pumped Water actual [m^3]	Post Pumped Mud plan [m^3]	Post Pumped Mud actual [m^3]
1	0.838	5.5	5.403	0.4	0.22	3.5	3.13
1	0.993	5.5	5.471	0.4	0.173	2.1	2.368
1	1.008	5	5.411	0.2	0.158	1.2	0.739

Table 8.16 - Atzbach 30 - pumped volumes

8.3.7 Simulation results

The simulation with Schlumberger shows no satisfying results with the planned values no matter if the annulus is filled or not. The simulation results with the actual pumped values are a better but still not 100% satisfying.

Annulus Not Filled Up: Plug Advisor: Simulation Volume Optimization, Pull Out of Hole		Annulus Filled UP : Plug Advisor: Simulation Volume Optimization, Pull Out of Hole	
simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]	simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]
884	843	820	826
625	658	571	572
404	340	347	329

Table 8.17 - Atzbach 30 - POOH Simulation results

The results of the placement simulation (Table 8.18) show intervals where the top of cement should be. The simulation with the planned values show better results compared with the simulation using real volumes.

Plug Advisor: Placement Fluid Mixing During Placement			
simulation with planned values: TOC (MD) high	simulation with planned values: TOC (MD) low	simulation with actual values: TOC (MD) high	simulation with actual values: TOC (MD) low
820	864	825	836
565	582	527	638
345	363	327	333

Table 8.18 – Atzbach 30 - Placement Simulation results

8.3.8 Comment

Only the last plug was tested. Although some operating parameters were not optimal the plug was categorised as successful.

The slow POOH speed and the placement in the vertical well could be reasons why the job was a successful. The recipe (discussed in Chapter 9.2.2) for the high viscosity pill worked perfect as a base.

8.4. Hipping 1

8.4.1 General

Hipping 1 was plugged in four stages to surface in May 2011. The purpose was to plug and abandonment the well. Only stage three was tested. The result of the plug was categorized as a fail because the top of cement was found at 240 m MD instead of 200 m MD.

Well	Rig	Cement Stage	planned Interval		
			Lower End [MD]	Upper End [MD]	Stage Length [m]
Hipping 1	E200	stage 1	1440	1245	195
Hipping 1	E200	stage 2	1245	1045	200
Hipping 1	E200	stage 3	400	200	200
Hipping 1	E200	stage 4	240	2	238

Table 8.19 – Hipping 1 – General

8.4.2 Base

The first stage was placed on a High Viscosity pill (Recipe in chapter 9.2.2). The second stage was placed directly on top. The third stage was placed again on a high viscosity pill. The last stage was placed on top of the third stage after the stage was tested. The high viscosity pills were placed from 1630 -1440 m MD and from 580 – 400 m MD with a density of 1.5 kg/l.

8.4.3 Geology

The formation where stage one and three were placed was identified as possible influence parameter for the plug. This is based on the sandstone layers occurring in that depth (shown in Table 8.20). For stage three and four no geological influence was found to be relevant.

Nettos [m]	G=gas w=water x=nothing	porosity [%]	Salinity [ppm]	Geology responsible for failure yes/no/possible
7.3	w	n/a	n/a	possible
1.4	w	18	n/a	no
n/a	w	n/a	n/a	possible
0	x	0	0	no

Table 8.20 - Hipping 1– Geology

8.4.4 Inclination

The first stage is placed in a 40° inclined section of the well. The second stage is placed in the build up section with up to 40°. The third section is placed in the 10° inclined section. Stage number four was placed in the vertical section.

8.4.5 Operating parameters

The average Pull Out Of Hole (POOH) speeds of the first three stages were exactly at the set limit. The POOH speed for the fourth stage was a little higher than the desired speed of 0.15 m/s. There was no rotation due to a breakdown of the rotary table and was therefore categorised as not satisfying.

POOH average Speed [m/s]	POOH max. Speed [m/s]	Rotation duration [min]	Rotation [rpm]	Rotation torque [Nm]
0.14	0.22	0	0.00	0
0.12	0.26	0	0.00	0
0.14	0.25	0	0.00	0
0.20	0.35	0	0.00	0

Table 8.21 - Hipping 1 - Operating parameters

8.4.6 Pumped volumes

The investigation of the pumped volumes shows that these pumped volumes match the planned volumes most of the time. The only exception is the cement slurry of the fourth stage, but this is of minor relevance because the stage is coming up to surface.

Pumped Volumes							
Pre Pumped Water plan [m^3]	Pre Pumped Water actual [m^3]	Cement plan [m^3]	Cement actual [m^3]	Post Pumped Water plan [m^3]	Post Pumped Water actual [m^3]	Post Pumped Mud plan [m^3]	Post Pumped Mud actual [m^3]
1.2	1.327	4.2	4.08	0.7	0.411	4.4	4.84
1.3	1.328	4.2	4.148	0.7	0.576	4.4	4.09
1.3	1.323	4.3	4.583	0.3	0	0.7	0.34
1.3	0.828	4.1	5.111	0	0.9		0

Table 8.22 - Hipping 1 - pumped volumes

8.4.7 Simulation results

The simulation with Schlumberger shows better results with an annulus that is filled up. This indicates that the plug was planned with an annulus that is filled up during the POOH process. The simulation with the actual pumped values shows a better result than with a filled annulus.

Annulus Not Filled Up: Plug Advisor: Simulation Volume Optimization, Pull Out of Hole		Annulus Filled UP : Plug Advisor: Simulation Volume Optimization, Pull Out of Hole	
simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]	simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]
1273	1246	1245	1256
1050	1060	1059	1043
200	188	202	191

Table 8.23 - Hipping 1 - POOH Simulation results

The results of the placement simulation (Table 8.24) show intervals where the top of cement should be. The simulation with the planned values shows not satisfying results. The simulation with the real volumes shows a little shift of the interval boundaries.

Plug Advisor: Placement Fluid Mixing During Placement			
simulation with planned values: TOC (MD) high	simulation with planned values: TOC (MD) low	simulation with actual values: TOC (MD) high	simulation with actual values: TOC (MD) low
1238	1260	1253	1267
1058	1064	1040	1052
204	208	192	196

Table 8.24 - Hipping 1 - Placement Simulation results

8.4.8 Comment

Due to the fact that only the third stage was tested there is no indication if the stage one and two were successfully placed. Stage three was tested and was categorised as a fail. An analysis of the parameters shows that the average POOH speeds are satisfying.

One problem that occurred was the breakdown of the rotary table which could lead to a bad cement slurry placement and an insufficient mud displacement. Another source of failure is the high viscosity pill. Nearly the same recipe was used that worked perfect on Atzbach 30. The main difference between Atzbach 30 and Hipping 1 is that Hipping 1 is inclined. This could have led to a partly fluid swab between the high viscosity pill and the cement slurry. This assumption is based on the fact that the top of the stage is 40 meters below the desired top of cement. A combination of a high viscosity pill and a CST could have shown better results.

8.5. RAG 55

8.5.1 General

RAG 55 was plugged in nine stages up to the surface in May 2011. The purpose was to plug and abandonment the well. Only the fourth and the eighth stage were tested. The fourth stage of the plug was categorised as a fail because the top of cement was found at 1580 m MD instead of 1550 m MD. Stage eight was categorised as satisfying due to the fact that the cement was tagged at 599.6 m MD instead of 576 m MD.

Well	Rig	Cement Stage	planned Interval		
			Lower End [MD]	Upper End [MD]	Stage Length [m]
RAG 55	E202	stage 1	2557	2300	257
RAG 55	E202	stage 2	2300	2050	250
RAG 55	E202	stage 3	2050	1800	250
RAG 55	E202	stage 4	1800	1550	250
RAG 55	E202	stage 5	1580	1323	257
RAG 55	E202	stage 6	1323	1074	249
RAG 55	E202	stage 7	1074	841	233
RAG 55	E202	stage 8	841	576	265
RAG 55	E202	stage 9	109	1.5	107.5

Table 8.25 – RAG 55 – General

8.5.2 Base

The first stage was placed from bottom of the well. The stages two to eight were placed on top of each other. The last stage was placed on a high viscosity pill. Underneath the high viscosity pill a hydro mechanical bridge plug was set. The high viscosity pill had a volume of 3 m^3.

8.5.3 Geology

The formation where stage seven and eight were placed definitely has an influence on the plug. The formation where the stages two to six were placed was identified as possible influence parameter for the plug. This is based on the sandstone layers occurring in that depth (shown in Table 8.26). For stage one and nine no geological influence was found to be relevant.

Nettos [m]	G=gas w=water x=nothing	porosity [%]	Salinity [ppm]	Geology responsible for failure yes/no/possible
0	x	n/a	n/a	no
51	w	n/a	n/a	possible
n/a	w	n/a	n/a	possible
67	w	n/a	n/a	possible
69.2	w	n/a	n/a	possible
90.5	w	n/a	n/a	possible
37	w	n/a	n/a	yes
12.6	w	n/a	n/a	yes
0	x	n/a	n/a	no

Table 8.26 - RAG 55 – Geology

8.5.4 Inclination

The first stage is placed in a 35.46° inclined section of the well. The second until the fourth stage were placed in the build up section with up to 35.46°. The fifth, sixth and seventh stage were placed in the 10° inclined section. Stage numbers eight and nine were placed in the vertical section.

8.5.5 Operating parameters

The average Pull Out Of Hole (POOH) speeds for all stages were exactly at the set limit. The maximum POOH speed, considered of minor relevance, was also perfect within the limits. There were stages with no rotation, at all these stages were categorised as not satisfying.

POOH average Speed [m/s]	POOH max. Speed [m/s]	Rotation duration [min]	Rotation [rpm]	Rotation torque [Nm]
0.11	0.15	0	n/a	n/a
0.06	0.13	0	n/a	n/a
0.09	0.14	0	0.00	0
0.10	0.14	0	0.00	0
0.12	0.15	20	16.00	4500
0.10	0.12	19	10.00	4000
0.07	0.15	0	0.00	0
0.11	0.15	0	0.00	0

Table 8.27 - RAG 55 - Operating parameters

8.5.6 Pumped volumes

The investigation of the pumped volumes shows that these pumped volumes match the planned volumes most of the time. Except the pre pumped water of stage 2 and 6 and the post pumped mud of the first stage. This could have an influence on the hydrostatic equilibrium. The comparison also shows that in the first four stages less cement than planned was pumped.

Pumped Volumes							
Pre Pumped Water plan [m³]	Pre Pumped Water actual [m³]	Cement plan [m³]	Cement actual [m³]	Post Pumped Water plan [m³]	Post Pumped Water actual [m³]	Post Pumped Mud plan [m³]	Post Pumped Mud actual [m³]
2	1.745	10.4	10.461	0.3	0.312	18.8	16.623
2	1.172	10.2	10.09	0.3	0.312	16.5	16.623
2	2.016	10.5	10.228	0.3	0.27	14.3	14.278
2	1.987	10.4	10.379	0.3	0.277	12	12.01
2	2.005	10.7	10.923	0.3	0.278	10	10.161
2	3.6	10.7	10.81	0.3	0.292	7.8	7.801
2	2.009	10.7	10.838	0.3	0.28	5.6	5.608
2	2.003	10.7	10.455	0.3	0.281	3.3	3.315

Table 8.28 - RAG 55 - pumped volumes

8.5.7 Simulation results

The simulation with Schlumberger shows better results with an annulus that is filled up. This indicates that the plug was planned with an annulus that is filled up during the POOH process. The simulation with the actual pumped values shows similar results as the one with the planned values.

Annulus Not Filled Up: Plug Advisor: Simulation Volume Optimization, Pull Out of Hole		Annulus Filled UP : Plug Advisor: Simulation Volume Optimization, Pull Out of Hole	
simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]	simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]
2327	2335	2300	2298
2072	2102	2039	2043
1825	1823	1791	1797
1571	1575	1538	1539
1354	1358	1324	1318
1106	1106	1076	1078
863	861	839	836
605	608	573	580

Table 8.29 - RAG 55 - POOH Simulation results

The results of the placement simulation (Table 8.30) show intervals where the top of cement should be. The simulation with the planned values shows excellent results. The simulation with the real volumes shows a little shift of the interval boundaries but the results are still very good.

Plug Advisor: Placement Fluid Mixing During Placement			
simulation with planned values: TOC (MD) high	simulation with planned values: TOC (MD) low	simulation with actual values: TOC (MD) high	simulation with actual values: TOC (MD) low
2289	2314	2289	2314
2022	2057	2034	2057
1784	1804	1784	1814
1521	1557	1530	1548
1319	1335	1311	1327
1072	1085	1065	1085
833	844	833	844
571	583	579	587

Table 8.30 - RAG 55 - Placement Simulation results

8.5.8 Comment

In this case only the forth and the eighth stage were tested. Stage four was categorised as satisfying and stage eight was categorised as not satisfying. The other stages were not tested. An analysis of the parameters shows that the average POOH speeds are satisfying. The simulation with Schlumberger show excellent results for a filled annulus. An analysis of the pumps showed that the annulus was filled up while pulling out of hole.

One possible influence parameter in this case could be the geology. The analysis shows that most of the stages are influenced by the formation. A huge water layers could dilute the cement slurry and lead to a longer hardening time.

Not using rotary table for some stages could lead to a bad cement slurry placement and an insufficient mud displacement. Another source of failure could be the difference between planned and pumped volumes. This could affect the hydrostatic equilibrium. The cement volumes for the first four stages differentiate between planned and actual pumped volumes. A 0.342 m^3 difference leads to a 9.3 meter length reduction. This could be one reason for the shifted (-30 meters) top of cement.

9. Conclusion

This chapter summarises the substantial elements of this thesis and points out recommendations for possible plug improvement.

9.1. Discussion

9.1.1 Communication

In context of this thesis it was found, that the communication between all involved parties was better for casing cementing jobs than for plug back jobs. This fact is also discussed by J.F Heathman[21]. A reason for bad communication can be that a plug-back job is normally associated with a non-successful well. Therefore the responsible engineer has already “finished” the project and his focus is on the next project. Another reason is that plug back jobs are not “everyday” jobs, therefore the rig crew is not always familiar with every detail of this job. Further on the cementing company is in a rush with planning the plugs, because the operation is normally unforeseeable. Consequently not all aspects might be discussed properly and failures based on communication can occur.

While working on the data gathering for the thesis the communication has significantly improved. This was induced by RAG’s interest in improving the cement plug jobs and forces all parties to pay more attention to the plug back job.

9.1.2 Quality management

The general statistics in Chapter 3.2 show that 62% of the plug stages from the last six years were not tested. Still, the success rate is better than the industry’s average[1]. The question is, if RAG is satisfied with the number of untested plug stages and if the relatively low sampling fraction can give a representative result.

One benefit of testing more or even every stage is that an investigation for probable errors would be a lot easier and could lead to an improvement of the plug success rate in the future (Probability of Success).

9.2. Recommendation

This chapter discusses possible methods and tools that could improve cement plug jobs in the future. During the literature research for improvement of cement plugs new options were found, those were discussed in this chapter. Some of the mentioned tools are used by RAG but not on a frequent basis. Adding supplementary test would improve operations in the future.

9.2.1 Cement Support Tool (CST)

The CST induces a mechanical barrier between the high viscous pill and the cement slurry. The setting process of this tool is shown in Figure 9.1- CST setting process. One example for such a CST is the Para Bow of BJ Services.

Figure 9.1 - CST setting process[22]

The CST was already used by RAG. In Chapter 4.2.1 it is shown that the tool worked once and failed twice. These two cases were observed during this thesis and failures were identified. In one case the CST had the wrong size and did not fit at the joints of the 2 7/8" cementing string. Therefore it was not possible to pump it down properly. In the other case there was a malfunction of the pump, therefore a proper pump process was not possible.

The learning curve of RAG for this tool is currently at the beginning. Therefore the author recommends using the CST, especially in highly deviated wells where the cement slurry tends to flow under the high viscous pill, in the future. A proper operation and setting of the tool could increase the plug success.

9.2.2 High viscosity / Reactive pill

A high viscous pill is a fluid that is mixed out of normal mud, used during drilling, and additives that weight it up. The task of this pill is to create a base for the cement slurry. The rheological parameters are normally between the mud and the cement slurry. The most important parameter is the specific weight. A weight difference that is too high would lead to an exchange of the mud and the cement slurry, which could affect the success of the job.

The recipe and the rheological parameters of a high viscosity pill are listed below. This recipe was already used at Atzbach 30 and worked successful in this vertical well. The application in a deviated well leaded to a satisfying result, but there is still room for improvement. One possibility would be to use a combination of a high viscous pill and a CST (discussed in Chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**).

Recipe of the viscous pill used in Atzbach 30:

Density 1.55 kg/l and Viscosity ∞

Recipe:

- K^2CO^3 / Polymer Mud 1 m^3
- Antisol PAC ULV 4.7 kg
- Baryt 555 kg
- Bentonit 200 kg
- Antisol FL 30 000 3.12 kg

Another method is to use a high viscous reactive pill. This pill contains additives that force the cement slurry to get hard when there is a contact. This method was not used within RAG so far. Future test runs should be applied to show if the reactive pill could improve the plug setting without a CST.

9.2.3 Top of cement testing

In general there are two ways of to test the cement after the wait on cement period is over. One of those methods is to pressure up the well (25 bars) and observe the pressure decrease over a certain time. This method indicates if the cement plug is tight, but it does not give any information about the depth of the top of cement.

The second method is to touch the top of cement after the wait on cement period is over and apply a load (3 to 8 tons). This is normally done with the drill bit. The advantage of using a bit is that in case of a kick-off plug the next drilling process can start right after touching the cement. Another benefit of using the bit is that, if there is some leftover from the cement in the well it can be drilled "clean".

The disadvantage of using a bit is that the area that touches the cement is not clear defined (Individual shape of each bit). A short calculation was done in order to show the forces acting on the cement while touching it. The touching area of the tubing is calculated as a circular ring (close to reality), the bit is calculated with a full circle area (assumption).

touching "device"	contact area [m^3]	Compressive strength acting on cement	
		touched with 3 tons	touched with 8 tons
2 7/8" tubing	0.00261	1637	4365
3" tubing	0.00370	1153	3074
5" Drill pipe	0.00481	887	2365
half of 6 1/8" drill bit	0.01000	427	1138
full 6 1/8" drill bit	0.01900	225	600

Table 9.1 - Compressive strength acting on cement

	Compressive strength [psi]	
	after 12 hours	after 24 hours
Cement; pure	886	2026
Cement; 5 % Mud	193	2300
Cement; 25% Mud	58	1121

Table 9.2 - Test results -compressive strength form Chapter 7.3

A comparison of these two tables shows that touching the cement with 8 tons develops more compressive strength than the cement can handle after 12 respectively 24 hours.

The results of this short calculation show that a defined area (not a bit) would be better for touching the top of cement and 3 tons are more than enough to test the compressive strength.

9.2.4 Leave cement stinger in the cement slurry

The idea to leave the cement stinger in the cement slurry was discussed by T. Marriott, H. Rogers, S. Lloyd, C. Quinton [23]. One big advantage leaving the string in is that critical parameters like pulling out of hole (discussed in Chapter 4.2.7) do not influence the plug result. Another advantage is that the cement can be adjusted to harden early and reduce the job time.

In context with this thesis a rough example was set up to compare the conventional method (300 m stages) to a method that leaves the stinger in (2000 m stage). The conventional job takes 66 hours the other on 48 hours, this leads to a reduction of 18 hours. Schlumberger charges a service fee of 13000 €/day, therefore the service cost would be reduced by 9750 €. Furthermore the pumped volume can be reduced from 84 m^3 to 71 m^3, which effects a cost reduction of 5200 € (Note: assumption that 1 m^3 of cement slurry cost 400 €). This reduction can be related to the metal displacement of the stinger and the amount of cement slurry that is normally reversed circulated out after each stage. In addition the pump pressure and the ECD were observed (simulation shown in Figure 9.2) and no restriction for the extended stage method was found.

Although cost savings occur, additional costs are generated. These are the costs for the stinger that is left in the hole and costs for additives like retarder. The string cost around 6150 € (Note: assuming a 2 7/8" tubing with 12.8 kg/m at a price of 24 cents/kg for the discarded metal). For the extended stages a lead and tail cement concept should be planned (not considered in this rough estimate). Besides the cost savings of 8800 € due to the appliance of this method, better results of the cementing job may occur, but these are not considered cost wise.

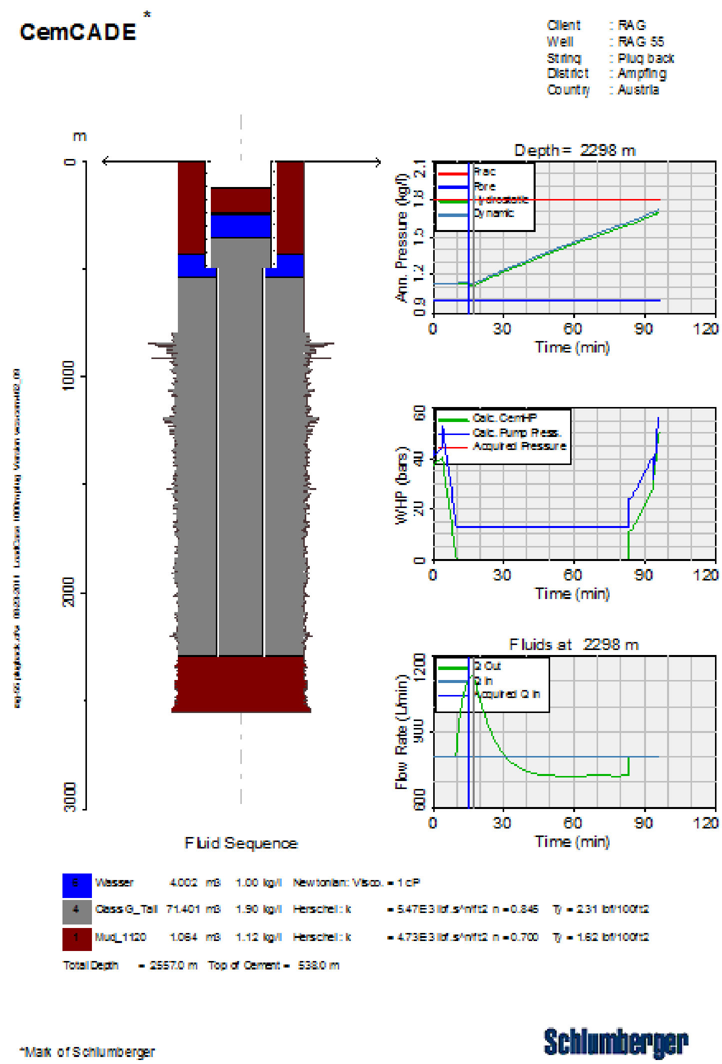

Figure 9.2 - Simulation result of a 2000meter stage

9.2.5 Synchronisation of real time data

During the data gathering for this thesis the author found out, that it is not possible to compare the real-time data from Schlumberger (pump rate, volume, etc) with the real time data, which is generated from the rig.

The solution for that problem was to install a pressure gauge on the cement line. This line connects the rig with Schlumberger's pump truck. The sensor is connected to the bus system of the rig. The data can now be synchronised when pressure peaks form both sides are correlated. Another advantage is that the driller can see pressure peaks, as they occur if the cementing plug reaches the end of the stinger. This enables a better observation of the whole cementing job. The sensor is installed on one rig for test purposes (Figure 9.3).

Figure 9.3 - Pressure Sensor for the cementing line - not mounted

9.2.6 Diverter tool

The purpose of a diverter tool is to redirect the flow from its normal direction (straight out of the stinger) to a direction that forces the fluids to exit the stinger on the side walls. The reason for the re-direction is that the fluid should not flow directly into the high viscous pill which is set below. If the cement slurry flows through the HV pill the slurry tend to slump under it. This phenomenon is especially known in inclined wells (discussed in Chapter 4.1.1). Figure 9.4 shows such a diverter tool.

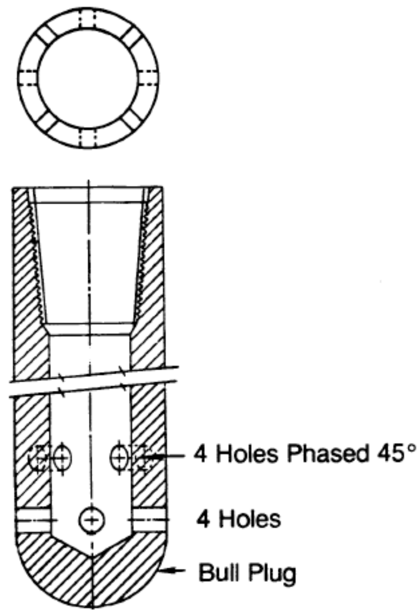

Figure 9.4 - Diverter tool[24]

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APPENDIX A –End of Job Report from Schlumberger

Schlumberger

Cementing Services
END OF JOB REPORT
für die
Zementation

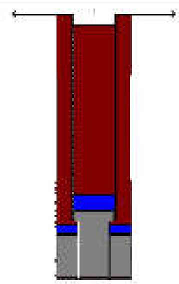
Rückverfüllung
in
Atzbach 30

Client	:	RAG
Field	:	Atzbach
Author	:	Stefan Essl

		Max. Deviation:	3 deg		
Well:	Atzbach 30			Date:	10 Jun 2011
PLUG	1100 - 850 m	MD:	1100 m	BHST	42℃
Cement Job:	Plug back	TVD:	1100 m	Simulated BHCT	29℃

Cement Volume

	OD	ID	Capacity	Top		Bottom	Length	Volume
OH / Bitsize	6 1/8"		19.01 L/m	850 m	to	1100 m -	250 m -	4.8 m³
Caliper Measurement	6.144 "		19.13 L/m					0.0 m³
Excess: On Open Hole	0.6%		On Annulus	1.4%				
								4.8 m³
						Annular Excess Over Caliper	33%	0.7 m³



Displacement Recalculate Before the Job

DP	E200	4 "	3.235	5.303 L/m	727 m	3855 L
Tubing	6.5	2 7/8 "	2.441	3.019 L/m	373 m	1126 L
Riser		4 1/2 "	4.000 "	8.107 L/m	0 m	0 L
Strangvolumen total						**4981 L**
Zement in DP						1200 L
Underdisplacment						400 L
				Total Maximum Displacement:		**3381 L**
Spacer in DP						400 L
				Displacement Spülung:		**2981 L**

Cement Volume: 5.5 m³

Pump Schedule

Volume	Fluid / Action	Density	Pumped by	Rate	Time
	Bohrloch mit 1000 L/min zirkulieren	S.G. 1.20 kg/L	Rig	1000 L/min	0.0 min
	Sicherheitsbesprechung (WEITERZIRKULIEREN!!)				30.0 min
					0.0 min
					0.0 min
0.5 m³	Wasser	S.G. 1.00 kg/L	SLB	600 L/min	0.6 min
	Leitungstest mit150 bar				10.0 min
0.5 m³	Wasser	S.G. 1.00 kg/L	SLB	600 L/min	0.6 min
	DP-Dart loesen				5.0 min
5.5 m³	Class G	S.G. 1.90 kg/L	SLB	600 L/min	6.9 min
0.4 m³	Verdrängung: Wasser	S.G. 1.00 kg/L	SLB	600 L/min	0.5 min
3.0 m³	Displacement: Spülung	S.G. 1.20 kg/L	SLB	600 L/min	3.7 min
0.5 m³	Spülung	S.G. 1.20 kg/L	SLB	400 L/min	1.3 min
	underdisplace by 400 L				
	Langsam bis mind. 2 Züge über Zementkopf ausbauen				20.0 min
20.0 m³	Überschuss wenn möglich links abzirkulieren		Rig	1000 L/min	15.0 min
				Total Job Time:	***47 min***

Wasser S.G 1.00 kg/l

	Component		1 m3 spacer			
	Water		1000 L	*	1.4 m³ =	1.4 m3
	D013	Retarder	3.30 kg	*	1.4 m³ =	4.62 kg
	YIELD		1000 L			

Class G S.G 1.90 kg/l

per unit mass blend	Component		1 m3 slurry					
443 lt	Water		582.1 lt	*	5.5 m³ =	3.2 m3	TT required:	167 min
0.50 lt	D206	Antifoam	0.7 lt	*	5.5 m³ =	3.62 lt	TT tested:	270 min
2.00 kg	D167	Fluid Loss	2.6 kg	*	5.5 m³ =	14.49 kg		
2.00 lt	D080A	Dispersant	2.6 lt	*	5.5 m³ =	14.49 lt		
1000.00 kg	D907	Class G	1314.1 kg	*	5.5 m³ =	7.25 to		
761 lt	YIELD		1000 lt					

Material Requirements

Chemical			Needed	Delivered	
D907	Class G	to	7.25		
D013	Retarder	kg	4.62	1	Sack
D080A	Dispersant	lt	14.49	1	Kanister
D167	Fluid Loss	kg	14.49	2	Sack

Fluid Storage Requirements

Mix Fluid Lead	0.0 m³	Mix Fluid Tail	5.5 m³
Spacer	1.4 m³		

Equipment

1 x Pumptruck with CemCAT monitor
1 x Bulktrailer 25 to
1 x Batch Tank 11 m3
1 x Hydraulic Power Pack
1 x Compressor

Notes

Casing hardware, centralizers, and cement plugs provided by the client

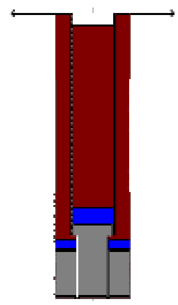
Schlumberger

Max. Deviation: 3 deg

Well:	Atzbach 30			Date:	10 Jun 2011
PLUG	850 - 600 m	MD:	850 m	BHST	35℃
Cement Job:	Plug back	TVD:	850 m	Simulated BHCT	25℃

Cement Volume

	OD	ID	Capacity	Top		Bottom		Length		Volume
OH / Bitsize	6 1/8"		19.01 L/m	600 m	to	850 m	-	250 m	-	4.8 m³
Caliper Measurement	6.144 "		19.13 L/m							0.0 m³
Excess: On Open Hole		0.6%	On Annulus	1.4%						
										4.8 m³
						Annular Excess Over Caliper		33%		0.7 m³



Displacement

Recalculate Before the Job

DP	E200	4 "	3.235	5.303 L/m	477 m	2529 L
Tubing	6.5	2 7/8 "	2.441	3.019 L/m	373 m	1126 L
Riser		4 1/2 "	4.000 "	8.107 L/m	0 m	0 L
Strangvolumen total						**3656 L**
Zement in DP						1200 L
Underdisplacment						500 L
				Total Maximum Displacement:		**1956 L**
Spacer in DP						400 L
				Displacement Spülung:		**1556 L**

Cement Volume: 5.5 m³

Pump Schedule

Volume	Fluid / Action	Density	Pumped by	Rate	Time
	Bohrloch mit 1000 L/min zirkulieren	S.G. 1.20 kg/L	Rig	1000 L/min	0.0 min
	Sicherheitsbesprechung (WEITERZIRKULIEREN!!)				30.0 min
					0.0 min
					0.0 min
1.0 m³	Wasser	S.G. 1.00 kg/L	SLB	800 L/min	1.3 min
	DP-Dart loesen				5.0 min
5.5 m³	Class G	S.G. 1.90 kg/L	SLB	800 L/min	6.9 min
0.4 m³	Verdrängung: Wasser	S.G. 1.00 kg/L	SLB	800 L/min	0.5 min
1.6 m³	Displacement: Spülung	S.G. 1.20 kg/L	SLB	800 L/min	1.9 min
0.5 m³	Spülung	S.G. 1.20 kg/L	SLB	400 L/min	1.3 min
	underdisplace by 500 L				
	Langsam bis mind. 2 Züge über Zementkopf ausbauen				20.0 min
20.0 m³	Überschuss wenn möglich links abzirkulieren		Rig	1000 L/min	15.0 min
				Total Job Time:	*46 min*

Wasser S.G 1.00 kg/l

	Component		1 m3 spacer				
	Water		1000 L	*	1.4 m³	=	1.4 *m3*
	D013	Retarder	3.30 *kg*	*	1.4 m³	=	4.62 *kg*
	YIELD		1000 L				

Class G S.G 1.90 kg/l

per unit mass blend	Component		1 m3 slurry						
443 lt	Water		582.1 *lt*	*	5.5 m³	=	3.2 *m3*	TT required:	166 min
0.50 lt	D206	Antifoam	0.7 *lt*	*	5.5 m³	=	3.62 *lt*	TT tested:	270 min
2.00 kg	D167	Fluid Loss	2.6 *kg*	*	5.5 m³	=	14.49 *kg*		
2.00 lt	D080A	Dispersant	2.6 *lt*	*	5.5 m³	=	14.49 *lt*		
1000.00 kg	D907	Class G	1314.1 *kg*	*	5.5 m³	=	7.25 *to*		
761 lt	YIELD		1000 *lt*						

Material Requirements

Chemical			Needed	Delivered	
D907	Class G	to	7.25		
D013	Retarder	kg	4.62	1	Sack
D080A	Dispersant	lt	14.49	1	Kanister
D167	Fluid Loss	kg	14.49	2	Sack

Fluid Storage Requirements

Mix Fluid Lead	0.0 m³	Mix Fluid Tail	5.5 m³
Spacer	1.4 m³		

Equipment

1 x Pumptruck with CemCAT monitor
1 x Bulktrailer 25 to
1 x Batch Tank 11 m3
1 x Hydraulic Power Pack
1 x Compressor

Notes

Casing hardware, centralizers, and cement plugs provided by the client

Schlumberger

Schlumberger GmbH
Rudolf - Diesel - Str. 23
D - 49377 Vechta
Tel.: +49 4441 953-0
Fax: +49 4441 953-113
Amtsgericht Oldenburg * HRB 112391
Geschäftsführer: Abraham Verburg

Bohrung:
Zementation:
Kunde:
z. Hd.

REFERENZ

MD:	1630 m
TVD:	1193 m
BHST:	45℃
BHCT:	36℃

Datum: 12.06.2009
Version: 1

Fluid 1	Wasser		1.00 kg/ltr	Rheologie Chan 35		
per to Zement	*Code*	*Name*	*per m³ Brühe*	Bob 1	22℃	
443 ltr	Wasser		1000 ltr	600		
				300		
				200		
				100		
				60		
				30		
				6		
				3		
				10' gel		
443 ltr	YIELD		1000 ltr	10" gel		

Testergebnisse

Bemerkungen:

Fluid 2	Class G		1.90 kg/ltr	Rheologie Chan 35		
per to Zement	*Code*	*Name*	*per m³ Brühe*	Bob 1	22℃	
443 ltr	Wasser		582 ltr	600	140	
0.5 ltr	D206	Entschäumer	0.7 ltr	300	83	
2.0 kg	D167	FLAC	2.6 kg	200	64	
2.0 ltr	D080a	Verflüssiger	2.6 ltr	100	41	
				60	31	
				30	22	
				6	13	
				3	12	
1000 kg	Dyck G	Zement	1314 kg	10' gel	13	
761 ltr	YIELD		1000 ltr	10" gel	36	

Testergebnisse

Freie Flüssigkeit:	0.0 % @ 0°
Fluidloss:	74 ml @ 36℃
Versteifungszeit (ohne Anmischzeit)	
100 Bc:	295 min
70 Bc:	270 min
40 Bc:	230 min
Beginn:	195 min
Aufheizzeit:	7 min
Anmischzeit:	15 min

Bemerkungen:

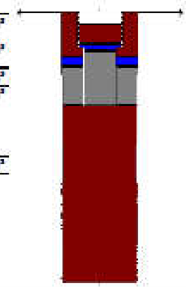
ausgefüllt von	angefragt von	kontrolliert von	
Heike Hanke	Stefan Essl / Juan Carlos Peña	Roeland Verbakel ☑	Leonardo Pagani
SLB Laborant	*SLB Field Engineer*	*SLB Geomarket Technical Engineer*	*Field Service Manager*

Die Mischanleitung (Field Mixing) beachten !

	Max. Deviation:	3 deg	Schlumberger
Well: Atzbach 30			Date: 10 Jun 2011
PLUG 600 - 350 m	MD:	600 m	BHST 27°C
Cement Job: Plug back	TVD:	600 m	Simulated BHCT 20°C

Cement Volume

	OD	ID	Capacity	Top		Bottom		Length		Volume
OH / Bitsize	6 1/8"		19.01 L/m	350 m	to	600 m	-	250 m	-	4.8 m³
Caliper Measurement	6.144 "		19.13 L/m							0.0 m³
Excess: On Open Hole		0.6%	On Annulus	1.4%						
										4.8 m³
						Annular Excess Over Caliper	10%			0.2 m³



Displacement *Recalculate Before the Job*

		OD	ID	Capacity	Length	Volume
DP	E200	4 "	3.235	5.303 L/m	227 m	1204 L
Tubing	6.5	2 7/8 "	2.441	3.019 L/m	373 m	1126 L
Riser		4 1/2 "	4.000 "	8.107 L/m	0 m	0 L
Strangvolumen total						**2330 L**
Zement in DP						1050 L
Underdisplacment						400 L
				Total Maximum Displacement:		**880 L**
Spacer in DP						200 L
				Displacement Spülung:		**680 L**

Cement Volume: 5.0 m³

Pump Schedule

Volume	Fluid / Action	Density	Pumped by	Rate	Time
	Bohrloch mit 1000 L/min zirkulieren	S.G. 1.20 kg/L	Rig	1000 L/min	0.0 min
	Sicherheitsbesprechung (WEITERZIRKULIEREN!!)				30.0 min
					0.0 min
					0.0 min
1.0 m³	Wasser	S.G. 1.00 kg/L	SLB	800 L/min	1.3 min
	DP-Dart loesen				5.0 min
5.0 m³	Class G	S.G. 2.03 kg/L	SLB	800 L/min	6.3 min
0.2 m³	Verdrängung: Wasser	S.G. 1.00 kg/L	SLB	800 L/min	0.3 min
0.7 m³	Displacement: Spülung	S.G. 1.20 kg/L	SLB	800 L/min	0.8 min
0.5 m³	Spülung	S.G. 1.20 kg/L	SLB	400 L/min	1.3 min
	underdisplace by 400 L				
	Langsam bis mind. 2 Züge über Zementkopf ausbauen				20.0 min
20.0 m³	Überschuss wenn möglich links abzirkulieren		Rig	1000 L/min	15.0 min
				Total Job Time:	***44 min***

Wasser **S.G** **1.00 kg/l**

	Component		1 m3 spacer				
	Water		1000 L	*	1.2 m³	=	1.2 m3
	D013	Retarder	3.30 kg	*	1.2 m³	=	3.96 kg
	YIELD		1000 L				

Class G **S.G** **2.03 kg/l**

per unit mass blend	Component		1 m3 slurry						
347 lt	Water		521.8 lt	*	5.0 m³	=	2.6 m3	**TT required:**	**164 min**
0.50 lt	D206	Antifoam	0.8 lt	*	5.0 m³	=	3.76 lt	**TT tested:**	**190 min**
0.00 kg	D167	Fluid Loss	0.0 kg	*	5.0 m³	=	0.00 kg		
3.00 lt	D080A	Dispersant	4.5 lt	*	5.0 m³	=	22.57 lt		
1000.00 kg	D907	Class G	1503.8 kg	*	5.0 m³	=	7.52 to		
665 lt	YIELD		1000 lt						

Material Requirements

Chemical			Needed	Delivered	
D907	Class G	to	7.52		
D013	Retarder	kg	3.96	1	Sack
D080A	Dispersant	lt	22.57	2	Kanister
D167	Fluid Loss	kg			Sack

Fluid Storage Requirements

Mix Fluid Lead	0.0 m³	Mix Fluid Tail	5.0 m³
Spacer	1.2 m³		

Equipment

1 x Pumptruck with CemCAT monitor
1 x Bulktrailer 25 to
1 x Batch Tank 11 m3
1 x Hydraulic Power Pack
1 x Compressor

Notes

Casing hardware, centralizers, and cement plugs provided by the client

Schlumberger

Seite 1 / 1

REFERENZ

Bohrung:
Zementation:
Kunde:
z. Hd.

MD:
TVD:
BHST:
BHCT:

Schlumberger GmbH
Rudolf - Diesel - Str. 23
D - 49377 Vechta
Tel.: +49 4441 953-0
Fax: +49 4441 953-113
Amtsgericht Oldenburg * HRB 112391
Geschäftsführer: Abraham Verburg

Datum: 20.04.2010
Version: 1

Fluid 1	1.00 kg/ltr	Wasser			Rheologie Chan 35			Testergebnisse
per to Zement	*Code*	*Name*	*Lot-Nr*	*per m³ Brühe*	**Bob 1**	**22°C**		
1000 ltr	Wasser			1000 ltr	600			
					300			
					200			
					100			
					60			
					30			
					6			
					3			
					10' gel			
1000 ltr	YIELD			1000 ltr	10" gel			

Bemerkungen:

Fluid 2	2.03 kg/ltr	Class G			Rheologie Chan 35			Testergebnisse	
per to Zement	*Code*	*Name*	*Lot-Nr*	*per m³ Brühe*	**Bob 1**	**22°C**			
347 ltr	Wasser		Vechta	522 ltr	600				
0.5 ltr	D206	Entschäumer	0817840J	0.8 ltr	300	132		Freie Flüssigkeit:	0.0 % @ 0°Neigung
3.0 ltr	D080a	Verflüssiger	FAB0902837	4.5 ltr	200	104			
					100	72		*Versteifungszeit (ohne Anmischzeit)*	
					60	59		100 Bc:	230 min
					30	47		70 Bc:	190 min
					6	28		40 Bc:	130 min
					3	23		Beginn:	60 min
1000 kg	Dyck G	Zement	Sieming 19787	1503 kg	10' gel	25		Aufheizzeit:	10 min
665 ltr	YIELD			1000 ltr	10" gel	30		Anmischzeit:	20 min

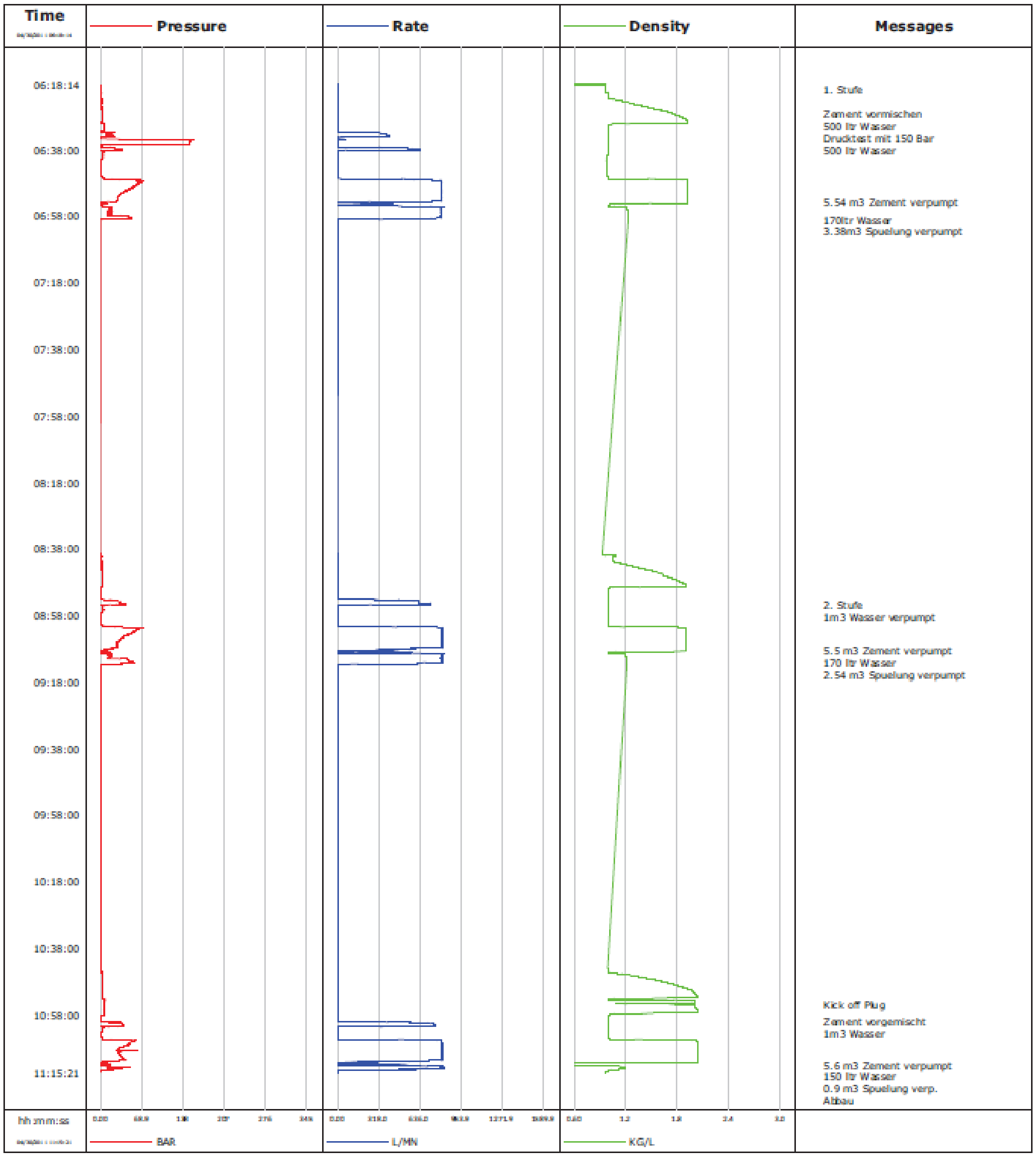
Bemerkungen:

ausgefüllt von	angefragt von	kontrolliert von	
Heike Hanke	Stefan Essl	Henning Blume ☐	Leonardo Pagani
SLB Laborant	*SLB Field Engineer*	*SLB District Technical Engineer*	*Field Service Manager*

Die Mischanleitung (Field Mixing) beachten !

Schlumberger | **Cementing Job Report** | CemCAT v1.3

Well	ATZ-030	**Client**	RAG
Field	Atzbach	**SIR No.**	110256
Engineer	Kim Diers	**Job Type**	Plug Back / Kick off Plug
Country	Austria	**Job Date**	04-30-2011



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APPENDIX B – Excel Sheet for last 5 plugs

Well	Rig	System Name	Cement Stage	planed Interval			OH /CH	"mech. Stop" (base,Cement Plug, Highpille, CST Tool,...)	Date / Time
				Lower End	Upper End	Stage Length [m]			
Bad Hall Nord 4	E202	Brücke 1	stage 1	2215	1915	300	OH	Base	28.01.11 14:00 - 29.01.11 13:00
Bad Hall Nord 4	E202	Brücke 1	stage 2	1915	1615	300	OH	Cement Plug	28.01.11 14:00 - 29.01.11 13:00
Bad Hall Nord 4	E202	Brücke 2	stage 3	980	680	300	OH	CST Tool	29.01.11 13:00 - 30.01.11 18:00
Bad Hall Nord 4A	E202	Brücke 1	stage 1	2215	1915	300	OH	Base	10.02.11 17:00 - 11.02.11 12:00
Bad Hall Nord 4A	E202	Brücke 2	stage 2	1915	1615	300	OH	Cement Plug	11.02.11 12:00 - 12.02.11 11:00
Bad Hall Nord 4A	E202	Brücke 3	stage 3	920	620	300	OH	Mud	12.02.11 11:00 - 13.01.11 01:30
Atzbach 30	E200	Brücke 1	stage 1	1100	850	250	OH	Highpille	30.04.11 06:00 - 30.04.11 14:00
Atzbach 30	E200	Brücke 1	stage 2	850	600	250	OH	Cement Plug	30.04.11 06:00 - 30.04.11 14:00
Atzbach 30	E200	Brücke 1	stage 3	600	350	250	OH u. CH	Cement Plug	30.04.11 06:00 - 30.04.11 14:00
Hipping 1	E200	Brücke 2	stage 1	1440	1245	195	OH	Highpille	27.05.11 06:00 - 27.05.11 14:00
Hipping 1	E200	Brücke 2	stage 2	1245	1045	200	OH	Cement Plug	27.05.11 06:00 - 27.05.11 14:00
Hipping 1	E200	Brücke 1	stage 3	400	200	200	OH/CH	Highpille	27.05.11 06:00 - 27.05.11 14:00
Hipping 1	E200	Brücke 3	stage 4	240	2	238	CH	Cement Plug	28.05.11 05:00 - 28.05.11 12:00
RAG 55	E202	Brücke 1	stage 1	2557	2300	257	OH	Base	30.05.11 05:00 - 30.05.11 18:00
RAG 55	E202	Brücke 1	stage 2	2300	2050	250	OH	Cement Plug	30.05.11 05:00 - 30.05.11 18:00
RAG 55	E202	Brücke 1	stage 3	2050	1800	250	OH	Cement Plug	30.05.11 05:00 - 30.05.11 18:00
RAG 55	E202	Brücke 1	stage 4	1800	1550	250	OH	Cement Plug	30.05.11 05:00 - 30.05.11 18:00
RAG 55	E202	Brücke 1	stage 5	1580	1323	257	OH	Cement Plug	31.05.11 19:00 - 01.06.11 08:00
RAG 55	E202	Brücke 1	stage 6	1323	1074	249	OH	Cement Plug	31.05.11 19:00 - 01.06.11 08:00
RAG 55	E202	Brücke 1	stage 7	1074	841	233	OH	Cement Plug	31.05.11 19:00 - 01.06.11 08:00
RAG 55	E202	Brücke 1	stage 8	841	576	265	OH/CH	Cement Plug	31.05.11 19:00 - 01.06.11 08:00
RAG 55	E202	Brücke 1	stage 9	109	1.5	107.5	CH	Highpille	01.06.11 23:00 - 02.06.11 04:00

Ok /not OK	comment
Cement at 715m loaded with 8tonnes, till 745m nearly no cement resistance	CST tool vor verpumpt
Cement at 1919.5m loaded with 3 tonnes Cement at 1623.5m loaded with 3 tonnes Cement at 632 m loaded with 3 tonnes	
Cement at 340m loaded with 4tonnes,drilled to 403m	1300m-1100m 4 m^3 highpille 1,5kg/l
Cement at 240m loaded with 3tonnes	highpille 3.8m^3 from 1630 - 1440 highpille 4 m^3 from 580-400m
Cement at 1580m Cement at 599.6m	Hydro Mech bridge plug + Highpille 3 m^3

Lithologie																
Total	check. Sum [m]	gravel (Schotter) [m]	marly clay (Tonmergel) [m]	interbedded marly clay -sandstone (Tonmergel-Sandstein Wechsel-lagerung) [m]	Interbedded marly clay - conglomerate (Tonmergel-Konglomerat Wechsel-lagerung) [m]	marly lime (Kalk-mergel) [m]	sandstone (Sandstein) [m]	conglomerat (Konglo-merat) [m]	lime (Kalk) [m]	Lithomien-kalk [m]	cyristallite (Kristallin) [m]	Nettos [m]	G=gas w=water x=nothing	porosity [%]	Salinity [ppm]	Geology responsible for failure yes/no/possible
bis 2123 Tor	300	0	220	40	0	0	0	0	0	0	40	9.4	w	15	n/a	possible
bis 1816 Tor	300	0	257	21	0	15	5	0	0	2	0	6.5	w	20	n/a	possible
bis 1816 Tor	300	0	300	0	0	0	0	0	0	0	0	0	w	0	0	no
bis 2118Ton	300	0	213	40	0	0	0	0	0	0	47	13.3	w	n/a	n/a	possible
bis 1850 Tor	300	0	258	30	0	9	0	0	0	3	0	10.9	w	n/a	n/a	possible
bis 1850 Tor	300	0	300	0	0	0	0	0	0	0	0	0	x	n/a	n/a	no
	250	0	250	0	0	0	0	0	0	0	0	6.9	w	22	n/a	no
	250	0	250	0	0	0	0	0	0	0	0	0	x	0	0	no
bis 1740 Tor	250	0	250	0	0	0	0	0	0	0	0	0	x	0	0	no
ab 330m To	195	0	195	0	0	0	0	0	0	0	0	7.3	w	n/a	n/a	possible
	200	0	200	0	0	0	0	0	0	0	0	1.4	w	18	n/a	no
	200	0	70	130	0	0	0	0	0	0	0	n/a	w	n/a	n/a	possible
	238	118	0	120	0	0	0	0	0	0	0	0	x	0	0	no
	257	0	225	29	0	0	3	0	0	0	0	0	x	n/a	n/a	no
	250	0	85	150	0	0	15	0	0	0	0	51	w	n/a	n/a	possible
	250	0	131	87	0	0	32	0	0	0	0	n/a	w	n/a	n/a	possible
	250	0	106	86	0	0	58	0	0	0	0	67	w	n/a	n/a	possible
	257	0	130	127	0	0	0	0	0	0	0	69.2	w	n/a	n/a	possible
	249	0	189	0	0	0	0	60	0	0	0	90.5	w	n/a	n/a	possible
	233	0	212	18	0	0	3	0	0	0	0	37	w	n/a	n/a	yes
	265	0	265	0	0	0	0	0	0	0	0	12.6	w	n/a	n/a	yes
	107.5	0	0	107.5	0	0	0	0	0	0	0	0	x	n/a	n/a	no

Annulus Not Filled Up: Plug Advisor: Simulation Volume Optimization, Pull Out of Hole						Annulus Filled UP : Plug Advisor: Simulation Volume Optimization, Pull Out of Hole					
simulation with planned values: length of contaminated cement after POOH [m]	simulation with actual values: length of contaminated cement after POOH [m]	simulation with planned values: length of uncontaminated cement after POOH [m]	simulation with actual values: length of uncontaminated cement after POOH [m]	simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]	simulation with planned values: length of contaminated cement after POOH [m]	simulation with actual values: length of contaminated cement after POOH [m]	simulation with planned values: length of uncontaminated cement after POOH [m]	simulation with actual values: length of uncontaminated cement after POOH [m]	simulation with planned values: uncontaminated TOC (MD) [m]	simulation with actual values: uncontaminated TOC (MD) [m]
0	93	306	240	1908	1974	0	1927(35)	306	287	1908	1927
69	22	262	307	1653	1608	1622 (0)	1615(0)	293	300	1622	1615
0	51	303	270	677	710	0	15	303	296	677	684
48	35	283	320	1931	1894	0	1901(25)	313	313	1901	1901
0	38	311	319	1604	1596	1607 (0)	38	308	319	1607	1596
0	47	300	295	650	635	n/A	47	0	295	0	635
118	40	216	257	884	843	820(0)	826(5)	280	274	820	826
102	152	225	192	625	658	571(0)	33	279	278	571	572
83	19	196	260	404	340	347(0)	329(20)	253	271	347	329
47	12	167	194	1273	1246	0	1256(0)	195	184	1245	1256
0	44	195	185	1050	1060	1059(0)	1043(0)	186	202	1059	1043
0	35	200	212	200	188	202(10)	79	198	209	202	191
39	53	230	222	2327	2335	0	0	257	259	2300	2298
44	83	226	196	2072	2102	0	5	259	255	2039	2043
56	42	225	227	1825	1823	8	1797(0)	259	225	1791	1797
44	49	229	225	1571	1575	0	0	262	261	1538	1539
43	54	226	222	1354	1358	0	0	256	262	1324	1318
44	48	217	217	1106	1106	1076(0)	10	247	245	1076	1078
36	38	212	214	863	861	839(0)	836(0)	236	239	839	836
46	42	234	231	605	608	0	580(0)	266	259	573	580

Plug Advisor: Placement Fluid Mixing During Placement															
simulation with planned values: Pipe Risk high	simulation with planned values: Pipe Risk medium	simulation with planned values: Pipe Risk low	simulation with planned values: Annulus Risk high	simulation with planned values: Annulus Risk medium	simulation with planned values: Annulus Risk low	simulation with planned values: TOC (MD) high	simulation with planned values: TOC (MD) low	simulation with actual values: Pipe Risk high	simulation with actual values: Pipe Risk medium	simulation with actual values: Pipe Risk low	simulation with actual values: Annulus Risk high	simulation with actual values: Annulus Risk medium	simulation with actual values: Annulus Risk low	simulation with actual values: TOC (MD) high	simulation with actual values: TOC (MD) low
223	89	402	77	11	260	1904	1926	214	80	464	77	11	238	1926	1937
178	62	352	335	19	273	1609	1637	162	62	452	77	10	263	1599	1609
63	24	422	39	5	277	671	681	67	28	410	34	5	282	657	701
205	71	446	542	22	249	1904	1926	214	80	482	89	11	260	1893	1915
174	140	177	326	19	302	1580	1647	170	62	483	278	19	254	1599	1618
61	23	456	43	10	264	646	656	60	22	476	47	9	258	623	637
110	62	279	50	6	283	820	864	93	31	433	44	6	239	825	836
61	20	385	30	9	270	565	582	72	48	323	38	4	278	527	638
58	24	309	30	6	251	345	363	36	12	418	27	6	248	327	333
162	87	251	79	7	169	1238	1260	133	52	401	65	7	148	1253	1267
110	80	308	50	6	165	1058	1064	135	75	268	44	6	190	1040	1052
34	11	220	22	4	203	204	208	29	10	289	24	4	209	192	196
236	123	313	89	13	224	2289	2314	247	133	282	89	13	224	2289	2314
213	120	289	69	11	236	2022	2057	213	129	271	57	23	224	2034	2057
181	115	282	72	10	241	1784	1804	181	107	298	62	10	231	1784	1814
152	79	320	54	9	239	1521	1557	145	87	320	54	9	239	1530	1548
121	70	333	55	16	233	1319	1335	121	70	327	55	16	241	1311	1327
101	59	328	46	7	228	1072	1085	101	59	328	40	13	228	1065	1085
73	48	336	38	5	223	833	844	78	43	340	38	5	228	833	844
50	20	380	42	8	245	571	583	50	20	376	34	8	241	579	587

Inclination [°]	Operation before/after Cement job			Rig parameter						
	Time [h]	Operation before	WOC [h]	POOH average Speed [m/s]	POOH max. Speed [m/s]	Rotation duration [min]	Rotation [rpm]	Rotation torque [Nm]	Nr. of Pipes pulled out	Pipe pulled out [m]
54.15	6.50	Round trip - Circulation	0.16	0.33	0.35	38.00	12.15	5000.00	33	306.90
max 54.15			16.0	0.25	0.37	32.0	11.60	3500.0	32	297.60
0.0			23.5	0.32	0.34	26.0	13.00	1950.0	32	297.60
38.91	7	SLB Test, Mud losses 500l/h	14	0.15	0.22	33	12.34	6500	33	306.90
max 38.91			11.5	0.14	0.35	23	4.25	4300	32	297.60
max. 15			11	0.53	1.05	17	14.50	1600	32	297.60
0	9	SLB Log: HALS PEX GR SP BHC		0.14	0.17	12	19.80	3050	28	260.40
0				0.14	0.19	11	20.00	3000	26	241.80
0			16	0.20	0.47	10	20.00	5776	29	269.70
40	8	pumping Highpill	0.1	0.14	0.22	0	0.00	0	21	195.30
max. 40			1	0.12	0.26	0	0.00	0	21	195.30
max. 10		pumping Highpill	12	0.14	0.25	0	0.00	0	19	176.70
0	12	wait on cement	99	0.20	0.35	0	0.00	0	24	223.20
35.46	15.5	Circulating gas out	0.1	0.11	0.15	0			29	269.70
max. 35.46			0.1	0.06	0.13	0			28	260.40
max. 35.46			0.1	0.09	0.14	0	0.00	0	27	251.10
max. 21.42			12	0.10	0.14	0	0.00	0	28	260.40
10	12	wait on cement	0.1	0.12	0.15	20	16.00	4500	29	269.70
10			0.1	0.10	0.12	19	10.00	4000	27	251.10
10			0.1	0.07	0.15	0	0.00	0	25	232.50
0	4	Set hydro mech bridge plug	10	0.11	0.15	0	0.00	0	29	269.70
0			99							

Mudpush/water - Mud Difference			Cement - Mudpush/water Difference			Cement - Highpille		Cement-Mud Difference		
Density [kg/l]	Viscosity [mPas]	Yieldpoint [lbs/100ft^2]	Density [kg/l]	Viscosity [mPas]	Yieldpoint [lbs/100ft^2]	Density Highpille [kg/l]	Density [kg/l]	Density [kg/l]	Viscosity [mPas]	Yieldpoint [lbs/100ft^2]
-0.30	-44.00	-43.00	0.90	82.00	7.00	0	No HighPill	0.60	38.00	-36.00
-0.30	-44.00	-43.00	0.90	97.00	26.00	0.00	No HighPill	0.60	53.00	-17.00
0.20	-26.00	-16.00	0.50	106.00	23.00	0.00	No HighPill	0.70	80.00	7.00
-0.29	-49.00	-29.00	0.90	85.00	24.00	0.00	No HighPill	0.61	36.00	-5.00
-0.29	-49.00	-29.00	0.90	95.00	20.00	0.00	No HighPill	0.61	46.00	-9.00
-0.26	-29.00	-12.00	0.90	-1.00	0.00	0.00	No HighPill	0.64	-30.00	-12.00
-0.23	-38.00	-6.00	0.90	89.00	25.00	1.50	0.40	0.67	51.00	19.00
-0.23	-38.00	-6.00	0.90	84.00	25.00	0.00	No HighPill	0.67	46.00	19.00
-0.23	-38.00	-6.00	1.03	84.00	80.00	0.00	No HighPill	0.80	46.00	74.00
-0.22	-28.00	-6.00	0.90	73.00	22.00	0.00	No HighPill	0.68	45.00	16.00
-0.22	-28.00	-6.00	0.90	61.00	28.00	0.00	No HighPill	0.68	33.00	22.00
-0.22	-28.00	-6.00	0.90	41.00	33.00	0.00	No HighPill	0.68	13.00	27.00
-0.22	-28.00	-6.00	0.90	43.00	26.00	0.00	No HighPill	0.68	15.00	20.00
-0.16	-28.00	-9.00	0.90	125.00	30.00	0.00	No HighPill	0.74	97.00	21.00
-0.16	-28.00	-9.00	0.90	123.00	32.00	0.00	No HighPill	0.74	95.00	23.00
-0.16	-28.00	-9.00	0.90	127.00	50.00	0.00	No HighPill	0.74	99.00	41.00
-0.16	-28.00	-9.00	0.90	129.00	70.00	0.00	No HighPill	0.74	101.00	61.00
-0.16	-28.00	-9.00	0.91	96.00	67.00	0.00	No HighPill	0.75	68.00	58.00
-0.16	-28.00	-9.00	0.91	93.00	27.00	0.00	No HighPill	0.75	65.00	18.00
-0.16	-28.00	-9.00	0.91	101.00	66.00	0.00	No HighPill	0.75	73.00	57.00
-0.16	-28.00	-9.00	0.91	63.00	48.00	0.00	No HighPill	0.75	35.00	39.00
-0.16	-28.00	-9.00	0.91	35.00	44.00	0.00	No HighPill	0.75	7.00	35.00

Mud before the Cementation																	
Type	Density [kg/l]	Flowtime [sec]	Temp.	Filtrate Water	Filter Cake	PH	Sand	PV [cps]	YP [lbs/100ft^2]	GST	Diameter [in]	Cement Liner Length [m]	Hole Diameter after Caliper [in]	calc. Cement Volume [m^3]	Cement Volume after caliper [m^3]	Safty margin [%]	Underdis-placement [l]
KK	1.30	102.00		1.70	0.40	10.50	0.20	45.00	43.00	5/14	3 1/2		8 1/2	11	13	18	450
KK	1.30	102.00		1.70	0.40	10.50	0.20	45.00	43.00	5/14	3 1/2		8 1/2	11	13	18	640
KK	1.30	102.00		1.70	0.40	10.50	0.20	45.00	43.00	5/14	3 1/2		8 1/2	11.1	12.5	13	680
KK	1.29	79		1.6	0.2	10.7	0.2	50	29	3 /5	3 1/2		8 1/2	11	13	18	680
KK	1.29	79		1.6	0.2	10.7	0.2	50	29	3 /5	3 1/2		8 1/2	11	13	18	730
KK	1.26	58		2.6	0.3	10.7	0.1	30	12	3	3 1/2		8 1/2	11	13	18	680
KK	1.23	60	30	1.8	0.2	10.6	0.1	39	6	1	2 7/8	373.36	6 1/8	4.7	4.6	15	400
KK	1.23	60	30	1.8	0.2	10.6	0.1	39	6	1	2 7/8	373.36	6 1/8	4.7	4.6	15	500
KK	1.23	60	30	1.8	0.2	10.6	0.1	39	6	1	2 7/8	373.36	6 1/8	4.8	4.8	15	400
KK	1.22	57	43	1.7	0.2		0.1	29	6	1	2 7/8	372	6 1/8	3.7	3.9	6	250
KK	1.22	57	43	1.7	0.2		0.1	29	6	1	2 7/8	372	6 1/8	3.7	3.8	8	250
KK	1.22	57	43	1.7	0.2		0.1	29	6	1	2 7/8	372	6 1/8	3.1	4.2	15	45
KK	1.22	57	43	1.7	0.2		0.1	29	6	1	2 7/8		7	5		0	0
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		10.3	0	1088
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		9.9	0	1060
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		10.2	3	1060
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		10.0	0	1113
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		11.0	3	1096
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		10.7	0	1062
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		10.0	0	1038
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2	372	8 1/2		11.7	0	1142
KK	1.16	55	45	2.4	0.3	10.3	0.3	29	9	1	3 1/2		9 5/8			0	0

Mudpush															
total Volume [l]	Density [kg/l]	water [m^3]	Baryte [kg]	D031 [kg] Retarder	D175 [l] Antifoam old	D182[kg] Mudpush II	D206[l] Antifoam new	600rpm	300rpm	200rpm	100rpm	6rpm	3rpm	Plastic viscosity [cps]	Yield point [lbs/100 ft²]
3200	1 1 1.5	2.7		2000		32	1.6	65	46	37	28	11	9	1 1 19	27
	1 1 1													1 1 1	
	1 1 1													1 1 1	
	1 1 1 1													1 1 1 1	
	1 1 1 1 1 1 1 1 1													1 1 1 1 1 1 1 1 1	

Cement																	
Class	total Volume [l]	Ammount of Cement [kg]	Density [kg/l]	Water [m^3]	Bentonit [kg]	S001 [kg] Salt	D013 [kg] Retarder	D047[l] Antifoam old	D076 [kg] Hematite	D080A[l] Dispersant	D095[kg] CemNet	D167[kg] UNIFLAC-S	D175 [l] Antifoam old	D182[kg] Mudpush II	D206[l] Antifoam new	D500 [l] GASBLOK LT	Silica [kg]
G	13000	17000	1.9	7.5			42.5					34			17		
G	13000	17000	1.9	7.5			42.5					51			8.5		
G	12500	18160	2	6.6			18.1			72.6		36.3			9		
G	13000	17000	1.9	7.5			42.5					51			8.5		200
G	13000	17000	1.9	7.5			42.5					51			8.5		
G	13000	17000	1.9	7.6											8.5		
Tailschlämm	5500	7250	1.9	3.2						14.5		14.5			3.6		
Tailschlämm	5500	7250	1.9	3.2						14.5		14.5			3.6		
Tailschlämm	5400	8500	2.03	2.6						14.5		14.5			3.6		
Tailschlämm	4200	5560	1.9	2.5						11.1		11.1			2.8		
Tailschlämm	4200	5560	1.9	2.5						11.1		11.1			2.8		
Tailschlämm	4600	6000	1.9	2.5											2.8		
Tailschlämm	5000	6500	1.9	1.5											2.7		
G	10400	13690	1.9	6.1			34			7		41			7		
G	10200	13400	1.9	5.9			33			7		40			7		
G	11000	13780	1.9	6.1			34			7		41			7		
G	10400	13600	1.9	6			27					41			7		
G	10500	14500	1.91	6.5						28.5		28.5			7		
G	10700	14500	1.91	6.5						28.5		28.5			7		
G	10800	13900	1.91	6.2						22.5		14.5			7		
G	10700	14500	1.91	6.2						22.5		14.5			7	1060	
G	4500	6000	1.91	2.5											3		

Cement											
600rpm	300rpm	200rpm	100rpm	6rpm	3rpm	Plastic viscosity [cps]	Yield point [lbs/100 ft²]	Thickening time req. [min]	Thickening time tested [min]	Comment
173	90	63	35	6	4	83	7	208	210	Lab test was performend with different Additive amounts
222	124	89	53	14	11	98	26	204	210	
300	175	121	64	6	4	125	50	191	NA	No Lab test for hardening time
196	110	81	48	13	10	86	24	208	210	Lab test without sand (silica)
212	116	84	48	9	7	96	20	204	210	
						0	0	191	305	HV-pill sugested but not pumped liNo Rheology test from RAG
205	115	83	50	16	14	90	25			
195	110	80	50	17	15	85	25			
250	165	135	95	30	20	85	80			
170	96	70	43	14	12	74	22			
152	90	68	45	20	18	62	28			
117	75	60	45	21	13	42	33			
114	70	56	42	22	19	44	26			
282	156	110	61	8	5	126	30			
280	156	11	63	9	7	124	32			
306	178	129	76	15	13	128	50			
330	200	152	93	24	20	130	70			
261	164	124	80	30	26	97	67			
215	121	89	54	16	13	94	27			
270	168	127	83	34	29	102	66			
176	112	89	59	20	16	64	48			
116	80	63	47	23	14	36	44			

Pumped Volumes											
Pre Pumped Water plan [m^3]	Pre Pumped Water actual [m^3]	Pre Pumped Mudpush plan [m^3]	Pre Pumped Mudpush actual [m^3]	Cement plan [m^3]	Cement actual [m^3]	Post Pumped Water plan [m^3]	Post Pumped Water actual [m^3]	Post Pumped Mudpush plan [m^3]	Post Pumped Mudpush actual [m^3]	Post Pumped Mud plan [m^3]	Post Pumped Mud actual [m^3]
3.5	3.56			13	12.89	1	1.06			15	14.46
3.5	3.69			13	13.31	0.9	0.93			12.3	12.34
		2.4	2.48	12.5	12.64			0.8	0.77	3.8	3.878
3.5	3.53			13	13.47	0.5	0.54			15.2	14.6
3.5	3.51			13	13.49	0.9	0.53			12.4	11.81
3	3.01			13	12.96	0.5	0.52			3.3	3.01
1	0.838			5.5	5.403	0.4	0.22			3.5	3.13
1	0.993			5.5	5.471	0.4	0.173			2.1	2.368
1	1.008			5	5.411	0.2	0.158			1.2	0.739
1.2	1.327			4.2	4.08	0.7	0.411			4.4	4.84
1.3	1.328			4.2	4.148	0.7	0.576			4.4	4.09
1.3	1.323			4.3	4.583	0.3	0			0.7	0.34
1.3	0.828			4.1	5.111	0	0.9				0
2	1.745			10.4	10.461	0.3	0.312			18.8	16.623
2	1.172			10.2	10.09	0.3	0.312			16.5	16.623
2	2.016			10.5	10.228	0.3	0.27			14.3	14.278
2	1.987			10.4	10.379	0.3	0.277			12	12.01
2	2.005			10.7	10.923	0.3	0.278			10	10.161
2	3.6			10.7	10.81	0.3	0.292			7.8	7.801
2	2.009			10.7	10.838	0.3	0.28			5.6	5.608
2	2.003			10.7	10.455	0.3	0.281			3.3	3.315

Pumprates [l/min]													Dart
Mudpush plan	Mudpush actual	Water before plan	Water before actual	Cement plan	Cement actual	Water afterwards plan	Water afterwards actual	Mudpush afterwards plan	Mudpush afterwards actual	Mud afterwards plan	Mud afterwards actual	Comments	
		800	800	800	680/800	800	800			800/400	800-715/400	Cem ent started pumping with 650 l/min	DP Dart
		800	640/500	800	680	800	800			800/400	715-800/400		DP Dart
800/600	516/715			800	680			800	500	800/400	640-760/400		DP Dart
		800	480-620	800	800	800	800			800/400	800		DP Dart
		800	600-300	800	800	800	640			800/400	800		DP Dart
		800	600-200	800	800	800	800			800/400	800		DP Dart
		800	400	800	800	800	400			800/400	800		DP Dart
		800	626	800	800/400	800	550			800/400	804		DP Dart
		800	751	800	804	800	542			800/400	800		DP Dart
			470		602		520			602			DP Dart
			602		607		550			602			DP Dart
			607		607					476			DP Dart
			520		410/120		300						
			500		809		493			804			DP Dart
			666		809		400			928			DP Dart
			770		840		666			810			DP Dart
			777		822		702			811			DP Dart
			800		804		813			810			DP Dart
			800		826		770			800			DP Dart
			817		835		777			809			DP Dart
			804		826		700			806			DP Dart