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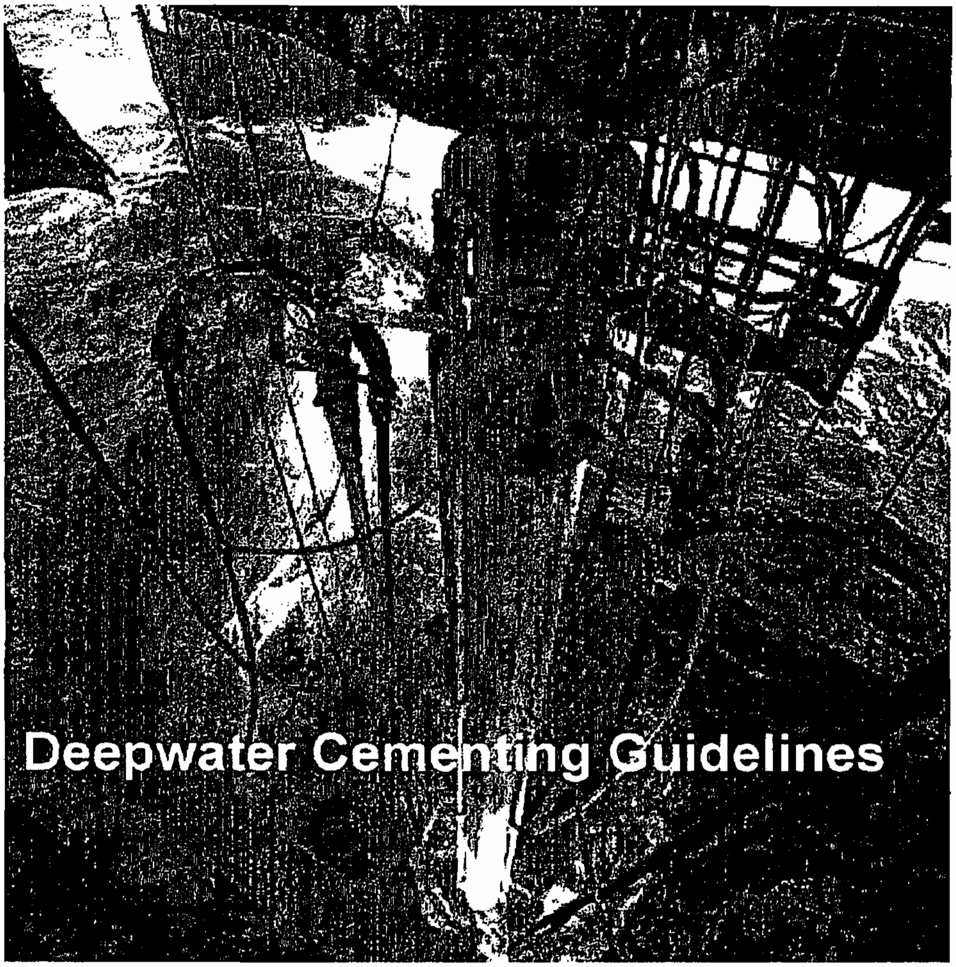


Executive Summary:

This document has been prepared to aid in the planning and execution of deepwater drilling. It addresses those aspects of cementing deepwater wells which are not generally found in cementing shallower-water wells or onshore. It does not address aspects which are common to all wells – e.g. the need for proper job planning, risk assessment and mitigation including, most importantly, good mud displacement. No slurry, however well designed or 'high-tech', will avoid the need for good mud displacement.

This document relies very heavily on the work done to prepare API RECOMMENDED PRACTICE 65, FIRST EDITION, SEPTEMBER 2002, Cementing Shallow Water Flow Zones in Deep Water Wells. This document should be read in parallel with these guidelines. Many of the considerations in this Recommended Practice apply, to some extent, to deepwater wells in general and to any circumstance where cementing close to balance. Although written around SWF cementing in GoM, there is much good practice which applies in a wider context.

Most of the issues which arise in deepwater cementing are concerned with the shallow casing strings. The deeper sections of the well can be approached in a relatively conventional manner, the main difference being one of economics and risk management (rig time) rather than technical difficulty in designing a cement slurry and placement schedule. However, tight annuli and narrow pore/fracture windows do complicate many deepwater wells, as do issues around trapped annular pressure.

Recent interest by the MMS in the US in the numbers of wells which show evidence of annular pressure communication is influencing assurance processes in the industry. Operators will increasingly be pressed to demonstrate use of best practice. This will require better documentation of risk evaluation and mitigation steps. These guidelines will aid such an approach.

Contents:

Assurance check list:

	Issue	Actions
1.	Ensure the cementing contractor understands the issues around planning and execution for deepwater wells: SWF's Narrow Pore/Fracture window Need for more complex Lab testing and simulation	-Competency assessment. -Check knowledge and understanding of API RP 65. -Lab audit.
2.	Good drilling practices - to produce good hole conditions - are essential and become extremely critical if cementing against a strong, shallow flow zone.	See API RP 65, Section 5, this document and facilitate teamwork with the mud contractor.
3.	Computer simulation of mud displacement should be undertaken for all critical hole sections using rheology data which accurately reflects what is in the well rather than assumed, or programmed, figures for PV, YP & Gels. Realistic estimates of hole size and casing eccentricity are essential. Do not assume bit size and 80% stand-off.	The latest CemCade model now represents 'state of the art' for fluid displacement.
4.	SWF potential – consider if the cement job design must be capable of stopping a flow and whether this may be a strong flow. Complexity (and cost) of the job design will increase exponentially. Do you really want to cover a low probability with a high cost, complex solution?	Do full Risk Assessment.
5.	For SWF control, the slurry design selection should be based on the criteria of pressure maintenance (foamed) or rapid gel strength development (to 500 lb/100ft^2 in ~20 minutes), or a combination of the two.	The Cementing Basis of Design Document (BoD) must address the choice of slurry by (for example) ranking and evaluating the options.
6.	Lab testing of high performance slurries must follow the likely temperature profile the slurry will see during mixing, pumping, displacement and following 'plug bump'	-Computer modeling of temperature profile for first, middle and last sack. -lab equipment and procedures in place to reproduce this profile.
7.	If using high performance blended cement, ensure suitable quality control measures are in place. Logistics and transfers must be covered in detail. Tanks must be cleaned and inspected.	Guidelines are given in this document and in RP 65.

8.	For tight annuli and/or situations where the pore/fracture window is tight, computer simulations of ECD/pressure drops/surge pressures should use realistic rheology data which takes account of temperature effects (low temperature in the riser and close to seabed). Consider well site real-time monitoring and modeling for critical cases. Good teamwork with the mud contractor essential.	Landmark Wellplan model has a fully transient surge/ swab program to optimise casing running. MI has a realtime rig site system.
9.	Ensure desired TOC's are clear and implications of failing to meet them are clearly defined & understood.	BoD to address.
10.	Ensure potential impact of production temperatures are addressed in the slurry designs for upper strings.	BoD.
11.	If significant shallow hydrates are present, consider if cement heat of hydration, or subsequent heating from production, will destabilise formation. There is little industry experience to date of problems.	Check recent industry experience.
12.	Complete the Key Parameters Matrix of questions for cementing across SWF zones, keeping in mind the potential for flow and the consequences of such flow.	Appendix F of RP 65

What is different about deepwater cementing?

There are two main inter-related issues which cause most of the perceived difficulty in deepwater cementing:

- Low seabed temperature – at, or close, to 40 deg F (0 deg C)
- Over pressured water zones in shallow hole sections drilled without the riser connected

Cementing laboratory test methods and procedures are generally unable to mimic these circumstances and this has resulted in inappropriate slurry designs and well failures.

Hole conditions in the shallow sections are usually poor and this results in inadequate mud (or annular fluid) displacement. Obviously, an inadequate slurry, imperfectly placed, will neither support casing nor seal the annulus. Unfortunately for the operator, the slurry design is the main source of revenue for the cementing service contractor who frequently has little real control over the issues around achieving good mud displacement.

The other issue which frequently presents a severe challenge is the relatively high number of casing strings, with tight clearances, coupled with a narrow pore/fracture window in which to work. This places great emphasis on proper planning and understanding of mud properties and hydraulics. Surge pressures and circulating pressures are more critical, but at the same time are more difficult to calculate. This is, again, partly due to the oversimplification of the issues and a lack of sound laboratory data on rheological properties of the mud at the temperatures which apply. Polymers can exhibit rheology which is very sensitive to temperature – very thick at low temperatures. Similar behaviour is seen with some oil muds. A powerful computer hydraulics program is of little use if the data does not accurately reflect conditions in the well. Thermal modeling and rheological profiling over the anticipated temperatures is necessary. Pressure drops should not be based on simple API rheology measurements at room temperature.

Some common misconceptions:

- Because the seabed temperature is very low, the cement must be tested for strength development with this low temperature maintained throughout the curing period.
    - This is incorrect because the heat of hydration of the cement will raise the temperature significantly (~ 50 deg F+)
- API Specification test schedules for Thickening Time can be used.
    - Invalid for deepwater.
- Long WOC is inevitable.
    - Not true, but requires a lot of detailed engineering and testing to establish confidence in time to (say) 100 psi.
- Using foamed cement will prevent a shallow water flow (SWF).
    - It may, but only if optimally engineered and applied.
- Only a low density (light weight) slurry will be successful
    - in deepwater, with a short cement column, the difference in hydrostatic pressure will be very small
- Only a 'high-tech', expensive slurry will work
- Most service company labs have the equipment to design jobs for deepwater
- That 'Transition Time' can be assessed from a consistometer trace
    - Transition Time is a static property, the consistometer is a dynamic test.
- Slurry design is more important than getting the optimum wellbore conditions for cementing – good hole, good fluid (mud) properties, good centralisation, good displacement (physical & chemical)

Slurry test temperatures – BHCT, BHST or Predicted BHCT, PBHCT:

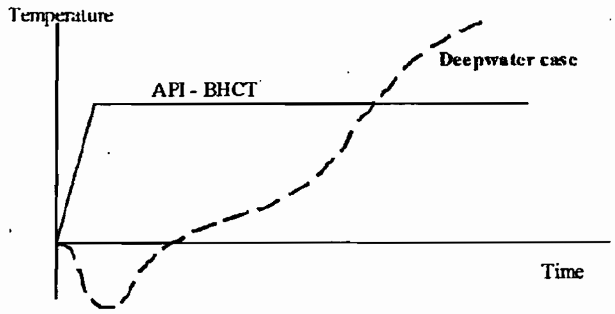
Generally, discussions about cement slurry behavior involve assumptions about the temperature profile the cement will experience during mixing, pumping and displacement. Certainly for 'normal wells, it is common to use 'so-called' API temperatures based on casing setting depth and static geothermal gradient. The limitations of this approach are frequently ignored. The industry 'gets away with it' simply because the API temperatures are conservative and allow for a very wide range of conditions. They are successful simply because they are in common use and generally allow cement to be placed without problems in the majority of non-critical wells. They are not about 'technical limit' engineering and if WOC time is planned, or experienced, the approach needs to be challenged.

For Deepwater operations, the API Temperatures are inadequate for the following reasons:

- In the original data only a few points were available for offshore wells and even this was limited to wells in less than 250ft water and water depths less than 3% of TVD
- No account is taken of the cooling while cement (and other fluids) circulate down drill pipe. This cooling is particularly severe when riser-less. Cement can be cooled to around 4 deg C within a few hundred feet of water
- There is no valid way to extrapolate from the existing data set to deepwater circumstances
- API schedules are a very crude approximation of actual temperatures even for simple, regular, wells

The API Schedules (derived from the equations rather than the old tables) approximate both the temperature and pressure the slurry sees to a straight line ramp from ambient to a maximum which is then held constant for the duration of the simulation.

Idealised Temperature history during placement



In contrast, deepwater wells will subject the slurry to rapid cooling, followed by a period at low temperature, followed by a steady rise to a higher temperature, possibly reducing later. The approximate temperature history can be modeled using a wellbore heat transfer model such as the one in Schlumberger's CemCade or the Halliburton Landmark model. BJ use an older version of the WellTemp model which later became the Landmark model. All these computer simulators can model the temperatures (with some assumptions) but all require quite detailed circulation history and fluid property data. Obviously, this is a matter of judgment and in inexperienced hands the computer models can be misleading and erroneous. Bracketing a wide range of scenarios, and running a number of sensitivity studies, is very time consuming.

A common approach is to try to simplify this complex deepwater slurry temperature history with something which approximates to the conventional API schedule. This can only be done with confidence if there is a sound body of test data using the same additive packages and the same source of cement to support simplifying the test conditions. Even so, there are issues about 'not knowing what you don't know'. Many slurries tested in retrospect at slightly different conditions have exhibited unpredicted behaviour.

The above discussion refers to simulation of temperatures during placement. Once the plug has bumped and the cement is static in the annulus, another set of considerations come in to play which again, in normal wells, are usually neglected, but in deepwater can become crucial – particularly if either shallow water flow or early support of casing (or conductor) is an issue.

The chemical reactions which cause cement to set are exothermic. In a 'normal' well this is ignored when considering the temperatures to use to test for strength development. Often the static geothermal temperature at the particular depth is used as the curing temperature. In many cases, particularly relatively small annuli, this is acceptable. In larger annuli – e.g. 30" in nominal 36" hole or 20" in nominal 24" hole – substantial temperature rises can be expected during curing. Normally, these will provide an additional conservative safety margin allowing (say) a conductor to be released earlier than the lab test may indicate. The problem with deepwater wells for the shallow, large diameter casings, is that the slurry starts from such a cold temperature that it takes time before the exothermic reactions start to heat up the cement. Once these reactions do kick in, the temperature will increase substantially. In the past, service companies have encouraged operators to believe that conventional cement at low temperatures in these strings does not set up for considerable periods of time – e.g. 20+ hours for 100 psi. This has been erroneously supported by tests run on small samples of cement which are continuously cooled to (say) 4 deg C (39 deg F). In such tests the heat of hydration is extracted by the coolant and the reactions are very delayed. This has led to holding on to casing (particularly drilled and cemented conductors) much longer than necessary. It has also resulted in overselling of high cost additive solutions to combat non-existent problems.

The whole issue is basically one of getting the lab testing to approximate to the actual conditions which the cement will see during and after placement. The industry is some way from being able to do this on a routine basis. It involves considerable extra effort and expenditure in the cementing service company lab. However, many of the service company deepwater slurry designs are high cost/high performance solutions and sound engineering requires that this work is done, and done well.

There are two ISO documents which address issues around lab testing of slurries for deepwater. These are:

ISO/NWI 10426-3 to be titled "Part 3: Testing of deepwater well cement formulations", and **ISO/NWI 10426-4** to "Part 4: Methods for atmospheric foamed cement slurry preparation and testing." Service companies should be aware of these, have copies and follow the requirements laid out. If they do not, they should explain in some detail why they do not comply.

Slurry Properties to combat SWF zones:

The main functions of the cement are:

- Support the casing weight
- Seal the annulus
- Resist long-term loading – chemical, mechanical, temperature induced, etc.

None of these are likely to be achieved without proper attention to mud displacement. However, assuming complete replacement of the annular fluid (water, mud, native mud?) with cement slurry, a number a factors come into play once the 'plug has bumped' and the cement has become static in the annulus. These can be summarised as:

- Need to maintain hydrostatic pressure above that of the highest pressured zone
- Require quick setting – minimum (zero) WOC
- Minimum loss of mix water to the permeable formations due to high overbalance

If hydrostatic pressure is not maintained, there is a risk that fluids will enter the cement column and migrate. In the severest case, the cement can be pushed out of the annulus and a blow out can occur. This case is the same as for 'normal' wells except that the temperature is low and the slurry lab testing issues highlighted above are important. Based on MMS records, of the 32 blowouts reported during the years 1992 through June 2000, 11 (33%) were caused by annular flows. During the first 6 months of 2000 alone, there have been five blowouts reported to MMS.

Once cement becomes static in the annulus and the chemical changes start, hydrostatic head decays rapidly from its initial value (given by the slurry density and height of column) to a value which can be below that of the surrounding formation pore pressure. This behaviour will 'suck' fluid from the formation into the slurry – again a potential to initiate a flow within the cement column.

The rapid reduction in hydrostatic head will also remove the driving force for fluid loss to the formation. The requirement for cement fluid loss additives should be reviewed against the overbalance during placement.

To combat flow, the transition from a fluid state (transmitting full hydrostatic pressure) to a set and solid state, needs to be minimised. Once set, the cement permeability will be the controlling factor and cement permeability is generally very low ~ 0.1mD.

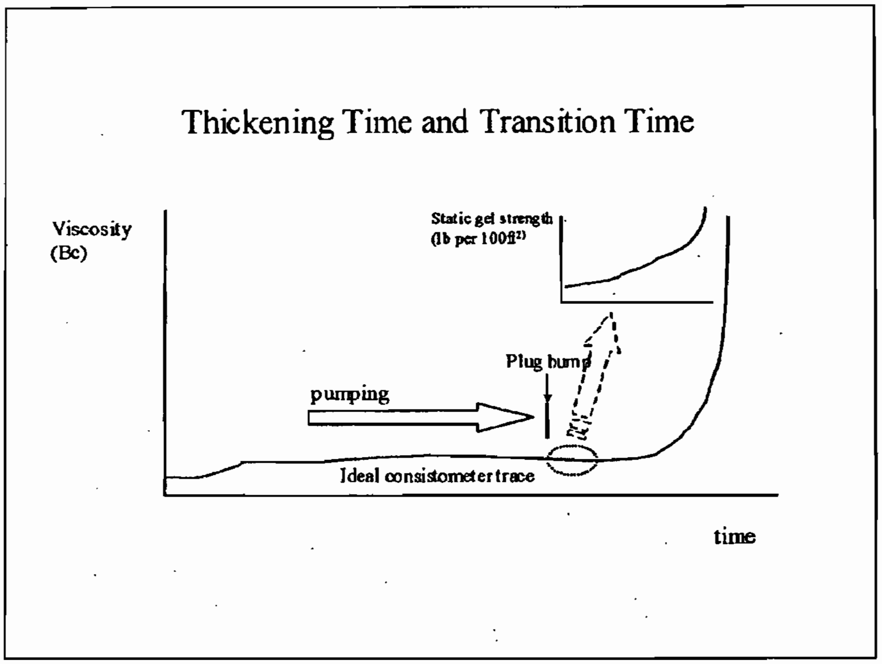
The requirement for this rapid transition is consistent with this second point – minimum WOC.

As previously discussed, in relatively large annuli, the temperature rise during cement setting can be substantial. Obviously, this will positively impact the transition from fluid to solid. However, in deepwater, a potential problem with this heat evolution may be dissociation of shallow hydrates. This aspect has not attracted the attention which has been given to SWF zones destabilising templates but may be a concern in some developments on future. Ways exist to minimise this heat of hydration but, again, lab testing is challenging.

It is important to understand that the transition referred to above cannot be accurately assessed in a conventional thickening time test. The Transition Time needs to be measured in a device which applies a very low shear to a fluid sample of slurry follow a period of shear which mimics placement.

Ideally, the slurry would be tested in a consistometer at conditions of temperature and pressure approximating those seen in practice up until the time the plug bumps. The slurry would then be transferred to a static gel strength measurement apparatus and the transition time measured. This transition Time should be defined as the time from 'plug pump' to obtaining 500 lb/100ft^2. A period of 20 – 30 minutes is the best that is likely to be achieved without compromising other aspects of slurry design which may increase the risk of a poor cement job.

The apparatus used to measure such Transition Time is either a MiniMacs Cement Analyser or a Vane Rheometer. These measurements are difficult to do accurately and reproducibly but there are very crucial aspects of the slurry design. Many of the high tech, expensive solutions for SWF cementing have relied on achieving a short Transition Time. Being able to demonstrate that what is being pumped meets the criteria is a fundamental assurance step.



The types of cement slurry design which can deliver the necessary properties have the following attributes:

- Ability to formulate at relatively low density (weak formations)
- Rapid Transition Time
- Reasonable strength development
- Good rheology

The use of calcium sulphate hemihydrate in a lightweight blend, with or without rapid hardening cement or microfine cement has been a popular route. There are many variations on this type of design and there are some chemistries which do not rely on the hemihydrate and can use the flexibility of liquid additives. Because there are so many ways to put a design together, it is important to concentrate on obtaining assurance that whatever the service company proposes meets the requirements and

- that this is demonstrated by actual test data on exactly the cement and additives which will be pumped
- and tested at conditions which do come close to those anticipated.

Without this assurance there is no reason to believe that the slurry will be successful.

If the issue is not prevention of SWF but assessment of strength development (e.g. earliest time to release a drilled/cemented conductor) then the testing needs to be done under conditions which thermally match those experienced in practice. Refer to the bibliography in API RECOMMENDED PRACTICE 65, FIRST EDITION, SEPTEMBER 2002, Cementing Shallow Water Flow Zones in Deep Water Wells. Several references deal with strength development including effects of heat of hydration.

Review of API RP 65, First Edition, September 2002 Cementing Shallow Water Flow Zones in Deep Water Wells

The Contents List of this RP document are reproduced below. Ideally, this guideline document should be read along with the full RP but attention is drawn here to the main issues.

Shallow water flow sands are typically encountered at depths of 600 ft - 2500 ft below mud line (BML). The conditions favoring the formation of shallow water flow sands include:

> *a. High rate of deposition (> 1500 ft/million years) sedimentary basins of current or ancestral river complexes, such as the Mississippi River depocenter.*
>
> *b. Areas with substantial regional uplift, in which once deeply buried sediments are encountered at shallow depths - North Sea, Norwegian Sea.*
>
> *c. Continental slope regions subject to large scale subsea slides - Storegga Slide area, Norwegian North Sea.*

Pore pressures equating to 8.6 lbm/gal to 9.5 lbm/gal equivalent mud weight (EMW) may be encountered in the SWF zones.

This [RP] document addresses the drilling and cementing process and makes recommendations for such wells. Appendix F gives a matrix for this process with values for each step. The resultant score provides the user with a factor of the relative chance of success of the cementation process. This process and matrix are based on known industry practices and are meant to be used to apply the process within the constraints of the well conditions with the greatest degree of risk minimization. The process includes:

a. Site selection.
b. Drilling.
c. Fluid properties.
d. Wellbore preparation and conditioning.
e. Operational procedures and good cementing practices.
f. Mud removal and placement technique.
g. Cement slurry design.
h. Pre-job preparation.
i. Cement job execution.
j. Additional considerations.
k. Post cementing operations.

I. Remediation of flows.

Note that this document is not meant to be a training manual. Although fairly comprehensive, there are still many details which are not discussed and which must be addressed when drilling and cementing wells in deep water. It is meant to highlight key parameters for increasing the chance of successfully drilling and cementing casings where there is a risk of shallow water flow and to discuss options that are available. Many more details can be gleaned from the references listed in the Bibliography. Most of the information in this document is from U.S. Gulf of Mexico experience. The concepts can be applied in other deep water environments with appropriate modifications. The user should consult experts within the industry for specific details of the cementing process relating to the technology being employed by a specific company for a specific scenario. The construction of the casings through the SWF zones must be a team effort to be successful. All parties involved must participate in the planning and execution of all phases of the process to ensure successful construction of the conductor and surface casings.

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Section 5 Drilling draws attention to the need to provide good hole conditions to obtain a good cement job. The use of PWD to control ROP and maintain hole cleaning is discussed.
Further discussion of drilling practices is contained in **Appendix B.**

Highlights the need for flow checks 'monitoring for as long as an hour'.

Flows, if detected, should be killed as soon as possible to avoid washouts & mining.

Reference is made to the use of fluid loss control in the mud. Where there is a high probability of flow this is good (ideal) practice. Unfortunately, obtaining good fluid loss control in such hole sizes with a sacrificial mud could result in considerable expenditure. In an exploration well this may not be justified unless a pilot hole has indicated the presence of a strong flow zone. It is important to consider risks v. cost. High risk could justify the high cost of a fluid loss controlled sacrificial mud system. A low risk would not.

Hole condition will be important for centralisation of casing and displacement of such sacrificial mud. A weighted and viscous mud (with fluid loss control) will be difficult to displace unless hole conditions allow good centralisation. Poor hole conditions, but with only seawater in the hole, might allow better displacement (without centralisation) since the cement will easily displace the water by gravity. This is addressed further in **Section 7 Fluid Properties** and **Section 8 Wellbore preparation and conditioning.**

Section 9 Operational procedures and good practices discusses inner string cementing and casing hardware. It again draws attention to the importance of centralisers emphasising the greater necessity for this if casing will not be moved during cementing.

Use of inflatable packers in open hole is discouraged.

Also consult **Appendix C** which provides a basis for a check-list of topics which will have to be addressed in the planning stage.

Section 10 Mud removal and placement technique draws attention to the need for computer modeling of the displacement process. It is vital that this modeling is done with representative fluid properties NOT some assumption about what might be in the hole. Kill mud, pad mud, sacrificial mud all pose a threat to good cement placement unless their properties are optimised to facilitate displacement. Do not assume that the mud company or the cementing company will necessarily take the appropriate steps without encouragement and supervision.

The importance of using the friction pressure drop hierarchy is mentioned with a target of 20% – 30% greater frictional pressure drop provided by each displacing fluid. Again, properties must be representative of what is in the hole not a casual assumption about what may be in the hole.

Section 11 Cement slurry design. This section discusses the approaches used in the industry including the use of foamed cements and the concepts around gel strength development. Foamed cement is thought to work very successfully because of the internal compensation for loss of hydrostatic pressure which occurs as the cement hydrates and begins to build structure. If interested in these issues you may want to access the parallel guidelines "Cementing in hostile environments: Guidelines for obtaining isolation in demanding wells. UTG December 2002" as well as the initial part of this document.

Foamed cement, of course, can be designed for a wide range of densities – low density being needed in many deepwater wells to avoid fracturing.

Foamed cements are the highest performing cements for low temperature and applications requiring potential flow control (IADC/SPE 59136, IADC/SPE 59170, SPE 62957, OTC 8304, OTC 8305, OTC 11976). The performance benefits of foamed cements are due to the following:
a. Compressibility of the gas in the slurry retains high pore pressure in the cement column to resist flow into and through the cement.
b. Base cement is mixed at a normal or a lower water/cement ratio.
c. Density is reduced by the addition of a gas which has no effect on cement hydration, setting time and strength development. The gas has a much lower specific gravity than lightweight additives used in non-compressible lightweight cements, thus allowing lower density cement with less sacrifice of strength.
d. Foamed cement provides enhanced fluid loss control (three-phase system).
e. Rheological properties of the foam are beneficial to displacement in large annuli.
f. Faster set and early compressive strength development.
g. Higher ultimate strength.
h. Higher shear strengths.

    1. Greater axial load bearing capacity.
    2. Better hydraulic seal between cement-pipe and cement-wellbore surfaces.

i. Durability is better than conventional cements due to the cellular nature of the cement matrix (although other methods are available to produce highly durable cements).
j. Flexibility to alter slurry design (density) throughout the cementing operation.

    1. Logistical advantage for operations.
    2. Single blend or material can be pre-tuned to optimal density just prior to use based on the actual well conditions known only after drilling the interval.
    3. Less sensitivity to density variations. Cement density can vary over a range of 5 lb/gal - 6 lb/gal, with minimal effects on the properties of the cement.

Foamed cement is also discussed in **Appendix D** and a check-list is included to aid operational planning.

It is common to use a blended cement which is then foamed on location. This introduces two areas of risk which need to be assessed and addressed:

- blend quality control
- faomed cement job planning & execution

Both these aspects are addressed in the parallel guidelines "Cementing in hostile environments: Guidelines for obtaining isolation in demanding wells. UTG December 2002" See also **Appendix E** on pre-job preparations.

Laboratory testing and temperatures for testing are addressed in this section but should be reviewed with the comments in the initial section of this document.

Section 14 Cement Job Execution covers many aspects of good practice which should be followed.

Section 15 Additional considerations and procedures makes valid observations on the differences when cementing with the riser in place and highlights the need for contingency planning.

Section 16 Post cementing operations refers to operations after 'the plug has bumped'. WOC is discussed and attention is drawn to the issue of determining the actual temperature profile the cement will be subjected to in the annulus (again see comments early in this document). A coffee cup of cement stored in the galley refrigerator is no guide to strength development on a rig costing $300,000 per day! Proper test protocols and methods do exist and should be in place. WOC is usually an admission of failure to plan.

Pressure testing of casing and LOT testing is addressed.

Section 17 Remediation of flows contains some general comments.

Section 18 Bibliography a good list of papers with more technical information on various topics.

Appendix F is a matrix which attempts to list and score all aspects of the planning and execution discussed above. This appendix is reproduced below:

Key Cementing Questions for SWF.

APPENDIX F—CEMENTING MATRIX

18.0.0.1 A data sheet (Key Cementing Parameters for Shallow Water Flow Hazards in Deep Water) is provided to assist in assessing the cementing process. The drilling team can use the spreadsheet to evaluate the plan prior to the implementation of the cementation. After the cement job, it can be used as a post-evaluation tool. When coupled with an assessment of flow control and other zonal isolation assessment, the cementing matrix can be used for continuous process improvement.

Table A-1—Instructions for Completion of Key Cementing Parameters for Shallow Water Flow Hazards in Deep Water

This matrix is to be used to evaluate the potential impact of elements of the cementing process on its success. The sheet should be completed by the operator during the planning of the well to highlight areas needing improvement. At the conclusion of each string on which it is used, the scores for each parameter should be evaluated again and used as a post job evaluation. The sheet can be printed at each of these stages and placed in the well file. The scores, both by major category and the total can be compiled in a database and, with evaluation of flow, used for process improvement.

Explanation of Terms	
Max Points	The maximum number of points to be assigned for the parameter if the recommended criteria are met completely.
Plan Score	The score for the parameter based on the degree to which the parameter is met in the design of the well.
Performance Score	The score for the parameter based on the degree to which the parameter was met when the operation was performed on the well.
Actual Value	The actual value (not score) of the parameter when the operation was performed. For instance, if the fluid loss of the pad mud is 12, enter 12 for the Actual Value while the Performance Score is 2.
Use of Matrix to Assess Areas for Improvement	
Individual parameter Totals	Each of the critical parameter categories can be evaluated by comparing the Total Score against the possible score (Max Points) for that category. If the earned score is less than half the possible score, consideration could be given to adjusting parameters to increase the score.
Sheet Total	If the earned sheet total is low, consideration could be given to increasing the score by improving individual parameters. The greater the risk and severity of shallow water flow, the more important to increase the score.
Parameter	**Directions**
Site Selection	Assign 10 points if the criteria listed in Appendix A or an equivalent process were used to evaluate and select the drilling site based on potential for shallow hazards. No points are assigned if not.
Gel Strengths @ BHT	Assign points if criteria are met. For greater gel strengths, assign less points, according to value.
Density	Assign 4 points if criterion is met or 0 if it is not.
Fluid Loss	Assign 2 points if criterion is met.
Hole Diameter	Assign points if criterion is met, or scale points if it is not.
Clearances	Scale points based on degree to which criterion is met.
Rathole	Assign full value if density is greater than that for the cement to be used.
Flows	If flow occurs, assign full value if action to control is initiated as soon as it is encountered. Reduce points if flow continues for long period.
End of outer string	Points are given if criterion is met.
Lost Circulation	Assign all points if full returns were observed and if computer simulations indicated that fracturing pressure is not exceeded during conditioning and cementing.
Static Time	To minimize gel strength development during static time, premix test fluids before beginning cementing. Assign all points if the static time is < 5 minutes total from start of conditioning until end of cementing. No points are earned if the time is > 15 minutes.
Mixing and Placement Rate	Full points are assigned if the rate at which fluids are circulated during cementing (when fluids are being displaced in the annulus) is designed to meet specific engineered mud removal criteria using computer simulations. Otherwise, no points are earned.
Centralization	All points are earned if centralization is optimized with mud removal criteria through the SWF zone. Otherwise, none are earned.
Spacer	Assign all points if the spacer is designed so that density never allows the wellbore pressure to fall below pore pressure and volume is sufficient for 500 feet of fillup in the annulus. Scale points if less than 500 feet of fillup with none given for less than 100 feet.

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Instructions for Completion of Key Cementing Parameters for Shallow Water Flow Hazards in Deep Water (cont.)

Parameter	Direction
Fluid compatibility tests	All points are earned if compatibility of spacer with mud and cement has been tested and found to be compatible. Otherwise, none are earned.
Circulation Volume	Scale points based on volume circulated before cementing. Give 0 if only drill pipe volume is pumped.
Well Control	Assign all points if the well is in overbalance condition at all times during the conditioning and cementing based on computer simulation and no flow occurs. If underbalance or flow occurs, assign no points.
Pipe Movement	All points are earned if pipe is moved during conditioning and/or cementing. Otherwise, none are earned.
Temperature for Cement Testing	All points are earned if temperature schedules have been established based on measurements combined with computer modeling and/or offset well data. No points are earned otherwise.
Slurry Design (compressible slurry)	All points are given if the slurry is a foamed cement slurry. If gas-generating slurries are used, assign 3 points. None are given otherwise.
Slurry Design (gel strength)	All points are given if the Critical Gel Strength Period is less than 45 minutes. The value assigned is scaled otherwise. This Critical Gel Strength Period is defined as the time required for the cement to progress from the Critical Static Gel Strength to a static gel strength of 500 lb/100 ft². The Critical Static Gel Strength is the gel strength of the cement that results in hydrostatic decay producing an exactly balanced condition in the well. The Critical Static Gel Strength (CSGS) can be computed by: CSGS = (OBP×300)/(D_{hy} L), where OBP = Hydrostatic Overbalance pressure (psi) 300 = conversion factor (lb in.) L = Length of the cement column (ft) $D_{hy} = D_h - D_{op}$ (in)
Slurry Design (fluid loss)	All points are assigned if slurry has controlled fluid loss below 100 mL/30 min. Otherwise, points are scaled with no points given if the fluid loss is greater than 500 mL/30 min.
Slurry Design (WOC criteria)	All points are given if WOC criteria (based on critical gel strength period or compressive strength development) are established and used for various phases of operations up to pressure testing and drilling out the shoe. None are given otherwise.
Slurry Design (density)	All points are earned if density meets requirements for maintaining wellbore pressure between pore and fracturing conditions.
Slurry Design (stability)	All points are given if free fluid, sedimentation and foam stability meet criteria.
Blend verification	All points are earned if tests of cement according to vendor's or operator's quality plan verify critical performance properties of the cement.
Cement Top	All points are earned if cement tops cover critical parts of wellbore, including SWF zone with high performance cement and returns of lead slurry to sea floor.
Rheological Relationships	All points are earned if cementing fluids have rheologies appropriate for effective displacement mechanics.
Cement Mixing Equipment	Points are earned if mixing is by fully functional density controlled mixer or all slurry is mixed to density in batch mixers.
Nitrogen Injection (foamed cement)	All points are earned if nitrogen injection is using automated process controlled equipment.
Foamer and nitrogen at proper ratio	Points are earned if all foamer and nitrogen are mixed within 10% of design.
Bulk cement delivery	Points are earned if there are no mixing constraints due to interruptions of delivery by bulk cement.
Density Control	All points are earned if cement slurry is mixed within +/-0.2 lb/gal throughout.

Table A-2—Key Cementing Parameters for Shallow Water Flow Hazards in Deep Water

Parameter	Recommended Criteria	Max Points	Plan Score	Performance Score	Actual Value
	Site Selection				
Site Selection	Site is analyzed to minimize potential for flow by Appendix A or equivalent process	10			
	Total	10			
	Critical Fluid Parameters				
Gel Strengths of Pad Mud @ BHT	10 second, 10 minute and 30 minute gels all < 25 lb/100 ft²	4			
Density	Sufficient to control flow	4			
Fluid Loss	Pad Mud < 15 API	2			
	Total	10			
	Critical Well Parameters				
Hole Diameter	Hole diameter is a minimum of 3.0 inches greater than the casing outer diameter	2			
Clearances	Wellhead cased hole inner diameters are a minimum of 1 inch greater than existing casing connector outer diameter at all points in the wellbore	2			
Rathole	Rathole is filled with mud with density greater than cement	2			
Flows	Action is taken to kill flow as soon as encountered	8			
End of inner string	Within 30 feet of shoe	2			
	Total	16			
	Critical Operational Parameters				
Lost Circulation	Full returns are maintained and fracturing initiation pressure is not violated at any time while running pipe or during conditioning and cementing	3			
Static Time	Pressure test lines before conditioning and < 5 minutes of non circulation time from start of mud circulation until completion of cementing operation	2			
	Total	5			
	Critical Displacement Efficiency Parameters				
Mixing and Placement Rate	Circulation rate in annulus before and during cementing meets mud removal criteria established by computer simulation	3			
Centralization	Optimized for mud removal through SWF zone	3			
Spacer	Optimized density and volume for 500 feet annular fill	2			
Fluid compatibility tests	Compatible	2			
Mud Conditioning Volume	> 1 Annular Volume	3			
Well control	There is no flow before or during conditioning and cementing	5			
Pipe Movement	Pipe is moved to enhance mud displacement	2			
	Total	20			
	Critical Cementing Fluids Parameters				
Temperature for Cement Testing	Temperatures established by measurement and/or thermal modelling software	5			
Slurry Design	Compressible slurries are used	5			
	Gel strength development meets transition time requirements	4			
	Reduced fluid loss slurries are used	2			
	WOC criteria established and followed	4			
	Cement density appropriate for well conditions.	3			
	Slurry stability (Free fluid, sedimentation and foam stability meet criteria)	3			
Blend verification	According to quality plan (vendor's or operator's)	3			
Cement Top	Returns of cement are observed at mud line and calculated top of high performance cement is above SWF zone	3			

continued on next page

Key Cementing Parameters for Shallow Water Flow Hazards in Deep Water (cont.)

Parameter	Recommended Criteria	Max Points	Plan Score	Performance Score	Actual Value
Rheological Relationships	Friction pressure of each laminar flow fluid is greater than the fluid it is displacing in all parts of the hole	3			
	Total	35			
Critical Cementing Equipment					
Cement Mixing Equipment	Computer assisted density controlled mixer or batch mixer	2			
Nitrogen Injection (foamed cement)	Automated, process controlled injection equipment	3			
Foamer and nitrogen at proper ratio	Within 10% of design	4			
Bulk cement delivery	No mixing constraints or interruptions due to bulk delivery problems	3			
Density Control	+ 0.2 lb gal	4			
	Total	16			
	SHEET TOTAL	112			

Guidelines: Handling Blended Cements, Specialty Cements and New Technology blends.

Introduction

Blended cements result from blending dry cement and dry additives to formulate a slurry which is typically of fixed density and properties. Specialty cements/new technology blends are those of an 'exotic' nature, e.g. LiteCrete, Tuned-Lite, Flexstone. They are typically systems without extensive field-testing. Blended cements offer simplicity of operation at the well site, in that all the blending of additives has taken place prior to the blend getting to location. This allows the cementer to better attend to the well and job execution rather than having to attend to mixing liquid additives. Specialty cements/new technology blends are designed to offer 'fit for purpose' solutions that cannot be handled by conventional means. They are multicomponent blends using particles, polymers and other chemicals.

Careful consideration needs to be given to the selection of these cements. The biggest detriment t is the inflexibility of slurry parameters such as density, rheology, compressive strength development and often thickening time and fluid loss control. Whenever possible, liquid retarder/accelerator should be used to allow for any variance in required pumping time should the well mandate.

Blending times, depending on the complexity of the blend, can be long. Sometimes as long as an hour per 100 sacks. Coordination of boats is essential due to these long blending times. Depending on the volume to be blended, several days may be required. A good understanding of well bore parameters is essential. Any unforeseen pressure ramp, or loss circulation, can make the slurry of a blended cement ineffective with regard to optimal mud removal or well control. Other potential problems are in the blending itself. Poor blending techniques, inadequate bulk facilities, and a lack of experienced blending personnel all add to the difficulty of obtaining a proper blend. Such blends and specialty cements can be exceedingly sensitive to contamination.

Once a blended system has been selected, a series of quality assurance steps need to be put in place to aid proper blending and minimize this risk of contamination.

Pilot Testing

Pilot testing is the pre-testing of the slurry with laboratory stocks of cement and additives that have passed routine QA/QC tests. The use of laboratory water is recommended in these first tests. This allows a baseline for later tests as well as assurance that the cement will fit the requirements of the well. A full complement of tests should be performed, thickening times, rheologies, fluid loss, free water, settling stability and compressive strength development. Usually the blend design can be altered at this stage to fit the requirements of the well.

Assuming that the blend pilot testing is adequate, cement and additives that are to be used in the actual blending should then be tested. Once again, tests for thickening times, rheologies, fluid loss, free water, settling stability and compressive strength development and ultimate strength should be performed. If available, tests should also be performed with the actual water from the rig which will be used on the cement job. This will allow for a comparison of the actual additives and cement to those used while blending to aid in determining possible contamination or inaccurate blending. At this time it would be wise to test for a maximum and minimum density allowable for the blend. That is, how heavy can the slurry be mixed with this blend formulation and how light can the slurry be mixed and still maintain adequate slurry properties. Once again a full battery of tests should be run at these maximum and minimum densities. Attention to the rheology is essential since unmixable slurry may occur at the higher density and settling may occur at the lower density.

Bulk Facilities

The bulk facility where the cement is to be blended should be inspected. The condition of the equipment, materials and personnel should be reviewed.

The equipment required is a weigh batch mixer (or blender), typically 250 cuft to 500 cuft capacity. This is used to weigh out the cement and additives. A recently calibrated digital scale and printer should be installed on the tank. Calibration records must be available and should be checked. In the event of a failure to the scale or printer a backup should be readily available.

A holding tank of substantial size should be available. This will allow holding of blended cement ready for transfer to a boat or other transport. Typical size would be from 1,000 cuft to 3,000+ cuft. The bigger the better, so that blending can continue without the transport vessel being present.

A transfer tank larger than the weigh batch mixer is also required. This will be used to transfer the blend from the weigh batch mixer to the transfer tank during the blending process. Also required is an additive bottle, or means of adding the dry additives to the weigh batch mixer. A typical size is 200-300 cuft.

All equipment should be thoroughly cleaned and inspected before any blending is started. Sampling of the cement is necessary for assurance of the accuracy of blend. Sampling may involve various methods - a series of isolation valves to trap the flowing cement, a ball valve in an extended vertical section of pipe, or an automated sampling device are all effective ways to take accurate cement blend samples.

Rock catchers should be installed inline; typically a screen that will not allow clumped/wet cement onto the transport vessel. At a minimum, rock catchers should be in place between the additive bottle and the weigh batch mixer to avoid wet, or caked, additives from being introduced to the blend. Also, between the neat cement and the weigh batch mixer to exclude clumped/wet cement from entering the blend and at the discharge of the system to prevent clumped/wet blend from entering the transport vessel.

Due to the number of transfers of the blend, water from the compressed air supply is liable to accumulate. A good air dryer is, therefore, essential. It is recommended that maintenance records be reviewed to assure proper operation. During blending the water trap should be emptied regularly, if applicable.

The materials to be blended should be inspected as well as the equipment. All cement and additives to be used should be isolated and should be of the same lot number (additives) and same mill run (cement). Excess cement and additives should be available in the event of misblending or contamination. A minimum excess of 20% is recommended above that which is to be blended. In the event that the volume blended exceeds that of a consistent lot of additives, or mill run of cement, all efforts should be made to obtain the same lot and mill run. If differing lot numbers have to be used, the varying blend should be treated as a different blend and contamination with the original blend must be avoided. This can present logistical problems, requiring separate bulk tanks on the boat and the rig to be utilized. The resulting two slurries should be tested for compatibility. Risks should be assessed.

Personnel who are to be present during the blending should be interviewed. Experience with the particular system to be blended should be reviewed. An accurate estimated time to blend can be captured at this time. Concerns with the blending process can be unveiled as well, i.e. insufficient personnel available for the timetable required. Laboratory personnel may need to be present and such requirements should be set forth and agreed at this time.

Blending Technique

The "Sandwich Technique" is considered to be the most efficient way of blending cement and dry additives. Typically a third of the cement of one batch is transferred into the weigh batch mixer. Then one half of the additives followed by one third of the cement , then the remaining one half of the additives, and finally the remaining third of cement. Between each addition of cement and additives a printed copy of the scale reading is required. The sandwiched blend is now transferred between the transfer tank and the weigh batch mixer. Six transfers are considered optimal.

On the last transfer of the batch a sample of the blend should be taken. The sample should be large enough to perform the tests at the bulk facility as well as the tests to be performed at the laboratory. One-gallon samples should be sufficient. The sample should be tested by a qualified laboratory technician at the bulk facility. The blend should be mixed with the mix fluid from the rig and the density checked (pressurized balance), and rheologies measured and recorded. These results must fall in an acceptable range before the blend is certified for placement into the holding tank and the next batch started. These tests should be performed on each weigh batch mixer batch processing. At a minimum, the first six batches should be fully tested to assure consistency and allow the personnel to get comfortable with the process. If time allows, this should continue throughout the blending process. If time becomes an issue, every second to third batch after the first six has been found to be sufficient. All results of the testing are to be recorded. Only qualified personnel are to verify the test results. If a batch is found out of the range of acceptability, that batch should be separated and not placed into the holding tank.

All tanks on the boat/transport vessel should be cleaned then inspected by the service company and a BP representative prior to loading. Also, the means of drying the air on the boat should be inspected for operational efficiency. The watertight hatches on the boat silos should be inspected. Once a boat silo is used for transport of blended cement, all effort should be made to avoid use for anything else until the blending and transporting is complete. All potential, possible sources of contamination should be identified and avoided.

Bulk Blend Laboratory Testing

During the blending process, samples that have been seen to represent an accurate blend should be sent to the laboratory for further testing. Thickening times, rheologies, fluid loss, free water, and compressive strengths should all be performed. Tests should be carried out on the first half and the second half of the blend. The samples from the first half are to be combined and the tests in the laboratory performed. This will confirm accuracy of the blend above and beyond that done at the bulk facility. The same test should be performed on the second half samples as well. Once again comparing the results to those of the pilot tests performed with the actual cement and additives used in the blend.

Wellsite Requirements

Bulk tanks at the rig site must be cleaned, then approved by both the cement service company and a BP representative. Ample silo space should be set aside for the blended/specialty cement system. Often, with a new technology or specialty cement system, the bulk load factor is unknown, or has a range of expectations. This 'bulk load factor' is the space 1 sack of blend will need in its fluffed state. In other words, how many sacks of blend will fit into a certain silo without excessive losses out the vent or over-flow line. This value, stated in cubic feet per sack, should not be mistaken for the yield of the slurry.

A feel for the bulk load factor can be obtained during the blending process. Qualified service personnel should monitor the loading process of the blend and always be aware of the vent lines and the possibility of overflow. A conservative error is always best when transferring blends.

Blend samples are to be taken during blowing onto the rig site. A typical sampling technique on a rig is through a ball valve. For optimum sampling through a ball valve, the valve should be placed in a long vertical section of the delivery line. This will allow gravity to have minimal effect on the different densities of the additives and cement within the blend. Whenever possible the blend should be split into more than one silo. In the event of plugging, or difficulty blowing down one tank, the other can be utilized while the first is being repaired and the mixing will not be adversely affected.

When transferring the blend from the transport vessel to the rig bulk tanks, discharge pressure from the boat should be optimized. If the discharge pressure is too high, excessive losses can occur. Typically, the losses will be of the less dense materials in the blend, thus adversely affecting the performance of the slurry.

To avoid any possible contamination of the blend while on the rig, the blend tanks should be isolated from the other bulk materials such as neat cement, barite, or gel. Avoidance of building mud while mixing cement will also aid in minimizing the possibility of contamination. If possible, it is best to not even pressure up the tanks of the other bulk materials as leaking valves are always a possibility.

Once the entire blend has been transferred into the rig silos, the tank volumes should be verified. Ultimately, the best way is with calibrated weigh scales on the silos. Strapping of the tanks - measuring the distance from the top of the silo to the top of the dry blend then calculating the volume - will often lead to inconclusive volumes and confusion. It will, however, offer a rough check of the volume on board. Strapping of tanks is best performed 10–12 hours after the transfer is complete to allow time for the blend to settle.

The rig blend samples should be sent to the service company laboratory for verification testing. The tests performed are similar to those for the bulk blend; thickening time, fluid loss, free water, rheology, and compressive strength development. All these tests are to be performed using rig samples of water. As with any cement testing, compatibility of the spacer, cement and mud should be reconfirmed and completed at this time. If differences occur in the testing of this blend from previous tests, immediate repetition of the tests with new samples is recommended. If the difference still exists, disposal of the blend should be considered.

It is recommended that, as with any blend/specialty cement or new technology, an experienced supervisor with knowledge of the new material be present during the blend loading and mixing of the slurry. As an optional backup, a service company laboratory technician on location during the mixing operation may be helpful. Rheologies, density and temperature can then be measured. With his/her experience with the slurry in the lab, observations during the job may prove valuable.

A test mix of the slurry should be performed with the cement unit once the blend is on the rig. This will assure that proper rate and density can be attained. Beware not to allow the test mix volume to exceed that of the extra blend available on board. Inspect the packings on all pumps for leaks and possible wear. Inspect the densitometer for accuracy against that of the calibrated pressurized scales. Also, check that the liquid additive system is operational and accurate if one is to be used.

Samples of the slurry on the test mix should be taken and observed.

Once the test mix is complete, verify the remaining volumes of cement blend and liquid additives, if applicable.

Check list to aid in getting blends and logistics of handling blends right.

Microsoft Excel
Worksheet

References:

API RP 65, First Edition, September 2002 Cementing Shallow Water Flow Zones in Deep Water Wells – includes further references.

Cementing in hostile environments: ***Guidelines for obtaining isolation in demanding wells:*** Ashley Hibbert, UTG Sunbury, December 2002.

> *This document includes detailed review and design guidelines for foamed cement. It also covers the use of reduced modulus cements (E.g. Schlumberger's Flexstone) and considers mechanical testing for complex loading.*

BP Shallow Water Flow web site (Mark Alberty UTG Houston) – includes further references:

> http://ut.bpweb.bp.com/swf/

GoM: MMS Site with information and maps of locations where SWF incidents have occurred:

> http://www.gomr.mms.gov/homepg/offshore/safety/wtrflow.html

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