Deepwater Well Design Overview

Peter Aird, March 8, 2001

Revision 1.0

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1. *Introduction*

This paper provides an overview of design considerations for the design of Deepwater wells by a drilling engineer. It is by no means intended as the definitive guide to deepwater well design but the design aspects of deepwater wells bring a number of issues to the attention of the drilling engineer that are normally not encountered. The intention is to review these issues in this paper.

Deepwater is defined as water depths from 400m to 1000m with greater then 1000m water depth classified as ultra deepwater.

Most deepwater exploration wells are currently drilled as vertical wells. Very little deepwater developments have been developed from a single drill site. For economic reasons however, it is expected that this will become more of a standard for future developments. In that case, the future deepwater development wells are expected to be drilled as high angle, horizontal wells or even as multilateral wells.

The design of deepwater wells can certainly not yet be considered as routine well design. Deepwater well planning must be considered as advanced well planning. Most operators have thus recognised that deepwater drilling is as complicated as High Pressure High Temperature or Under balanced drilling and most drilling engineers will be part of a team to deal with the issues associated with deepwater drilling from project pre-well planning right through to post well reviews. Deepwater field developments are becoming more and more important.

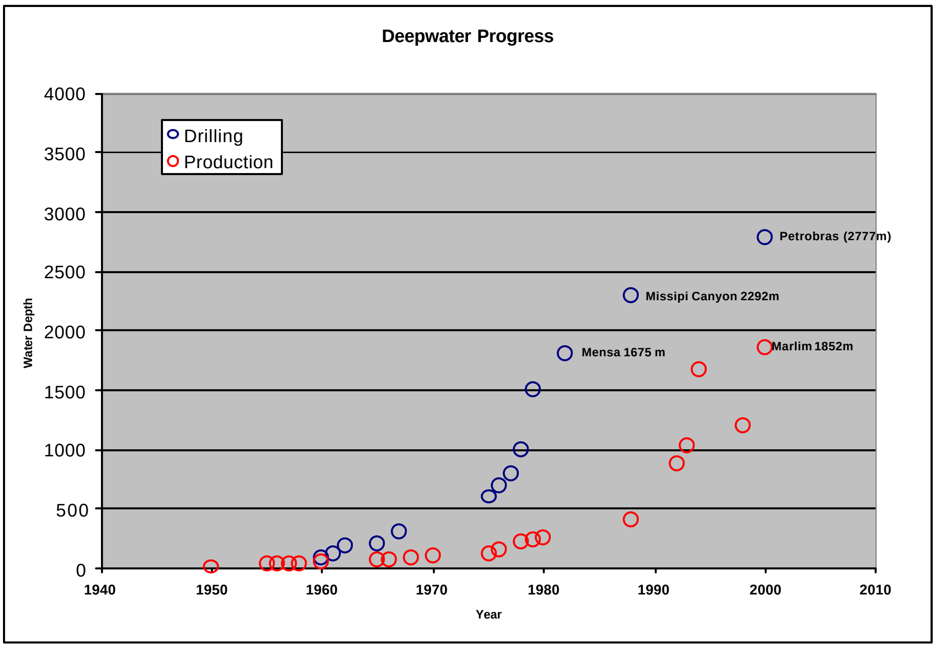

Figure 1.Maximum water depths for drilling and production versus time

2. Deepwater Well Design

As with most wells the deepwater wells start with the geologists and geophysicists. Once the seismic has been acquired and processed, a potential prospect can be selected. An appropriate location is selected and the outline well design started to begin the exploration and possibly the development of a potential prospect.

2.1 Objectives for Deepwater Exploration Wells

The objective of an exploration well is to obtain the maximum amount of information from the well during its life at the minimum cost in the safest way possible.

A vast amount of data is thus required to be gathered during an exploration well, not only geological, drilling and testing information but, and especially in deepwater, the environmental information on waves, currents and wind speeds.

Gathering data on the exploration wells may not seem very relevant at the time of drilling. But it has been proven that data gathered in exploration can result in huge cost saving during future developments. Even if they are in different area's of the world. The impact of cost savings from data collected from exploration wells on as development project is huge as the following graph shows:- *After H Robert Inglis (Production for deepwater oil and gas development)*

2.2 Objectives for Deepwater Development Wells

Once a field has been discovered and appraised, the development of the field starts with the drilling of the development wells. In most deepwater areas the development drilling costs can be as much as 50 0r 60% of the total cost of a project. This once again emphasises that information gathered during the exploration phase can lead to significant cost savings during the development phase. Because of the high drilling costs, it is important that development wells are designed to maximise production from the field during its life at minimum cost with a minimum well intervention work as possible and of course in the safest way.

It is as we can imagine important that the objectives of each well are kept in focus not only during the design phase, but also during the drilling phase of the well.

3. *Environmental Factors*

One of the most important issues in well design for deepwater wells is the environmental factors associated with deepwater drilling. This is not normally an issue that is of concern to the drilling engineer and this therefore is an area where certain critical issues can be easily overlooked. These issues once overlooked, cause major delays and great expense to put right later on during the operations.

Environmental factors for deepwater are:-

- Water depth
- Seabed condition (Visibility, Slope, Hardness, Shallow Gas)
- Weather (Wind and Waves)
- Currents
- Ecosystem (Birds, Whales, Corals etc)

3.1 Water Depth

Water depth in a deepwater well is the most obvious factor to be considered in the well design. Not all commonly used tools and technologies are suitable for all water depths. Mooring and anchor technology is still very much water depth dependant and if your well is in water too deep for a moored rig a DP vessel must be selected. Other equipment limitations such as on ROV's and risers must be considered.

3.2 Seabed Condition

It is important that a seabed condition is assessed as soon as a location area is defined. Seabed mapping and a debris survey are normal in most offshore wells. For deepwater wells seabed sampling for the design of the mooring system and for the design of the conductor must be undertaken. The soft seabed normally encountered in deepwater has caused problems for a number of operators. Shallow gas is to be avoided bit is not considered as dangerous in deepwater as in shallow waters. More important is seabed visibility for ROV's. This must be assessed since the ROV plays a major role in the early (open water) part of a deepwater well. The seabed slope must be assessed to ensure the stability of the wellhead and/or template.

For water depths above 1100m seabed surveys with conventional wire line deployed coring tools can be taken but the risks of loosing the tools is much greater. Acoustic buoys have to be attached to the barrels and wire line running is becoming more and more complicated.

Getting seabed samples from water depths of 1300m and deeper, requires a drill ship and can no longer be deployed by wire line from a survey vessel.

3.3 Weather

In the Atlantic Frontier areas the weather plays a big factor in the drilling of a well. In other areas of the world the weather may not be as severe but things such as hurricanes or tropical storms must still be considered before drilling starts. You may have incorporate contingency plans during the well design.

3.4 Current

A current survey is a necessary requirement in many deepwater drilling operations. Before operations commence currents at various levels must be assessed in order to select the correct equipment. Current meters should be deployed in an area for the entire period that drilling is expected to last. Current meters deployed on the rig will provide valuable information to assist in operational decisions.

A full current profile must be drawn up to anticipate problems with riser and surface casing loading or with vortex induced vibrations. Anti vibrational devices may have to be installed before a well can be safely drilled.

3.5 Ecosystem

Once a location area has been selected, consideration must also be given to the marine life. One operator recently had to delay its well programme by 12 months and present a study of Whale migration routes through its location before drilling could commence. It is clear that these types of issues must be known long before the rig sails to location.

4.0 Rig Selection

Selecting a rig for a deepwater prospect can be one of the most time consuming parts of the well planning operation. The rig must be carefully selected to match the environmental criteria and this is one of the issues that is an extra burden for the drilling engineer designing a deepwater well. Rig rates especially for deepwater drilling have increased enormously. Rig upgrades are not always the answer to your problems. Let us see this last statement in more detail.

4.1 Rig Upgrades

The present '***upgrade then upgrade again'*** situation is typified by two DP drill ships that are currently on long-term contract to an operator. Both rigs were upgraded in 1996 from 900m water depth capabilities to 1500m water depths. In 1998 the plan called for both drill ships to be upgraded again to 1800m. This was long before the present problems associated with station keeping at their current maximum water depths have been solved. The ramifications of retrofitting old monohulls with more equipment for either being ignored or are not fully appreciated. With increased water depth comes the need to store more riser on deck, more riser tensioners are required and more power is required to cope with the increased demands on the DP system. More power equals more engines required in the engine room that is already full. This leads to the position of engines elsewhere on board and a split engine room. More topsides weight reduces the variable deck load, and to situate heavy items such as engines aft of the existing engine room adversely affects the motion characteristics of the drill ship. This in turn leads to more demands placed on the DP system, which in turn requires more power to stay on location, which means more engines.

Operators are recommended to avoid being caught up in this law of diminishing returns scenario. To efficiently develop deepwater fields, Operators would do well to make a significant technological leap forward by considering the introduction of a new build semi or drill ship with full DP station keeping. A purpose built rig could significantly enhance drilling and field development technology. A newly built rig with a dual derrick facility, improved riser, BOP, casing and drill pipe handling, plus a limited Floating Production and Storage Offshore (FPSO) capability would allow for significant advances to be made in deepwater field development, such as combined drilling and Extended Well Testing (EWT) and early production.

4.2 Rig Operating Limits

Once a rig has been created or once a rig has been selected it is important that the operating limits for the rig are fully understood.

- Maximum Operating Limits (What is the weakest link)
- Survival Limits
- Disconnect Operations
- Sub sea Operating Limits
- Mooring
- Deck loads
- ROV Launch and Recovery Limits

Operating Limits

These will tell the engineer when he has to suspend operations to avoid serious problems. Once maximum operating limits are known in conjunction with the historic weather data, an estimate of the expected downtime can be made. This will indicate if we can operate during bad weather.

Survival Limits

These limits will give an indication when emergency situations will occur. Survival limits should never be exceeded as this has obvious safety implications.

Disconnect Operations

If the rig is a certain distance away from the well (Normally 5% of water depth) or during severe weather, the rig/riser will have to be disconnected from the well.

Operating limits for when to disconnect and when we can no longer disconnect must be known to ensure safe operations.

Sub sea Operating Limits

Mainly governed by currents and water depth. Equipment designed to operate in 1000ft of water may not work or may fail if operated in 2000ft of water. All the limitations of the equipment must be known and must be incorporated into the well design.

Mooring

A careful mooring analysis and mooring design must be undertaken by specialist companies to ensure that the correct mooring system is deployed. A review of the impact of a single line failure must also be undertaken to ensure that operations are not compromised.

Deck loads

Maximum deck loads and deck space is required for deepwater operations. A rig drilling in 2000ft of water will have to carry some 35 joints if marine riser. Taking up a significant amount of space. Deck loads during drilling are maximised since the weather may prevent a re-supply of the rig for a number of days or even weeks.

ROV Launch and Recovery

Since extensive ROV operations are required during the early and later stages of a well, it is important that ROV operating limits are known before the operation commences. With rig rates of \$150,000 to \$200,000 per day an ROV failure of 2 hours may cost a lot more than a state of the art launch and recovery system.

5. Well Design Data

Currently over 150 wells have been drilled West of Shetlands. So it can be said that a fair amount of offset data is available for well planning purposes.

Other than BP's Schiehallion, Foinhaven and some appraisal work on Clair, which is not deepwater, no deepwater field developments have taken place in Western Europe.

Water depths have so far been limited from 1000 to 2400ft. The ultra deepwater of 3000ft + has not really been an issue in Europe. This unlike Brazil, where field development in water depths of 2000m (6600ft) is now being considered.

For the drilling engineer deepwater drilling has some very specific issues that need to be considered for well design.

The design of a deepwater well cannot unlike a normal well be done separately from the rig. In deepwater the rig and the well are very closely linked.

5.1 G & G Issues

For the Geological and geophysical issues the deliverables of the well need to be focused. Exploration wells need to maximise the information so coring, logging and well testing are important considerations. The well must be designed that the correct logs and cores can be obtained. For development wells it is important that reservoir targets are carefully selected to optimise production. Reservoir modelling is extremely important. Once the reservoir targets and a surface location known a well trajectory can be designed. Geology and formation depths will need to be supplied.

5.2 Pressures and Temperatures

Formation Pressures

Pressure regimes in deepwater important are mostly normally pressured. No abnormal pressures (HPHT deepwater has been explored to date). A fair amount of FMT data is available to verify this fact.

Fracture Pressures

Lower fracture gradients due to the deeper water need to be taken into account. With over 120 wells been drilled West of Shetlands a fair amount of offset data is available and certainly fracture gradients need to be carefully established before selecting casing points. Certainly fracture gradients form the first issues associated with deepwater well control. In certain areas cementing of conductor and surface casing strings has been problematic due to fracture gradients.

Temperatures

Lower temperatures at seabed (normally around 1 or 2 deg C), have an influence not only on mud viscosity but also on the formation of Hydrates during a well control situation. Cement recipes must be adjusted for the seabed temperature in the surface casing and the conductor.

5.3 Subsurface Hazards

Subsurface hazards such as shallow gas and potential aquifer water flows must be considered during the well design. Boulder beds under the seabed as a result of the last ice age have caused problems West of Shetland. Icebergs are of concern in Polar regions and offshore Canada.

5.4 Casing Programme

Once all of the above issues have been addressed the casing design can start. Most deepwater casing designs have followed conventional routes. Top down designs for the exploration wells and hopefully the bottom up design for the production wells.

Most exploration and appraisal wells are vertical wells. If the well is to be kept as a producer, it may need to be converted into a horizontal well to be cost effective so this must be considered during the casing design.

For development of a deepwater fields wells will need to be designed for maximum production. The required production tubing size will then determine the minimum casing sizes required. Maximising production and minimising cost might mean drilling wells from a single drilling centre possibly drilling horizontal, extended reach or multilateral wells.

Most current deepwater wells are based on the following casing design:

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30” Conductor

30” x 36” conductor although some 30” heavy wall pipe is still being used by some operators.

The drilling engineer does not normally address the conductor design. In deepwater wells the stresses on a conductor must be analysed by specialist companies and the conductor analysis must form part of the standard casing design for a deepwater well.

A number of wellhead/surface casing failures have occurred during the earlier days of the Atlantic campaign.

The conductors in deepwater will take some of the possible bending loads and stresses in the case of a drift off or drive off. Remember that these Conductors are set some 400-450ft into a very soft seabed.

20” Casing

This casing design is not only analysed from a well design point such as fracture gradient and pore pressures but this casing must also be reviewed for bending in the currents. This casing set at +/- 2000ft below the seabed is exposed to the whole of the water column when its being run. Connectors need to be carefully selected to cope with bending.

The shoe depth of this casing will have to withstand the full column of mud back to the drill floor. With the lower fracture gradients this surface casing has to be set deeper than normal.

13-3/8” Casing

As can be seen this from the offset casing chart, this casing is set at various levels depending on the Geology and fracture gradients.

9-5/8” Casing

This string is normally set above the reservoir. This allows sufficient well control to drill the reservoir safely.

Omitting a string in deepwater will have to be carefully considered. The lower fracture gradients could result in an underground blowout situation. Drilling ahead to TD with a 12-1/4” bit may be a cheap option to get the well drilled and logged, but if a higher pressured reservoir is encountered, one has a long open hole section back to the 13-3/8” shoe. This could potentially result in an underground blowout if a high-pressured zone is encountered.

7” Liner

This string is run through the reservoir and forms part of the well completion. If required a contingency string of 4- ½ liner is still available in this design.

5.5 Fluids Programme

Mud systems used in the top hole sections are all based on water based muds with returns back to the seabed. Once the riser is connected and returns are taken back to surface, any suitable mud systems for the formations can be used. It is advisable to consider a glycol-based system to avoid potential hydrate problems in case of a well control situation.

Most deepwater rigs will have to be equipped with three mud pumps to cope with the required hole cleaning. Two pumps to drill the well and one pump used to assist with riser cleaning.

The cement programme in a deepwater well needs to consider the low fracture gradients as explained before. Top up cementations of the conductor and surface casing will also need to be considered in the well design. Cement recipes may have to be designed to cope with the lower temperatures at the seabed. Dropping of the cement through the long seawater section may present complications when cementing deeper casing strings.

5.6 Wellhead and BOP's

Rigs suitable for deepwater drilling will have their BOP equipment upgraded to cope with the deepwater. Multiplexed control systems will have to be used for BOP control. A special ROV operated emergency panel may have to be added to a stack for emergency situations in deepwater.

Most deepwater wellhead systems are 18-3/4" with some of the older rigs still equipped with a 16-3/4" connector. Special crossovers will ensure that all rigs can connect to 18-3/4" well heads. Options for hydrate prevention will have to be considered in deepwater systems. Riser booster lines will also be required to provide extra velocity in the long marine riser.

For deepwater development well X-mas trees and production flow lines need to be considered. If pull in flow lines are to be used, the Drilling Engineer must ensure that the conductor and surface casing is designed to cope with the additional loads.

Trawler guards are not normally considered in deepwater applications. Acoustic beacons may have to be placed on single wellheads to assist re-entry and to provide locator options if submarine activity is expected in an area.

5.7 Directional Drilling

Directional drilling for horizontal and ERD wells in deepwater areas must also consider the uncontrolled surface formations in deepwater. Well can be kicked off while still drilling riser less but this may prove challenging.

If the deepwater reservoir is shallow, short radius horizontal wells may have to be considered for the development of the field.

Horizontal drilling in unconditional formations is a challenge in a land well let alone if we add the deepwater and harsh weather to the equation.

Location of the drilling centre for a field development must be optimised to minimise drilling costs and minimise footage to be drilled. It is important that for a field development down hole locations are selected to optimise production and minimise drilling footage.

5.8 Evaluation

Deepwater well evaluation is the main objective for exploration and appraisal wells. All standard Coring and logging technologies can be applied. Emergency disconnect operations must always be considered when wire line operations are in progress.

Mud logging must take into account the velocity in the riser and the potential use of riser booster pump to ensure that lag times are calculated correctly.

6.0 Completions

Completion technology for deepwater production wells must be considered with great care. Well repairs and well intervention must be minimised and completions should be designed to last the life of the field. Well interventions in deepwater will mean bringing a rig back over the well and re-connecting BOP's. A repair programme that can be completed in 1 or 2 days on a platform may take as much as 14 days in a deepwater well.

Produced fluids must be assessed for corrosion, scale and wax problems to minimise well intervention.

The introduction of so-called "Smart Completions" is aimed to reduce well intervention. These completions allow certain sections of the reservoir to be closed off if water production becomes a problem.

The use of permanent down hole gauges will eliminate the need for production logging tools to be run. Reservoir engineers will be able to monitor well production on an ongoing basis. Several companies are offering permanent down hole gauges and research is ongoing for permanent down hole flow meter systems.

Coiled tubing technology in deepwater is limited especially if long horizontal sections are drilled in the reservoir. Friction and buckling of coiled tubing has resulted in limitations of CT in certain deepwater wells.

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7.0 Well Suspension/Abandonment

In the new regime in the UK well abandonment must be considered during its design for deepwater wells. Wellhead removal and Guide base removal will have to be considered during its design phase. Can the 36" conductor be cut and recovered tripping operations in 2000 to 4000ft of water all take longer.

8.0 Drilling Procedures

A management system must be in place before operations commence. In the hostile environment of the Atlantic margin, minimum stock levels must be assessed before drilling commences.

Procedures for well control, emergency disconnect, BOP and riser running must all be in place before operations commence. Special operations that require ROV/Drilling crew co-operations must be considered and all safety implications for the entire operation need to be assessed.

9.0 Well Control

Well control in deepwater is a special subject in the deepwater drilling industry. Many joint industry projects are in place to work on issues associated with well control.

Issues are:

- The use of Sub sea chokes
- Gas removal from the BOP after a kick
- Gas in the Riser
- Bubble chopping. Detecting the kick once it is at the BOP. This could result in the well being closed in but some gas already above the BOP still rising undetected in the riser
- Long cold choke and kill times
- Kill rates

10 Well Testing

Well testing in deepwater can be safely executed provided that the possibilities of an emergency disconnect is always taken into account. Flaring of oil or gas may not be allowed and storage of hydrocarbons on an extended well test may present other problems. A full Hazop/Hazid should be undertaken before any testing is considered. The cold seabed temperatures may cause wax or hydrate problems and these will have to be addressed during the design stage of a well test programme.