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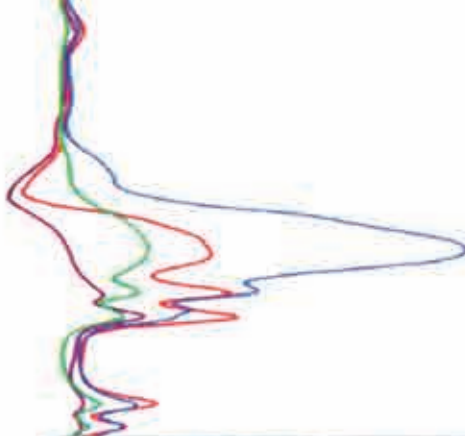
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Torpedo Base - A New Conductor Installation Process

By E.F. Nogueira, A.T. Borges, C.J.M. Junior and R.D. Machado, Petrobras

In late 1984 Petrobras started its deepwater campaign in Campos Basin in the Marlim field using dynamic positioned (DP) drillships. Among the many problems related to deepwater drilling such as high wellhead stresses, wellhead equipment inadequacy, lack of experience with DP rigs, and the loss of wells during the spud in caused considerable prejudice. Many actions were taken with the goal of reducing this problem. New dedicated equipment was designed, an extensive soil sampling campaign was carried out, and adequate operational procedures were written, amongst other actions.



Figure 1 – Torpedo Base Assembly

After the implementation of these actions the number of well losses has dropped considerably but some wells were still lost each year.

Thus a group of engineers aiming to improve the well performance decided to use Petrobras' mooring torpedo experience to be fitted for well spud in. The idea is to install the 36" or 30" conductor casing prior to the DP arrival to the location. This would be carried out through the use of a DP tug with ROV support while delimiting the well location with buoys. This would save significant money since the drillship's daily rate cannot be compared to the tug's rate. Besides the well drilling time is reduced by about 1 to 1.5 days since the conductor casing is already installed.

Conductor Casing Installation Procedures

The standard deepwater casing well design at Campos Basin is 36"/30" x 13 3/8" x 9 5/8" x 7" (optional). Nor-

mally the 36" or 30" conductor casing with 36m length can be installed by drilling and cementing or by jetting depending on soil conditions of the location.

The jetting procedure in clay soils is reliable in most cases and adopted all over the world but from time to time a very poor spud in happens causing, on some occasions, the loss of the well. To understand this occurrence it is important to know that the conductor casing is held in place by soil friction with the outside of the casing. Very little support is provided by the bottom of the casing shoe. This total friction must be greater than the total weight of the drilling guide base, 36"/30" and 13 3/8" casings and the high and low pressure housings. If the friction value is less than the total weight of the drilling system the well will sink and a new well must be started.

So, in order to cope with the situations where low friction after jetting is probable to occur and to gain spud

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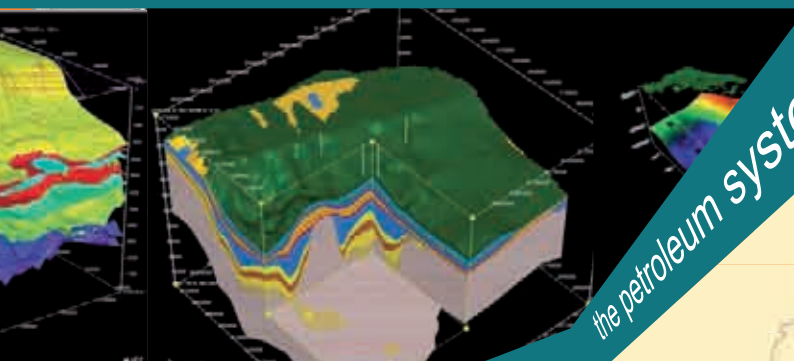
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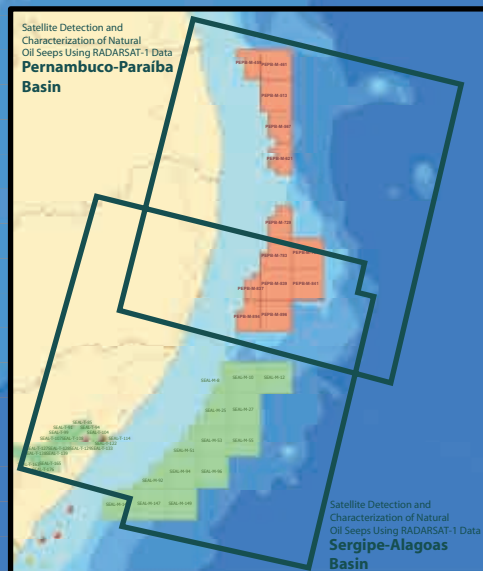
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Figure 2 – Torpedo Base



Figure 3 – Torpedo

in time Petrobras decided to evaluate the already tested method for pile anchors to install the conductor casing. This method is the most common procedure used today to moor floating production units and uses the AHV (anchor handling vessel) that have considerably lower costs compared to the dynamic positioned rigs.

Thus it was decided to evaluate this installation instead of the jetting procedure due to the more intensive friction obtained between the soil and the conductor casing. This happens because the soil is not removed during the installation procedure but squeezed to the side causing less disturbance to the soil and as a consequence a better interaction with the casing outside.

Torpedo Base Elements

In order to understand which elements are necessary for this new method it is important to remember that piling is a technique that uses a driving hammer transferring its impact energy on the top of the casing into a compressive force. This action will force the casing gradually into the surface formations. For offshore applications, hammers have progressed from rated energies of 27,645 to 290,272 m·kg. The hammers for this type of application can be air/steam, diesel and hydraulic actuated.

In our specific situation hydraulic hammers could perform the hammering action but are associated with other problems such as high rental costs and time consuming hydraulic operational problems.

Therefore in this case the cheapest way to hammer the conductor casing is through the use of a free fall weight. This must be designed to allow the full penetration of the conductor casing into the soil and to avoid logistic

problems such as AHV deck space, harbor crane capacities, road transportation, etc.

Based on these premises the torpedo base assembly (figure 1) was designed with two main parts:

- Torpedo Base (figure 2)
- Torpedo (figure 3)

The first is composed by joints of the conductor casing welded together having at the top a standard wellhead low pressure housing. After several Campos basin soil analysis it was decided that a length of 18m of 30" conductor casing plus four large fins were sufficient to produce greater friction than the standard 36m of jetted conductor casing. These fins provide great flexibility because it is possible to increase the friction by either increasing their length or by adding extra fins. The large fins are also responsible for the high wellhead performance, with capacity to absorb the high bending moments from the drilling risers used in ultra deep waters.

At the top of the conductor casing four boxes connected to the large fins and the conductor casing itself constitute what is called the geotechnical break. It has the function of allowing the soil to penetrate inside until it plugs producing a breaking action of the system. This behavior gives the torpedo base a greater capacity of holding loads down than upward. The correct location of this geotechnical break is of great importance for the positioning of the torpedo base related to the seafloor. Finally two hanging supports welded below the low pressure housing enable the installation of the launching cable system.

In order to facilitate the penetration of the torpedo base into the soil an attacking nose is added to the bottom



Figure 4 – Reduced Scale Model

part of the conductor casing. Many materials can be used for its manufacturing such as cement, polymers, etc.

For the selection of the best nose attacking profile and for the goal of deepest soil penetration the engineers decided to use the studies and experiences gained with the successful pile anchor project.

The second part of the torpedo base system is the torpedo that is responsible for the hammering action allowing the final penetration of the whole system to the correct position related to the seafloor.

It comprises two concentric pipes welded to an upper part named stopper. The outside pipe is 26" OD and the inner pipe diameter will depend on how much weight is needed for the hammering action. For the first test this diameter was 13 3/8" and the annulus of the pipes was filled with a mixture of iron and cement giving a total weight of 20 ton. Other mixtures can be used but one important aspect to be considered is to keep the torpedo's centre of gravity as low as possible.

The torpedo works inside the torpedo base and lands at a special designed area below the low pressure housing. This landing area is of special importance since it is designed in such a way to avoid any damage to the low pressure housing during the hammering action of the torpedo.

In order to avoid considerable dampening effects during the hammering of the torpedo base the inner pipe is left open allowing the water to flow through it.

Therefore after the torpedo base driving, the insert torpedo is retrieved and placed on the deck of the vessel and it can be used in a new wellhead installation.

The assembly constituted by conductor pipe with fins, low pressure wellhead housing and torpedo, is a patented concept called the Torpedo Base.

Finally, it is important to mention that a great deal of care, mainly alignment control, was taken during the manufacturing of the Torpedo Base and the Torpedo. This has the aim of avoiding interference between the parts in any situation.

Design Procedure

The steps of the design methodology for defining the torpedo base geometry and weight can be described as:

- Identify the most critical loads found in the drilling riser analysis for this location;
- Define a first approach of the torpedo base geometry based on field test results and soil properties. Next perform the soil-pile interaction analysis using the PILEMI-CRO program, which uses a non linear soil-pile interaction analytical model (P-Y and T-Z curves), as defined in the API RP 2A (Ref. 1);
- Perform a conductor drive analysis to evaluate the penetration of the torpedo base system using a computer program based on a True model;
- Define the total torpedo base weight and the free fall height, taking into account the driving analysis and the conductor verticality
- Carry out a more detailed non linear analysis, using the 3D FEM computer program, AEEPEC3D, which adopts an undrained soil condition and applies Mohr-Coulomb criteria.



Figure 5 – Torpedo on AHV deck



Figure 6 – Torpedo Base Assembly Going Overboard

Finally, supporting the design steps above a series of lab tests with a reduced scale model (figure 4) of the torpedo base system was accomplished to evaluate the system free fall path. The tests were executed at the laboratory of Oceanic Technology which is a facility built at the campus of Federal University of Rio de Janeiro.

The main goal of these tests was the monitoring of the angles and accelerations of the torpedo base system during the free fall. These falls were monitored by an optical system with four cameras and two accelerometers at the top of the model. A total of 43 tests were carried out with different configurations of the cable launching system.

After these tests the results confirmed that the design was correct and that depending on the configuration of the cable launching system adopted it could help in keeping the vertical path of the system.

Installation Methodology

For the installation of the torpedo base in a new offshore oilfield a series of trial tests prior to the final installation must be carried out in order to adjust the free fall height. These tests are carried out in a 30m circle around the final well coordinates and this is normally done in about 8 to 12h of work. The results of these tests such as first penetration, inclination angles and hammering performance should be consistent.

If necessary the first free fall test can be monitored and a drop height of greater than 120m is recommended in order to reach the critical velocity of the torpedo base assembly. These data will help in calibrating the soil analysis studies supporting future installations.

After the drop of the torpedo base assembly three situations can occur. The most probable situation is with the whole assembly stopped in some part of the geotechnical break. This means that the top of the torpedo base is about 3.5 to 5m above the seafloor. The part of the cable launching system attached to the torpedo base must be released allowing the inner torpedo to hammer the final meters locating the whole assembly at the correct position related to the seafloor.

The next situation is when, after the free fall, the assembly is located at the right position. So the only necessary operation is to free the cable launching system from the torpedo base and retrieve the system.

The last situation and the most uncommon is when the torpedo base assembly sinks a few meters into the seafloor. In such situation the best action is to retrieve the whole system and drop from a lower height in a nearby location. This is due to the difficulties in relocating the torpedo base assembly in the correct position since the AHV has no motion compensator system.

Offshore Tests

The whole project including the offshore tests was sponsored by the Albacora East asset. The idea of the first test (figures 5 and 6) was to carry out a series of tests limited to six days of AHV operation in order to calibrate launching height, gather data to calibrate the soil studies, evaluate the difficulty of the AHV deck operations, obtain friction data and evaluate the performance of the cable launching system.

After a week of work thirteen free fall tests in a water depth of about 1330m were carried out around the location. The first two tests were done with the goal



Figure 7 – Torpedo Base at the Seafloor

of gathering data for the calibration of the soil studies and the rest to analyse the performance of the cable launching system, ROV operations, torpedo base system penetration, inclinations after the free fall, etc.

At the end of these tests the conclusion was that the torpedo base system was not having the expected performance. Problems related to the cable launching system, ROV operations and the geotechnical brake pushed Petrobras to redesign some elements.

So the torpedo base was brought onshore and sent to a local manufacturer. After some meetings of the working group a series of modifications were authorized to be carried out by the manufacturer. Those modifications were:

- Repositioning of the geotechnical brake;
- Modification of the Torpedo concept;
- Installation of new supports for the launching of the whole system;
- Modification on the geometry and materials of the cable launching system.

After one month of implementations the torpedo base was ready to face the second offshore test. Again this test was performed at the Albacora East field employing the AHV Normand Borg.

So on the 25th November 2004 the tests were executed taking a total of twelve hours to make three trial tests in a 30m circle around the location. These tests were successful and so it was decided to move the AHV to the well location to perform the final installation of the torpedo base.

Repeating the success of the trial tests the torpedo base was installed with a maximum angle of 0.5 degrees with a hammering time of 27 minutes and the friction loads after one hour of soaking was 43 ton.

Right now this well is drilling the pay zone and so far no subsidence of the torpedo base has occurred confirming the feasibility of this kind of installation.

Finally the second installation was already carried out in less time than the first one. After the installation (figure 7) the torpedo base angles were of 0.25 degrees and the friction loads were 75 ton.

Conclusions

The Torpedo Base has proved to be a successful new casing conductor installation method. One of its advantages is the use of an AHV with a low daily rate if compared to the DP drillship. Also this AHV can carry, handle and install three torpedo bases in four days of work. Its costs are less than the standard drilling guide bases plus the three joints of casing and related casing connectors.

Moreover the most important feature is that due to the adopted installation method it generates higher friction loads than the traditional jetting conductor installation method.

The adoption of this methodology will provide an approximate saving of one and a half big days.

Finally this kind of installation can be used for production applications such as hosting wells for subsea electrical pumps located in the proximity of productions wells.

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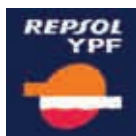
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Casing and Liner

By João Carlos R. Plácido, Fernando Antônio S. Medeiros, Petrobras

Introduction

Casing or liner drilling technique consists of drilling and casing simultaneously. The casing or liner is used to transmit mechanical and hydraulic energy to the drill bit or to the drill shoe. The main reasons to use this technique are to reduce trip time, eliminate well conditioning time before running casing or liner into the well, overcome troublesome formations with well instability and loss circulation problems, and improve well control.

Casing and liner drilling techniques have been used mainly to solve well instabilities. In Brazil some tests have been done¹. The main scenario to apply this technique is from land rig or offshore fixed platforms such as jack-up rig and TLP. Casing and liner drilling can also be applied from floating rig with surface BOP².

There are basically three primary casing drilling techniques available in the market. Casing Drilling® allows the BHA to be changed without tripping the casing. The others are Drilling with Casing® and EZCase®, which use fixed cutter drill shoe.

This paper describes these techniques and the results of Casing Drilling® tests performed in Brazil

As most of the scenarios in Brazil are offshore deep water, the application of casing drilling techniques is strongly limited. That is the main reason liner drilling is being considered to solve well instabilities in this scenario. Then, this paper will also present the planning to apply, for the first time, liner drilling technique in Brazil.

Casing Drilling® Technology

This process^{3, 4} eliminates the conventional drill string by using the casing string to transmit mechanical and hydraulic energy to the bit. A pilot hole is drilled using a conventional bit and an underreamer enlarges the well diameter. Tessari⁵ describes how the retrieval system

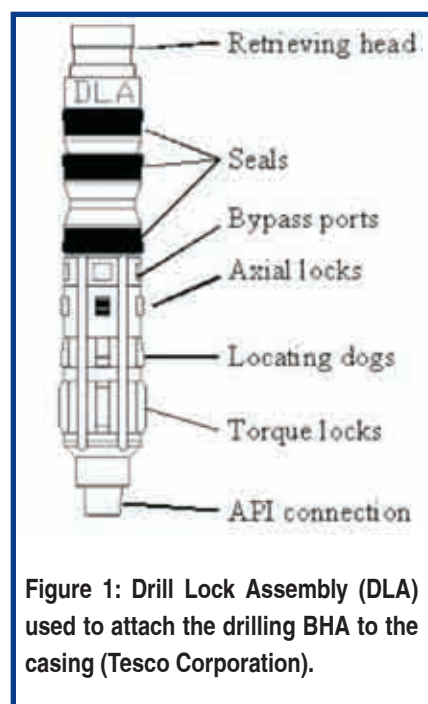


Figure 1: Drill Lock Assembly (DLA) used to attach the drilling BHA to the casing (Tesco Corporation).



Figure 2 – Casing Profile Nipple – CPN (from Tesco website)

works. The BHA is attached to a DLA (Drill Lock Assembly - Fig. 1), which connects the BHA to a casing profile nipple (CPN - Fig.2) immediately above the casing shoe joint. The BHA can be tripped with wireline, coiled tubing or drill pipe. When the BHA is run into the well, spring-loaded dogs in the DLA stop the tool at the

Drilling in Brazil

proper depth to lock it to the profile nipple. The locking process is accomplished by shifting a sleeve downward to positively extend lock dogs into recesses in the profile nipple.

Any type of BHA can be used, depending on the operation. For vertical wells, the BHA may consist of a pilot bit, stabilizers, and underreamer. For directional wells, the BHA would include a downhole motor and MWD (or LWD).

Figure 1 shows the DLA where the retrieving head, sealing system, axial locks, locating dogs, and torque dogs can be observed, from top to bottom. The sealing system forces drilling fluid to flow through the BHA and drill bit. A bypass system is activated to prevent swab and surge while tripping the BHA.

If using wireline, a split traveling block is available to allow the use of a wireline BOP. A top drive is mandatory in Casing Drilling®. It is attached to the casing using the Casing Drive Assembly (Figure 2). This tool can be adapted to any top drive and allows fluid circulation while the casing is rotated.

A casing connection must have adequate torque capacity to withstand drilling loads. A torque ring⁶ (Fig. 4) increases casing torque connection capacity. This ring increases torque capacity of 9 5/8" casing Buttress connection from 8,700 ft-lb to over 44,000 ft-lb.

Drilling with Casing® and EZCase® Technology

The Drilling with Casing® (DwC®) and EZCase® systems employ fixed cutters on a casing shoe, as shown in Fig. 5 and Fig. 6, respectively. The casing string replaces the conventional drill string and a top drive rotates the casing.



Figure 3: Top Drive and Casing Drive Assembly (from Tesco website)

The original DrillShoe (DrillShoe® I – Fig. 5) uses cutters developed for unconsolidated formation normally found near the surface. A new generation shoe was developed for more consolidated formations (DrillShoe® II – Fig. 5), using PDC elements for gauge protection.

Drilling with Casing® was first used on a floating rig, Transocean's Sedco 601, in November 2002 where

Casing or liner drilling technique consists of drilling and casing simultaneously. The casing or liner is used to transmit mechanical and hydraulic energy to the drill bit or to the drill shoe.

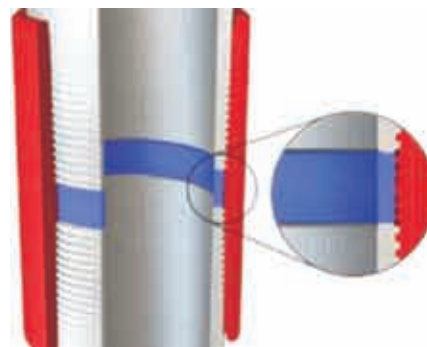


Figure 4: Torque ring (from Tesco website)

Santos drilled in 13-3/8" surface casing to the depth of 69 m (228 ft) in Indonesia².

The EZCase[®] casing bit system comprises a special alloy crown fitted with a full PDC cutting structure (Fig. 6). This unique tool allows operators to combine drilling and casing in one run, reducing flat time and lowering the risks associated with problematic wells. The EZCase[®] bit comes with a full PDC cutting structure. Set on either 4 or 6 blades, the use of PDC extends the application and performance range of casing/liner running operations. Drill out with roller cone or custom PDC drill out bit. One of the primary obstacles to utilizing a full PDC cutting structure is drilling out with a PDC bit. This PDC bit that can drill out float equipment, the EZCase[®] bit and drill on in the new hole size. Secondary bypass port allows normal circulation or cementing to continue in the event of nozzle plugging. Tapered leading edge gauge design incorporates a tapered leading edge to reduce reactive torque and sidecutting aggressiveness. This minimizes the chance of unintentionally sidetracking the wellbore. The increased torque requirement when drilling or reaming down is accommodated by casing connections being cut to customers' requirements.

Experience in Brazil

The experience in Brazil consists of three tests using the Casing Drilling[®] system¹. All tests were performed at Northeast Brazil. The tests covered a wide range of complexity, from very simple vertical wells to high angle directional wells.

The first Casing Drilling[®] test was conducted by Petrobras in the Pilar field on June 2003. The objective was to introduce the technology in Brazil and to verify its potential use on a conventional onshore drilling rig adapted to use this technology. This field did not present

any special problems to justify the application of this technique. Casing Drilling[®] was used to drill and case the 13-3/8" and 9-5/8" intervals. The 9-5/8" casing was used to directionally drill to 30 degrees.

The BHA was retrieved several times successfully. However, the underreamer cutters were severely worn, probably caused by several back-reaming operations.

The second Casing Drilling[®] test was conducted in October 2003, in the offshore Curimã field, using a jack-up rig. The test objective was to run the 13-3/8" surface casing. The casing included Buttress connections with torque rings to provide higher torque. The Casing Drilling[®] technology was selected for this well to overcome problems in the troublesome fractured limestone formation. When drilled conventionally, this zone experiences total loss circulation, causing difficulties to the casing running operation. The casing often stops before reaching TD.

A problem was observed in retrieving the DLA and, by the end, the casing had to be set and cemented before the planned depth.

Finally, a 9-5/8" directional Casing Drilling[®] system was used in November 2004 to drill through a troublesome section in an onshore Petrobras well in Northeast Brazil. Previous attempts to drill horizontal wells in the Aracas field were unsuccessful in penetrating through an over pressured (11.5 ppg) shale to set casing in an under pressured (2-4 ppg) pay zone. Mud weights adequate to keep the troublesome fracture limestone formation from collapsing caused massive lost circulation at the top of the pay zone. No further attempts to drill wells in this field were anticipated unless a technical solution to the well instability problem was found.



Figure 5: DrillShoe® I and DrillShoe® II (from Weatherford website)

The Casing Drilling® system was selected for a trial because it has demonstrated that it can solve these kinds of problems in vertical wells and has demonstrated the ability to drill directional wells at lower inclinations.⁵

The directional work in the Aracas well demonstrates that 9-5/8" casing can be used to drill directional wells with adequate directional control and drilling rate to be competitive in offshore environments where synthetic muds are used. This has not been the case with most directional Casing Drilling® with smaller casing.

By the end of the phase, a failure happened while trying to retrieve the BHA, and the well had to be sidetracked. This problem pointed out the need to make improvements in the retrievable drilling system. While over 300 intervals have been drilled with the retrievable tools, and it has sometimes been difficult to recover the BHA, this was the first incidence where it has been left in the well.

The Aracas well provides a good example of the type of well where the Casing Drilling® technology can make a difference for the operator. There was a unique problem to be solved and the technology seemed capable of solving it in a reasonable fashion. The Casing Drilling® technology was not needed for the entire well and in fact would not have been competitive for drilling the entire well.

At the beginning of this year, a surface test was performed in Brazil to check the modifications done

by the manufacture to the retrievable system that has failed in the last field test. The results of this surface test showed that the modifications were effective and allowed Petrobras to decide to continue using this system. At the moment, a new test with Casing Drilling® is being planned in an onshore rig at the asset of San Rafael, located in an onshore field at North Espirito Santo state. The test is predicted to start on February 2008.

Liner Drilling

Since Petrobras' main oil fields are located in deep water areas, Casing Drilling® technology can not be applied. Therefore, liner drilling technology appears to be a solution to these scenarios. In fact, liner drilling can be considered as an improvement of the rotative liner system, conventionally used for improvement of cementing operations.

A liner is a string of pipes installed from the TD of the well to a predetermined point in the wellbore, and is hung off inside the previous casing or liner string. In order to run a liner string in the wellbore, it may have to be connected to a drill pipe string. Therefore, it is necessary to find a way to connect and disconnect the drill pipe from the liner and pull the drill pipe out of the well. In order to perform this operation two items are normally used: setting tool and setting sleeve.

The main limitations of the available liner drilling technology are the same as the casing drilling non-retrievable BHA systems, which use drill shoe at the



Figure 6: EZCase drilling shoe
(from Baker Hughes Christensen
website)

bottom. The drill shoe can not be retrieved; consequently, it results in drilling short intervals. Also, the hardness of the formation limits the use of drill shoe, which are not adequate for very hard formations. Also, only straight sections can be drilled with this system, once the BHA is not able for directional control. Based on this fact, another liner drilling system must be developed by the industry in order to meet this demand.

Petrobras Scenarios for Liner Drilling Application

Petrobras is analyzing the liner drilling technique to solve some drilling problems, which normally happen in offshore scenarios. The first test is being planned for 2009 to solve a problem in Badejo field, in Campos Basin, which presents severe loss circulation problems, impairing the drilling operation of the limestone formation in the intermediate sections with thickness of 150m.

At the moment, Petrobras is analyzing several available liner drilling alternatives to solve this problem, and a Technological Cooperative Agreement (TCA) is being planned to evaluate the best technique among several service companies. With the possibility of achieving good results, liner drilling will be considered in the technical and economical assessment for this field.

Casing Drilling® system has presented a great potential to overcome troublesome zones, but is also prone to mechanical unreliability. Tests of this system have been conducted in Brazil. During the tests, the tools were significantly changed and the complexity of the application increased. Several positive and negative aspects were observed. The negative points were treated and some equipment has been improved. The next test with this technology will be performed in February 2008.

Also, a very challenging application is now being considered as an alternative to drill deep water wells in Santos Basin, where the objectives are located bellow thick salt layers. The well path in the salt formation will be directional in order to permit to install the completion system in a horizontal section of the well. In this case, liner drilling also plays an important role to make feasible to drill such salt formation.

Conclusions

Casing Drilling® system has presented a great potential to overcome troublesome zones, but is also prone to mechanical unreliability. Tests of this system have been conducted in Brazil. During the tests, the tools were significantly changed and the complexity of the application increased. Several positive and negative aspects were observed. The negative points were treated and some equipment has been improved. The next test with this technology will be performed in February 2008.

Definitely, there is room for improving operational planning and logistics in order to increase the chances of delivering a successful outcome.

Liner drilling is another technique that is being considered to solve well instability problems in offshore

scenarios in Brazil. This technique has been mostly used from jack rigs. The challenge in Brazil is to turn this technique successfully when also drilling from floating rigs.

Acknowledgements

We would like to thank Petrobras for the support in this project and for allowing publication of these results.

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BJ

BJ ComPlete MST - Single Trip Multi Zone Sand Control Completion – A system Overview

By Fred Carvalho, BJ Services, Rio de Janeiro - Brazil

BJ Services completion tools division has focused on optimization and enhancing of well and reservoir performance in order to provide rig time and cost saving for world wide operators. The ComPlete System Family is the key solution that allows continuing optimization of all phases of the completion cycle. The benefits of these systems are not limited to time saving and minimization of rig costs. Each component of BJ ComPlete System are designed and built for heavy duty operations offering the best-in-class performance of the oil industry.

BJ ComPlete MST System

Gravel/Frac pack multiple zones in a single trip with complete zone isolation and selective production capability.

Main applications:

- Multi zone frac packs of vertical or deviated wells;
- Multifracturing of open hole or cased hole horizontal wells*.

The ComPlete MST system eliminates a number of operational steps compared with traditional multi-zone frac-pack and gravel-pack completions:

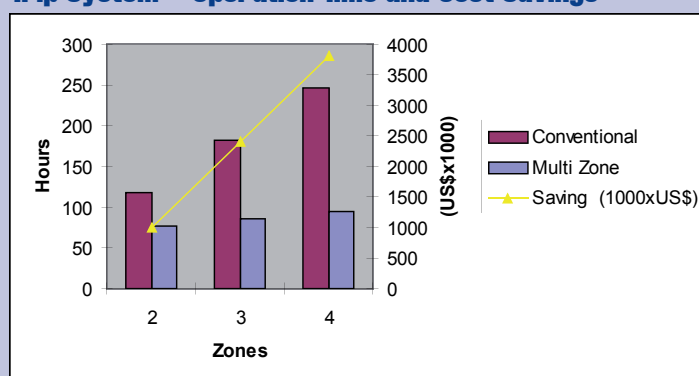
- Multiple perforating trips;
- Packer plug retrieval runs;

- Multiple gravel pack assembly runs;
- Stimulation trip runs on workstring.

Benefits to the operator include:

- Individual zone isolation while treating;
- Zone isolation after treating;
- Selective access for production;
- Maintain large bore for optimal flow;
- Support large-bore service tools for optimal treating rates;
- Quicker realization of production initiation.

MST System Completion Cycle Time X Conventional Multi Trip System – Operation Time and Cost Savings



*SPE 108075 - Horizontal Well Completion and Stimulation Techniques - A Review with Emphasis on Low-Permeability Carbonates - Valdo Ferreira Rodrigues, SPE, Petróleo Brasileiro S.A., Luis Fernando Neumann, SPE, Petróleo Brasileiro S.A.; Daniel Torres, SPE, Cesar Guimarães, SPE, Ricardo Sadowski Torres, BJ Services.

Well P



Planned

PART 3

The third of three articles based on excerpts from the book *Hydrocarbon Highway*

By Wajid Rasheed

Pressure While Drilling

These types of tools are used to make accurate downhole measurements of:

- Equivalent circulating density (ECD);
- Kick detection, including shallow water flows;
- Swab/surge pressure monitoring while tripping and reaming;
- Hole cleaning;
- Hydrostatic pressure and effective mud weight;
- Accurate leak-off test (LOT) and formation integrity test (FIT) data;

Coring

Formation core samples may be taken. These are the most important way of examining formations and any oil bearing strata. Mostly, cores are used with a “core barrel” which drills formations. As the core barrel is rotated, it cuts a cylindrical core a few inches in diameter that is received in a tube above the core-cutting bit. A complete round trip is required for each core taken. The second is a

sidewall sampler in which a small explosive charge is fired to ram a small cylinder into the wall of the hole. When the tool is pulled out of the hole, the small core samples come out with the tool. Up to thirty of the small samples can be taken at any desired depth. This provides positive real evidence of cross-flow, permeability and porosity. Lab tests are complex and can include Fluorescence (TSF) Gas Chromatography.

Oil can be found in cores as 3-D seismic surveys offers much enhanced imaging of subsurface fluid flow. Cores usually measure between 3 to 4 meters in length.

Sampling and Screening of Cores

On board ship, cores are physically described, logged and sampled. Three sections from the bottom half of each core are sampled for geochemical analysis. Deeper core sections are used in order to avoid contamination from modern petroleum pollution sources near the surface. Analysis of three sections per core increases the likelihood of encountering petroleum seepage, which is typically not distributed homogeneously throughout the sediments. All core material is stored frozen until return to the laboratory.

The final section of the hole is what the operating company hopes will be the production hole. But before long, the formation of interest (the pay zone, the oil sand, or the formation that is supposed to contain hydrocarbons) will be penetrated by the hole. It is now make or break time - “Does this well contain enough oil or gas to make it worthwhile to run the final production string of casing and complete the well?”

The objective of these analyses is to characterize the composition and origin of solvent-soluble hydrocarbons. The cores are stored in specially created conditions to preserve characteristics.

Drilling to Total Depth

The final section of the hole is what the operating company hopes will be the production hole. But before long, the formation of interest (the pay zone, the oil sand, or the formation that is supposed to contain hydrocarbons) will be penetrated by the hole. It is now make or break time - “Does this well contain enough oil or gas to make it worthwhile to run the final production string of casing and complete the well?”

After the operating company carefully considers all the data obtained from the various tests it has ordered to be run on the formation or formations of interest, a decision is made on whether to set production casing and complete the well or plug and abandon it. If the decision is to abandon it, the hole is considered to be dry, that is, not capable of producing oil or gas in commercial quantities. In other words, some oil or gas may be present but not in amounts great enough to justify the expense of completing the well. Therefore, several cement plugs will be set in the

well to seal it off more or less permanently. However, sometimes wells that were plugged and abandoned as dry in the past may be reopened and produced if the price of oil or gas has become more favorable. The cost of plugging and abandoning a well may only be a few thousand dollars. Contrast that cost with the price of setting a production string of casing - \$50,000 or more. Therefore, the operator's decision is not always easy and is invariably oil or gas price driven.

Setting Production Casing

If the operating company decides to set casing, casing will be brought to the well and for one final time, the casing and cementing crew run and cement a string of casing. Usually, the production casing is set and cemented through the pay zone; that is, the hole is drilled to a depth beyond the producing formation, and the casing is set to a point near the bottom of the hole. As a result, the casing and cement actually seal off the producing zone-but only temporarily. After the production string is cemented, the drilling contractor has almost finished his job except for a few final touches.

Cementing

After the casing string is run, the next task is cementing the casing in place. An oil-well specialist cementing

service company is usually called in for this job. A good cementing job is crucial to the longevity of the well and incorporates many factors incl. annular volumes, formation-cement-wellbore interaction, slurry and set properties at any density, high or low. Cement behaviour at different pressure, temperature and loading conditions

Cementing applications include sealing the annulus after a casing string has been run, sealing a lost circulation zone, setting a plug in order to 'kick-off' a wellbore deviation or to plug and abandon a well.

Perforating

Since the pay zone is sealed off by the production string and cement, perforations must be made in order for the oil or gas to flow into the wellbore. Perforations are simply holes that are made through the casing and cement and extend some distance into the formation. The most common method of perforating incorporates shaped-charge explosives (similar to those used in armor-piercing shells).

Acidizing

Sometimes, however, petroleum exists in a formation but is unable to flow readily into the well because the formation has very low permeability. If the formation is composed of rocks that dissolve upon being contacted by acid, such as limestone or dolomite, then a technique known as acidizing may be required. Acidizing is usually performed by an acidizing service company and may be done before the rig is moved off the well; or it can also be done after the rig is moved away. In any case, the acidizing operation consists of pumping appropriately sized volumes of acid down the well. The acid travels down the tubing, enters the perforations, and contacts the formation. Continued pumping forces the acid into the formation where it etches channels - channels that provide a way for the formation's oil or gas to enter the well through the perforations.

Fracturing

When sandstone rocks contain oil or gas in commercial quantities but the permeability is too low to permit good recovery, a process called fracturing may be used to increase permeability to a practical level. Basically, to fracture a formation, a fracturing service company pumps a specially blended fluid down the well and into the formation under great pressure. Pumping continues until the formation literally cracks open. 

When sandstone rocks contain oil or gas in commercial quantities but the permeability is too low to permit good recovery, a process called fracturing may be used to increase permeability to a practical level. Basically, to fracture a formation, a fracturing service company pumps a specially blended fluid down the well and into the formation under great pressure. Pumping continues until the formation literally cracks open.



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VENDA • LOCAÇÃO

A Novel Approach for Drilling and Gravel Packing Horizontal Wells in the Presence of Reactive Shales Using a Solid-Free Synthetic Fluid

By A. Leibsohn Martins, SPE; Atila Fernando Lima Aragao, Agostinho Calderon, Andrea Sa/Petrobras; Lirio Quintero, SPE and Alex. McKellar, SPE/ Baker Hughes Drilling Fluids and Allen D. Gabrysch, SPE/ Baker Oil Tools

Drilling build-up and horizontal sections in a single step is an attractive design approach aimed at cost reduction and increased performance efficiency in offshore field development, including the re-entry of old wells in mature fields – infill drilling. Constructing the well using a solid-free synthetic fluid can reduce total rig time, in addition to saving casing costs.

Most of the production wells in sandstone reservoirs require sand control due to poorly consolidated formations. OHGP is still the most popular solution for sand control in offshore deepwater reservoirs.¹ The petroleum industry has developed a number of fluid systems for a successful OHGP using water-based drill-in fluid (DIF) and gravel carrier fluid, or a synthetic DIF and water based gravel carrier fluid.^{2,3,4} In addition, some efforts have been made to develop an oil-based carrier fluid.^{5,6,7,8}

The petroleum industry has made efforts to develop high performance water-based fluids; however, the use of synthetic fluids guarantees superior wellbore stability, lubricity, inhibition and drilling performance.

One important case, where DIF shale inhibition is critical, is in the drilling of horizontal sections, where the reservoir zone contains interlayers of reactive shales.

Displacing of synthetic DIF for water-based gravel carrier fluids is a complex operation, due to the potential for fluid interaction, formation damage and problems of offshore logistics.

Another challenging case is to provide a reliable sand control technique in the horizontal section with operational safety and minimum formation damage.

This article proposes a new approach, in which synthetic fluids are used for all steps of the well construction (drilling and completion). Using a solid-free invert emulsion synthetic fluid as the carrier medium to pack the gravel in a conventional alpha-beta wave deposition technique eliminates the need for introduction of a water-based gravel pack fluid. This approach would be useful in the two cases previously mentioned.

The goal was to optimize the synthetic fluid to provide Newtonian behavior, especially at low-shear rate, minimum viscosity for a given density, compatibility with the drilling fluid, minimum formation damage, wellbore stability, and gravel wettability.

Experiments were conducted using a large-scale acrylic flow loop to evaluate the performance of the synthetic fluid as a carrier medium in horizontal gravel packing

	Fluid density, lb/gal			
	9.0	9.5	10.0	10.5
n-paraffin, bbl	0.487	0.585	0.519	0.455
Emulsifier/wetting agent, lb/bbl	10	10	10	10
11.6 lb/gal CaCl ₂ , bbl	0.482	-	-	-
14.2 lb/gal CaBr ₂ , bbl	-	0.384	0.449	0.514
Oil/brine ratio	52/48	62/38	55/45	49/51
Properties at 120°F after hot-rolling for 16 hours at 150°F				
Plastic viscosity, cP	13	8	11	18
Yield point, lb/100 ft ²	0	0	0	1
3-rpm reading	0	0	0	0
10-sec gel, lb/100 ft ²	0	0	0	0
10-min gel, lb/100 ft ²	0.5	0	0	0
Electrical stability, volts	280	360	340	340
Properties at 120°F after static aging for 48 hrs at 200°F				
Plastic viscosity, cP	12	7	11	18
Yield point, lb/100 ft ²	1	1	0	1
3-rpm reading	0	0	0	0
10-sec gel, lb/100 ft ²	0	0	0	0
10-min gel, lb/100 ft ²	0.5	0	0	0
Electrical stability, volts	230	200	200	220

Table 1 - Fluid formulations and properties

operations. Alpha wave deposition heights and packing qualities were measured for different proppant materials and densities. The resultant fluid formulation has densities ranging from 9.0 to 10.2 lb/gal, and guarantees proper alpha-beta wave gravel deposition and minimal formation damage.

Fluid Development

For gravel-pack applications, a solid-free invert emulsion carrier fluid was required that would be compatible with the paraffin-based DIF that would be used for drilling the horizontal section.

The required specifications of the designed invert emulsion carrier fluid are:

- The carrier fluid should exhibit near-Newtonian behavior with zero or near-zero values for yield point, low rpm oil field viscometer readings and gel strength.
- The carrier fluid should remain stable, with no brine breakout, for 48-hours during static testing

Formulation of an invert carrier with these desired characteristics requires the proper choice of base oil and surfactant package. Laboratory testing determined that low kinematic viscosity paraffins and mineral oils were most appropriate for this application, particularly for providing minimal viscosity and near-Newtonian behavior. A surfactant package consisting of an emulsifier and wetting agent was also developed to optimize fluid performance. Use of this blend of surfactants is critical in maintaining fluid stability at temperature, achieving

near-Newtonian rheological behavior, and desirable wetting of the gravel. Care must also be taken to utilize the proper ratio and total concentration of emulsifier and wetting agent to obtain the required fluid properties.

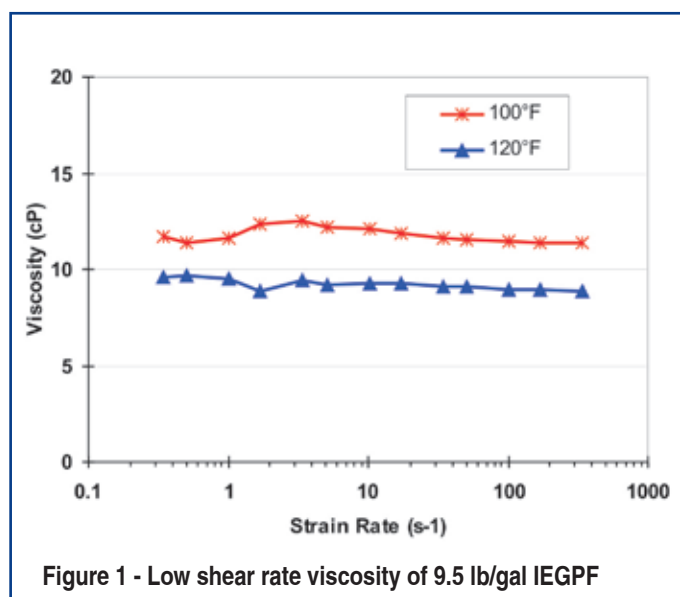
Solids-free invert emulsion carrier fluids using paraffin base oil were designed with densities of 9.0, 9.5, 10, and 10.5 lb/gal. Calcium bromide and calcium chloride brines were used as internal phases in the invert emulsion formulations.

The following test matrix includes the most critical laboratory testing steps for evaluation of these carrier fluid formulations:

1. Rheological evaluation using a Fann 35A viscometer and RFS-III rheometer.
2. Long term emulsion stability under static conditions for 48-hrs at 200°F.
3. Fluid properties of the carrier fluid contaminated with
 - a. 3% low-gravity solids (Rev-Dust)
 - b. Formation water
 - c. Conditioned oil-based drilling fluid
4. Settling conditions of 20/40 sand in the invert carrier fluid.
5. Evaluation of the impact of filtrate invasion after displacement to solids-free invert
 - a. Quantify filtrate invasion after displacement to solids-free invert
 - b. Determine if the solids-free filtrate reduce the permeability of the sandstone (formation damage test).

Fluid formulations evaluation

The solids-free invert emulsion fluids formulated with densities between 9.0 and 10.5 lb/gal are described in Table 1. The fluids were mixed with oil/brine ratios between 49/51 and 62/38 using calcium chloride or calcium bromide brine to achieve the desired density. After mixing, these fluids were then hot-rolled at 150°F and static aged at 200°F for 48 hours, after which the Fann 35 viscometer measurements and electrical stability were evaluated. The data collected for these fluids, exhibited in Table 1, indicated that the fluid formulations had near zero yield point, 3-rpm reading, and gel strengths after 150°F hot-rolling for 16 hours. The rheological properties exhibited minimal changes when the samples were static aged for 48 hours compared to the results determined after hot-roll. The near-Newtonian behavior observed in these fluids was verified by measuring the



low shear rate viscosity of the fluids, which exhibited minimum variation with shear rate measured as low as 0.3 seconds-1. Figure 1 details the viscosities measured over a wide shear rate range for the 9.5 lb/gal invert carrier. These results satisfied the specified requirement for use of the invert emulsion carrier fluids in gravel pack operations.

Fluid contamination tests

Table 2 shows the properties of the 9.0 and 10.5 lb/gal invert carrier fluids after contamination with 3% Rev-Dust to simulate the incorporation of low-gravity solids into the fluid. The contaminated fluid exhibits rheological properties similar to the solids-free fluid, indicating that the solids-free formulation has adequate wetting agent to minimize the effect of the introduction of low gravity solids into the fluid. A slight increase in the plastic viscosity and a minor reduction in electrical stability were observed. As expected, the vast majority of the Rev-Dust was found to have settled out in the heat cup during the measurement of the gel strengths, consistent with the objectives of this fluid.

The rheological properties were also determined for solids-free fluids contaminated with: (1) 5% and 10% of the 10.5 lb/gal highly-viscous synthetic drilling fluid; and (2) 5% and 10% of formation water. The composition of

Components	Concentration, mg/L
NaCl	82,500
Ca ⁺⁺	7,425
K ⁺	175
Mg ⁺⁺	1,254
HCO ₃ ⁻	658.9
SO ₄ ⁻	350

Table 3 - Composition of formation water

	9.0 lb/gal		10.5 lb/gal	
	IEGPF	IEGPF w/ Rev-Dust	IEGPF	IEGPF w/ Rev-Dust
n-paraffin, bbl	0.487	0.487	0.455	0.455
Emulsifier/wetting agent, lb/bbl	10	10	10	10
11.6 lb/gal CaCl ₂ , bbl	0.482	0.482	-	-
14.2 lb/gal CaBr ₂ , bbl	-	-	0.514	0.514
Rev-Dust, %	-	3	-	3
Oil/brine ratio	52/48	52/48	49/51	49/51
Properties at 120°F after 16 hrs dynamic aging at 150°F				
Plastic viscosity, cP	13	16	18	22
Yield point, lb/100 ft ²	0	1	1	1
3-rpm reading	0	0	0	0
10-sec gel, lb/100 ft ²	0	0.5	0	0
10-min gel, lb/100 ft ²	0.5	0.5	0	1
Electrical stability, volts	280	240	340	270

Table 2 - Contamination tests of 9.0 lb/gal and 10.5 lb/gal solids-free invert emulsion with Rev-Dust

the formation water used is described in Table 3.

The rheological properties determined after the 9.0 and 10.5 lb/gal invert carrier fluids were contaminated with 5 and 10% highly-viscous synthetic drilling fluid are shown in Table 4. Relative to the data gathered for the uncontaminated fluids shown in Table 1 after 150°F hot-rolling for 16 hours, the rheological properties determined for the contaminated fluids change very little.

Table 5 exhibits the effect of contaminating the 9.0 and 10.5 lb/gal invert carrier fluids with 5 and 10% formation water. Compared with the results obtained for the uncontaminated fluid, a slight variation is noted in the plastic viscosity, gel strength, and electrical stability. These results indicate that the fluids contain enough excess emulsifier to properly tolerate an influx of formation water into the carrier fluid.

The results shown in Tables 4 and 5 indicate that contamination with drilling fluid and formation water does not affect the rheological properties of the carrier fluid.

Properties at 120°F	DIF	9.0 lb/gal		10.5 lb/gal	
		DIF/ IEGPF		DIF/ IEGPF	
		5/95	10/90	5/95	10/90
Plastic viscosity, cP	25	14	14	18	18
Yield point, lb/100 ft ²	39	0	1	1	1
6-rpm reading	23	0	0	0	0
3-rpm reading	21	0	0	0	0
10-sec gel, lb/100 ft ²	22	0.5	0.5	0	0
10-min gel, lb/100 ft ²	23	0.5	0.5	0	0
Electrical stability, volts	630	300	320	340	360

Table 4 - Contamination tests of 9.0 lb/gal and 10.5 lb/gal IEGPF with synthetic DIF

Properties at 120°F	9.0 lb/gal			10.5 lb/gal		
	Formation water/ IEGPF			Formation water/ IEGPF		
	0/100	5/95	10/90	0/100	5/95	10/90
Plastic viscosity, cP	13	15	18	18	21	21
Yield point, lb/100 ft ²	0	1	0	1	1	1
6-rpm reading	0	0	0	0	0	0
3-rpm reading	0	0	0	0	0	0
10-sec gel, lb/100 ft ²	0	0	0	0	0.5	0.5
10-min gel, lb/100 ft ²	0.5	0.5	0.5	0	1	1
Electrical stability, volts	280	280	240	340	400	440

Table 5 - Contamination tests of 9.0 lb/gal and 10.5 lb/gal IEGPF with formation water

Settling of the proppant in an invert emulsion carrier fluid

The sand settling was evaluated by mixing specific proportions of 20/40 sand with the 10.5 lb/gal solids-free invert emulsion fluid. The sample was shaken vigorously until the gravel was dispersed in the IEGPF, and then quickly transferred to a 500-mL graduated cylinder. The settling rate of the gravel was then determined as a function of time by recording the volume of free fluid and sand/IEGPF slurry.

Figure 2 shows how the sand fully settles after less than 100 seconds, reaching the final sand volume of 225 mL.

Several additional tests were performed using smaller amounts of fluid and sand to determine the difference in the packing of sand when different carrier fluids were employed. These tests compared the height of the sand after complete settling had occurred using IEGPF, base oil, and water as the carrier fluid. Appropriate amounts of carrier fluid and 20/40 sand were introduced into a vial and shaken vigorously. After the sand settled, the heights were compared to a sample of dry 20/40 sand placed in a vial. Little difference was observed between the heights of the settled sand, indicating the use of the IEGPF carrier does not significantly affect the packing of the sand compared to using a low-viscosity aqueous or base oil carrier.

Formation Damage Evaluation

A return permeability test, using a standard Hassler Permeameter with 500 psi differential pressure and 200°F, was carried out to evaluate the impact of filtrate invasion by the solids-free invert emulsion on formation damage.

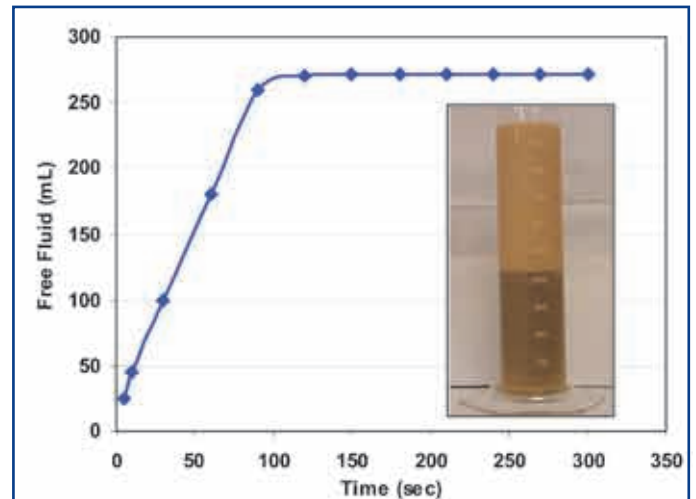


Figure 2 - Settling of 20/40 sand in 10.5 lb/gal IEGPF

The test was performed using 2.8 Darcy Berea sandstone and a 10.5 lb/gal solids-free invert emulsion fluid, which flowed through the core because no filter cake existed. The results of the test show a permeability return of 95%, indicating no potential damage to the sandstone formation (see Figure 3).

A return permeability test was also made in a Sandpack permeameter using a 9.4 lb/gal IEGPF. The procedure includes the deposition of a filter cake prior to the placement of the invert emulsion carrier fluid for gravel pack. Results presented in Table 6 show a return of permeability of 100%. Also important were the low break-through pressures required to initiate return flow (0.5 psi).

Filtration Tests

A modified procedure of static and dynamic filtration tests was used to determine the filtration invasion after displacement of the synthetic drill-in fluid by the invert

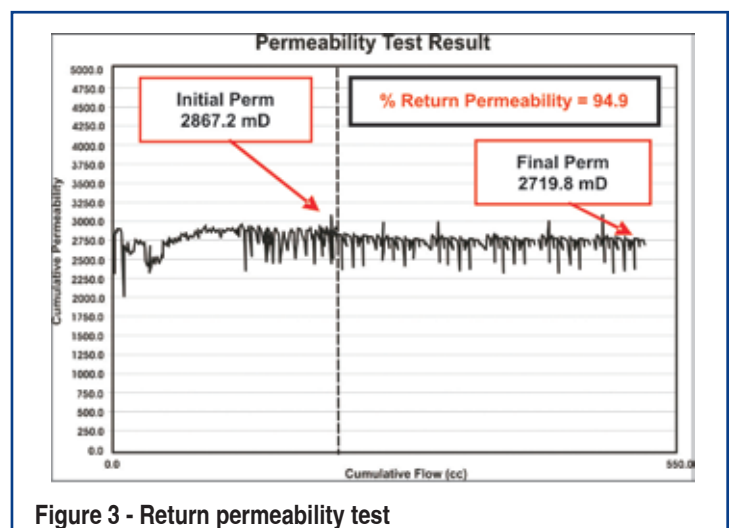


Figure 3 - Return permeability test

Temperature, °F	160
Differential pressure, psi	500
Initial permeability, mD	448.5
Final permeability, mD	450.5
Return permeability, %	100
Breakout pressure, psi	0.5

Table 6 - Sandpack test with 9.4 lb/gal IEGPF

emulsion carrier fluid. The modified procedure included the deposition of a paraffin DIF filter cake on a 10-micron ceramic disk for 16-hours, followed by the placement of the invert emulsion carrier fluid on top of the filter cake for 2 hours. The tests were carried out at 160°F and 500 psi differential pressure and 160°F.

Figure 4 details the results gathered when the modified procedure was performed under static conditions. At 160°F and 500 psi differential, the mud-off volume was 15.2 mL. After contacting the cake with the invert carrier for 2 hours, an additional 1.2 mL of filtrate was collected. Under dynamic conditions, the mud-off volume was 18.2 mL, and an additional filtrate of 3.0 mL of filtrate was collected after contacting the cake with the invert carrier for 2 hours.

These results indicate that the invert emulsion carrier fluid did not disturb the filter cake and consequently, no increase in filtrate invasion should be expected from the displacement of the drill-in fluid by the invert emulsion carrier fluid.

Gravel Pack Tests in Flow Loop

The next objective was to evaluate the gravel pack quality and pressures obtained with invert emulsion carrier fluids in a flow loop. Different proppants and carrier fluid densities were tested in a series of flow loop trials.

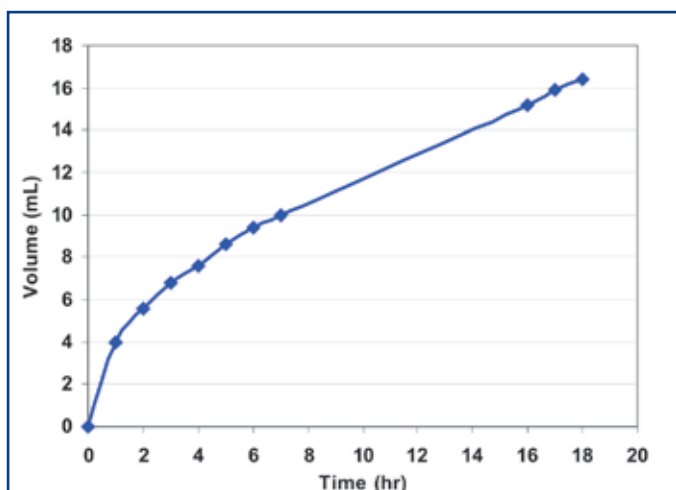


Figure 4 - Effect of IEGPF on static filtration

Test facility - 30 ft Gravel Pack Simulator

The Gravel Pack Simulator reproduces field conditions during gravel packing operations. The 30 foot long transparent acrylic casing of the simulator allows visual inspection of the gravel pack assembly, as well as observation of perforation filling, and any voids or bridging during the pumping process (Figure 5). Production can also be simulated. In the flow loop, there are 18 feet of perforations with a variable shot density from 12 SPF downwards. Fluid leak-off into the perforations can be varied over the interval as required. Wellbore deviation can be set at any value from horizontal to vertical (inclusive). For the testing reported, the wellbore was horizontal, and all of the perforations were closed (i.e., 100% returns were simulated).

Phase 1 of Gravel Pack Tests

The first phase of the evaluation of invert emulsion fluid in the gravel pack simulator involved four tests with the conditions described in Table 7. These tests were designed to evaluate the likelihood of an alpha-beta wave packing sequence occurring with this oil-based fluid. In addition, information was sought concerning how the gravel/proppant density affects pack quality, as well as the effect that blank pipe sections may have on void formation.

The first three of these tests were carried out with a 10.2 lb/gal solid-free invert-emulsion fluid at a temperature of approximately 100°F. Table 8 shows the rheological properties of the carrier fluids measured before and after each test. In addition to the measured data, videos of each test were recorded. Test #4 was performed with 9.36 lb/gal NaCl as a carrier fluid. This test allows direct comparison between the IEGPF tests and water packing.

The data recorded during the testing was obtained manually and through electronic data acquisition. Dune



Figure 5 - Detail of the Gravel Pack Simulator

Test #	Flowrate (bpm)	Mix Ratio (ppa)	Carrier fluid	Gravel/proppant type
1	3	1	10.2 lb/gal IEGPF	20/40 gravel sand
2	3	1	10.2 lb/gal IEGPF	20/40 bauxite
3	3	1	10.2 lb/gal IEGPF	20/40 resin coated
4	3	1	9.36 lb/gal NaCl brine	20/40 gravel sand

Table 7 - Test matrix of 10.2 lb/gal IEGPF evaluation in the Gravel Pack Simulator

	Test 1: 20/40 GP sand	Test 2: bauxite	Test 3: resin coated
n-paraffin, bbl	0.5112	0.5112	0.5112
emulsifier/wetting agent, lb/bbl	10	10	10
14.2 lb/gal CaBr ₂ , bbl	0.4576	0.4576	0.4576
Rheological Properties at 100°F			
	Initial/ after test	Initial/ after test	Initial/ after test
Plastic viscosity, cP	17/17	17/17	18/18
Yield point, lb/100 ft ²	0/1	1/0	0/0
3 rpm reading	0/0	0/0	0/0
10-sec gel, lb/100 ft ²	0/1	0/0	0/0
10-min gel, lb/100 ft ²	0.5/0.5	0/0	0/0

Table 8 - Properties of fluids tested in flow loop

heights were measured by marking the equilibrium height at referenced locations. The tests were made with a volume fraction of gravel or proppant in carrier fluid of 0.043. Table 9 summarizes the results of these measurements.

Figure 6 shows the pressures recorded during Test 1, as follows: inlet pressure (dark blue), wash pipe inlet (pink), pump pressure (yellow) and flow rate (light blue). This chart illustrates the stability and good control of flow rates and, consequently, normal pressure curves. Similar behavior was obtained in the other tests. An estimate of proppant/gravel placed was carried out for each test, except Test 1, with 100% for Test 2 (bauxite), 76% for Test 3 (resin coated) and 92% for Test 4 (sand and water as the carrier fluid).

This series of tests shows that an alpha-beta wave packing sequence is maintained for this fluid. However, this fluid does not seem to pack blank pipe sections as well as water. Part of the reason for this observation was related to the testing configuration, namely absolutely no leak-off. Typically during water pack tests, some fluid is allowed

to leak-off to the perforations. This is assumed to be reasonable since it is rare that zero leak-off is observed in the field. This small amount of leak-off will provide an additional fluid flow path over the blank pipe section during beta-wave placement. We have found that even minimal flow will cause gravel to be carried between 5 and 10 feet along the top of the alpha wave previously placed across the blank pipe. However, without any leak-off, all of the flow had to pass through a sand pack, which was not as easily done with this 13 cP fluid as it is with water. It has been noted that the increased permeability of bauxite assisted this process, resulting in a significantly smaller void remaining at the conclusion of pumping.

While a minor benefit was obtained through the use of resin-coated sand, the high density bauxite provided the best packing efficiency. The alpha-wave was much more stable, and appeared to behave in a manner more similar to water packing than did natural gravel pack sand. It has been observed that when packing with natural sand, the viscosity of the IEGPF was such that the initial packing was nearly a toe-to-heel (as demonstrated by a very low initial alpha-wave). This would be similar to the packing

Test	Flow rate, bpm	Mix ratio, ppa	Final dune/hole ratio	Palpha/Pbeta, psi	Observations
1	3	1	0.521	49/66	Multiple alpha waves, small void on top of blank section
2	3	1.344	0.69	51/68	Two alpha waves, small void on top of blank section
3	3	0.974	0.635	51/69	Two alpha waves, small void on top of blank section
4	3.2	1	0.77	40/60	One alpha wave, small void on top of blank section

Table 9 - Summary of alpha-beta wave results using 10.2 lb/gal IEGPF

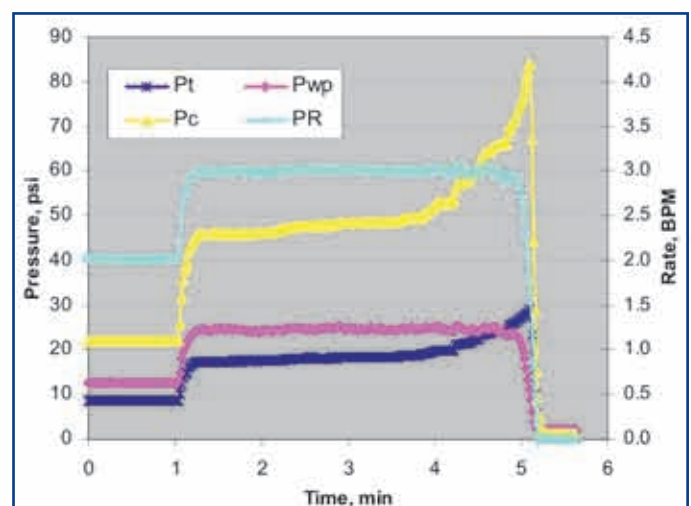


Figure 6 - Pressures recorded during Test 1

	Test 1	Test 2	Test 3	Test 4
Plastic viscosity, cP	11	11	11	11
O/W ratio	49/51	49/51	49/51	49/51
Proppant type	Bauxite 20/40	Bauxite 20/40	Gravel 20/40	Gravel 20/40
Proppant SG	3.56	3.56	2.56	2.56
Specific gravity abs, lb/gal	29.65	29.65	21.32	21.32
Bulk density, lb/gal	18.19	18.19	14.1	14.1
Mix ratio, ppa	3	1	3	1
Flow, bpm	3.5	3	3	3
Volume of proppant in simulator 1	21.85	22.11	20.84	25.83
volume in simulator	24.80	24.80	24.80	24.80
compaction 1	88.1	89.2	84.0	104.2

Table 10 - Matrix of tests in the gravel pack simulator using 9.4 lb/bbl IEGPF

	Test 5	Test 6	Test 7	Test 8
Fluid density, lb/gal	9.0	8.9	8.9	8.9
Plastic viscosity, cP	19	15(*)	15(*)	15(*)
O/W ratio	49/51	42/58	42/58	42/58
Proppant type	Bauxite 20/40	Bauxite 20/40	Gravel 20/40	Gravel 20/40
Proppant SG	3.56	3.56	2.56	2.56
Specific gravity abs, lb/gal	29.65	29.65	21.32	21.32
Bulk density, lb/gal	18.19	18.19	14.1	14.1
Mix ratio, ppa	3	1	1	1
Flow, bpm	3.5	3	3	3
Volume of proppant in simulator 1	17.85	20.71	27.13	30.98
volume in simulator	24.80	24.80	24.80	24.80
compaction 1	72.0	83.5	109.4	124.9

Table 11 - Matrix of tests in the gravel pack simulator using 9.0 lb/gal IEGPF

mechanism when using a gelled fluid. However, by the end of the test, a secondary alpha-wave had been deposited, and the pack was completed in a manner closer to that of a water pack. Nevertheless, the void left over the blank pipe section was the largest during this test.

Phase 2 of Gravel Pack Tests

A second set of tests was performed to evaluate packing quality in the following situations:

- 9.4 lb/gal IEGPF with a CaBr₂ brine as internal phase; proppants: sand and bauxite at 1 and 3 ppa. This fluid closely resembles several application requirements in the Campos basin, offshore Brazil.
- 9.0 lb/gal IEGPF with a CaCl₂ brine as internal phase. In this case, the objective was the definition of minimum weight limits for the fluid in order to broaden its range of application.

Tables 10 and 11 show the performed test matrix, as well as the results obtained for gravel compaction and fluid properties. The tests performed with the 9.4 lb/gal fluid containing CaBr₂ were all considered successful with normal alpha-beta wave deposition and increasing compaction values from the sand to the bauxite, regardless of their feed concentration.

On the other hand, the first test performed with the 9.0 lb/gal fluid containing CaCl₂ and using bauxite as proppant, showed low definition in the alpha-wave deposition process. The test was considered inadequate. This was initially attributed to the higher absolute viscosity of the fluid (19 cP) when compared with 11 cP for the 9.4 lb/gal fluid. The 9.0 lb/gal fluid was then diluted with paraffin until viscosity reached 15 cP. The resultant fluid density was 8.9 lb/gal.

The gravel pack tests with 8.9 lb/gal were performed at lower pump rates (2 and 1 bpm); however, the alpha-wave depositions were not successful. The next strategy was to confirm viscosity values (assure Newtonian behavior) at the low shear rates which are representative of the alpha-wave sedimentation mechanism. Low shear rate viscosity determinations were then made to quantify viscosities at shear rates as low as 0.01 seconds. The results illustrated in Figure 7 confirm the hypothesis of non-Newtonian behavior for the fluids containing CaCl₂ brines. This behavior was produced by an excess of emulsifier; as it was later determined that CaCl₂ required less concentration than CaBr₂ to achieve a good solid-free invert emulsion with Newtonian behavior. The fluids with CaBr₂ brines showed the expected Newtonian behavior at low shear rates.

Two additional gravel packing tests were performed at lower flow rates, in order to try to visualize alpha-wave

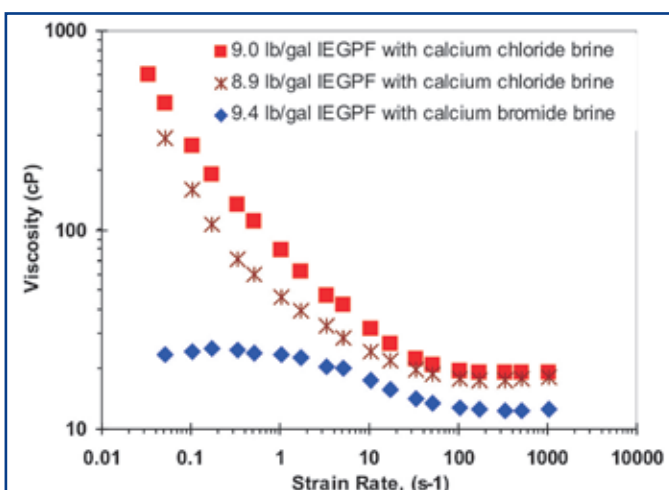


Figure 7 - Non-Newtonian behavior of IEGPF with calcium chloride brine

deposition. This test was made at 2 bpm and a premature screen-out was observed, as expected, at the 1 GPM test.

Final Remarks and Conclusions

- The extensive lab and gravel pack placement experimentation program performed allowed validation of the concept of using invert emulsions containing CaBr₂ brines as gravel pack carrier fluids. Fluid with densities between 9.4 and 10.2 lb/gal were successfully tested.

- Although tests performed with bauxite showed superior gravel placement, all proppants achieved satisfactory results. The pumping of 3 ppa proppant concentration seemed to be an interesting alternative for the reduction of operational time and of fluid volume requirements.

- Tests performed with the 9.0 lb/gal IEGPF with calcium chloride brine showed poor alpha-wave deposition due to the non-Newtonian behavior at low shear rates of the fluid formulation. The types of brine and surfactant concentration are important parameters that affect the low shear rate viscosity.

- The extension of the concept for fluids designed with densities in the range of 9 lb/gal is certainly possible, but still requires some future lab effort.

- The strategy for implementation of this technology in the field includes the following steps:

1. Perform three gravel pack operations at wells with conventional designs, utilizing the IEGP fluid containing CaBr₂;

2. With the operational success of the conventional well designs, perform gravel pack operations with the proposed fluid in wells where the buildup and reservoir sections have been drilled in a single phase (new development wells or re-entry wells).

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Nomenclature

- IEGPF = Invert emulsion gravel pack fluid
- OHGP = open-hole gravel pack
- DIF = drill-in fluid
- WBM = Water Based Mud
- OBM = Oil Based Mud
- CaBr₂ = calcium bromide
- CaCl₂ = calcium chloride
- NaCl = sodium chloride
- bpm = barrels per minute
- P_{alpha} = casing pressure at conclusion of alpha wave
- P_{beta} = casing pressure at conclusion of beta wave
- lb/bbl = pounds per barrel
- lb/gal = pounds per gallon
- ft = feet
- °F = temperature in Fahrenheit
- °C = temperature in Celsius

Petrobras Exec

Q: Brazil Oil & Gas - What are the main Petrobras projects in the Brazilian Growth Acceleration Plan?

A: Gabrielli - The Brazilian Growth Acceleration Plan (GAP) includes 183 of Petrobras' Strategic Plan projects, representing investments in the order of R\$171.7 billion in oil and gas and in renewable fuel programs to be made by Petrobras and its partners through 2010.

Underpinned by socio-environmental responsibility and profitability principles, the Strategic Plan is in line with the GAP's goals. Consistent with the company's goals, the GAP's premises for the sector include:

- Ensuring Brazil's long-term oil self-sufficiency, with a minimum production 20% above Brazilian internal consumption, with a minimum 15-year reserve/production ratio, and heightened light oil production;
- Boosting and modernizing the refining complex, increasing Brazilian oil participation in the processed load and improving by product quality;
- Accelerating Brazilian gas production and offer;
- Ensuring Brazil's leadership in the Biofuel area.

The wide-ranging project portfolio, Petrobras' Business Plan, also seeks to grow oil and gas reserves, to expand transportation and distribution infrastructure, and to augment alternate and renewable fuel and energy source research and development.

Q: Brazil Oil & Gas - How will Petrobras increase investment and focus on exploratory activities?

A: Gabrielli - Intensifying the exploratory activity (the search for new oil fields) is vital to ensure long-term self-sufficiency sustainability. The exploration activities undertaken through 2010 will have special impact on production after this period, allowing Brazil to maintain production above the country's byproduct demand.



Petrobras will invest R\$15.5 billion in exploration through 2010. Including investments made by other companies (partners and third-parties), the resources to be invested in oil exploration in the PAC are estimated at R\$23.5 billion through 2010.

The high investments in Brazil, in the coming years, will allow Petrobras to maintain the robust growth goals the company has taken-on for several activities since 2003, with emphasis on the Country's industrial development. Oil production will continue to rise simply with the use of reserves that have already been discovered and with the deployment of the projects that have already been defined and are currently in motion.

utive Interview

Q: Brazil Oil & Gas - Can you detail how Petrobras has become more involved with the Bio-Diesel Programme?

A: Gabrielli - Petrobras' biodiesel program foresees, initially, industrial unit installation in Candeias (BA), Montes Claros (MG), and Quixadá (CE) with capacity to produce 50,000 tons/year each and with operations slated to begin by late 2007. The program will involve total resources of the order of R\$570 million. Petrobras is also analyzing the possibility of building other biodiesel plants, in partnership with the private sector, in several places nationwide by 2008. The foreseen availability of 855,000 cubic meters of biodiesel per year in 2010 will allow 2.3 million equivalent tons a year of carbon emissions to be prevented.

Ethanol: Initial Ethanol Export Corridor project deployment phase, involving the construction of ethanol pipelines to transport ethanol for exports.

HBIO: Technological process Petrobras developed to produce diesel using a petroleum and vegetable oil mix at conventional refineries. The process will be deployed in four refineries in 2007, in Minas Gerais, Paraná, Rio Grande do Sul, and São Paulo and will involve R\$150 million in investments. The demand for vegetable oils will reach 425,000 cubic meters in 2010. By 2011, HBIO will also be produced in Petrobras' other refining units in Brazil.

Q: Brazil Oil & Gas - How is Petrobras sustaining self-sufficiency?

A: Gabrielli - Seeking to maintain Brazil's oil self-sufficiency, Petrobras has a portfolio that includes dozens of projects and will involve R\$81 billion in investments in exploration and production through 2010. The portfolio's main projects include:

Marlim Leste Development: Installation of an FPSO-type platform vessel (P-53), capable of lifting 180,000 barrels per day, expected to go online in the first quarter of 2008 in the Campos Basin.

Petrobras' biodiesel program foresees, initially, industrial unit installation in Candeias (BA), Montes Claros (MG), and Quixadá (CE) with capacity to produce 50,000 tons/year each and with operations slated to begin by late 2007.

Marlim Sul Development: Installation of a semi-submersible-type platform (P-51) in the Campos Basin, the first of the type built entirely in Brazil, with operations set to commence in the first quarter 2008 and capacity to produce 180,000 barrels.

Roncador Module 1 Development: Installation, in the first quarter of 2007, of a semi-submersible-type platform (P-52) with capacity to produce 180,000 barrels per day in the Campos Basin.

Roncador Module 2 Development: Use of a platform vessel (FPSO), called P-54, to be installed in the Campos Basin during the third quarter 2007 and capable of lifting 180,000 barrels per day.

Piranema Field Development (SE): Installation of a floating platform to produce 30,000 barrels of high-quality light oil per day, in the second quarter 2007, in the Sergipe Basin.

Frade Field Development (RJ): Installation of a floating platform to produce 100,000 barrels per day in 2009.

Jubarte Field Development Phase 2 (ES): Installation of platform P-57, to be contracted, with capacity to produce 180,000 barrels per day and foreseen to go online in 2010.



Roncador Field Development Phase 2 (RJ): Installation of a floating platform, P-55, to be contracted with capacity to produce 180,000 barrels per day and foreseen to go online in 2011.

Q: Brazil Oil & Gas - How will Refining be improved?

A: Gabrielli - The projects to enhance and modernize Petrobras' refineries will broaden the processed load by 100,000 barrels per day and raise the processed Brazilian oil volume by 250,000 barrels per day (from 80% to 90% processed load). The R\$22.6 billion in investments (by 2010), involving work in all Petrobras refineries, also hope to improve fuel quality, rendering it "cleaner," and having an important socio-environmental effect too.

Improved diesel fuel quality will prevent emissions calculated at upwards of 86,000 tons of SO₂ per year, contributing to quality of life in the cities.

Q: Brazil Oil & Gas - What Gas Pipeline plans and LNG projects are underway?

A: Gabrielli - The gas pipeline network Petrobras is either currently constructing or that it plans to build involves total investments of R\$15 billion (R\$12.5 billion through 2010) and deploying liquefied natural gas (LNG) projects, which are budgeted at R\$5 billion (R\$2.9 billion through 2010). The main projects are the following:

Urucu - Manaus gas pipeline: Extending for 662 km, this pipeline will transport natural gas produced in Urucu to Manaus. The project includes building a pipeline between Urucu and Coari to flow the liquefied petroleum gas (LPG) production. It is slated to go online in the first quarter of 2008 and to involve investments nearing R\$1.26 billion.

Southeast - Northeast Gas Pipeline (Gasene): Designed to fully interconnect the Southeastern gas system to the Northeastern one, the project includes the Cacimbas - Catu, Cacimbas - Vitória and Cabiúnas - Vitória sections. Together with the gas pipelines in the Northeastern Network, such as the Catu-Carmópolis (265 km long, with a flow of 9.1million cubic meters a day, and with operations foreseen to commence in the second quarter 2008), it involves investments of R\$4.6 billion through 2010.

Southeastern Network: Campinas-Rio Gas Pipeline construction, which will extend for 453.6 km, be capable of transporting 5,800,000 cubic meters a day of natural gas, and involve total investments estimated at R\$862.5 million.

Liquefied Natural Gas (LNG): Projects are currently being studied to contract converted vessels to re-gasify the LNG which will be installed in the Guanabara Bay (Rio de Janeiro) and in the Pacém Port (Ceará). This project is hoped to go online in the first quarter 2009, involving investments of some R\$2.0 billion through 2010.

Petrobras is a company committed to Sustainable Development. When it interacts with the environment and uses its natural resources, the company is aware that it should render accounts to society on the impact of its operations on the biosphere, and contribute towards a better quality of life for the population.

Q: Brazil Oil & Gas - *Is any growth in Production foreseen?*

A: Gabrielli - To maintain long-term growth in production, Petrobras has been boosting its exploratory portfolio. It currently has, for future exploration, more than a hundred blocks purchased in National Petroleum, Natural Gas and Biofuel Agency (NPA) auctions. Additionally, it has exploration agreements in several other countries, allowing it to set a production goal of 4,556,000 barrels per day for 2015. For the end of the decade, the forecast is a total oil and gas production of 3,493,000 barrels per day, 2,925,000 of which is from Brazilian fields.

Q: Brazil Oil & Gas - *Can you describe some of Petrobras' Social & Environmental activities?*

A: Gabrielli - Petrobras has added to its core business the principles of human rights, labor, environment and fighting against corruption, when in 2004 it joined one of the most important projects of corporate social responsibility in the world, the Global Compact.

The company set a new performance benchmark in the area of Social Responsibility when it launched the Petrobras Zero Hunger Program on September 1, 2003, agreeing to invest R\$ 303 million by the end of 2006 in actions to strengthen public policies against poverty and starvation. Many actions are being implemented

throughout Brazil, with direct participation of the communities, contributing towards a better quality of life for the Brazilian population.

By means of a public selection process, the company chooses projects that are aligned with the Program's activities, with priority given to education and professional training, jobs and earnings, guaranteed rights of the child and adolescent, and social and volunteer projects.

Petrobras is a company committed to Sustainable Development. When it interacts with the environment and uses its natural resources, the company is aware that it should render accounts to society on the impact of its operations on the biosphere, and contribute towards a better quality of life for the population. Accordingly, the company has enormous socio-environmental responsibility and invests in programs that not only defend environmental preservation but also encourage the development of ecological awareness within the communities.

Over the past three years, Petrobras has invested around R\$ 5.2 billion in the environmental security of its facilities and more than R\$ 18 million in projects with environmental sponsorship, such as the Tamar, Humpback Whale and Manatee projects, for example. With its 50th anniversary in October 2003, the company launched the Programa Petrobras Ambiental. The Program, with projects chosen through a public selection process, considers investing R\$ 40 million for the first two years. ●

PETROBRAS TRANSPORTE S.A.

World Leader in

By Danny Aronson, Renewables Coordinator and Daniela Cerqueira das Dores, New Terminals and Pipelines Coordinator – Petrobras



The international demand for cleaner and renewable energy sources as well as the increasing competition regarding production costs when comparing the prices and limitations of fossil fuels and biofuels, are rising the world's demand in a sustainable way, up to unbelievable levels, creating a unique opportunity for Brazil to enhance its already highly developed Ethanol industry.

After the signature of the Kyoto protocol, the industrialized countries were obliged to adopt the Clean Development Mechanism (CDM) in order to reduce the emission of pollutants throughout compensation practices, which is done, either by the capture of carbons from the atmosphere (by reforestation, for example) or by buying carbon credits from developing countries.

With the increasing world conscience of the problems derived from global warming and the following appeal for the reduction of the CO₂, there are very strong incentives to the development of renewable fuels, which present themselves as the solution for energy problems.

Considered as a transition fuel, Ethanol is a clean fuel that contributes to the reduction of the emission of pollutant gases. Besides that, as can be seen in Brazil, the same agricultural by-products that feed us can also generate renewable energy in a sustainable way, with no shortage of any of the products and by-products in the process.

This way, Ethanol opens a diversification possibility of energy sources due to today's environmental and climate changes pressure, as well as the need for security in energy supply and several other geopolitical problems caused by the world's dependency on the countries that possess fossil fuels reserves.

In this new world scenario, Brazil has the potential of becoming a major supplier of renewable fuels, considering the fact that it possesses the proper climate and large portions of adequate land for sugar-cane grow, not to mention a highly efficient productive process that by far surpasses the American production, which is based on corn. However sustainable supply must be assured, as

Biofuels Logistics

well as product quality and strong investments in a transportation infra-structure that will enable cross country integration.

Federal Government Incentives to the Biofuels Industry

With the creation of the Accelerated Development Program 2007/2010 (Programa de Aceleração de Crescimento 2007/2010 – PAC) by the federal government, the investments in logistics infra-structure became a necessity in order to guarantee Brazil's leadership in the biofuels field, not only by the elimination of shortages for economic development, but also to increase productivity and reduce the regional unbalances and social inequality.

This way, strategic projects have been conceived with the goal of achieving levels of excellence, in the energy industry, towards the reduction of Green House Gas (GHG) emissions in processes and products, contributing to the business sustainability and risk mitigation of global climate change.

Regarding renewable fuels, the Program establishes investments of over 17 billions Reais until 2010 to achieve the following goals:

- Biodiesel: production of 3,3 billions liters per year with 46 new processing plants;
- Ethanol: production of 23,3 billions liters per year with 77 new distilleries;
- Ethanol pipeline/Multi-purpose pipeline: construction of 1.150 Km of new pipelines.

Studies and projects under development by the PETROBRAS System

Not only does Brazil have an excellent opportunity to consolidate itself as a world leader in Ethanol, but also the Petrobras System. It is present in all of the logistics supply chain of transportation, possesses a privileged position in the production area and large technological expertise acquired with operations with Ethanol since the ProAlcool, needing only to increase its infra-structure

logistics in order to consolidate Brazil's participation in this market throughout the use of pipelines, tank storage, ship loading and maritime transportation.

Petrobras has stated in its Business Plan (2007/2012) its goals of assuming the leadership in the commercialization and logistics of biofuels, thus being the biggest national producer of Biodiesel and increasing its participation in the Ethanol business. To achieve these goals, it intends to make investments of over 1 billion dollars in biofuels until 2012, with more than

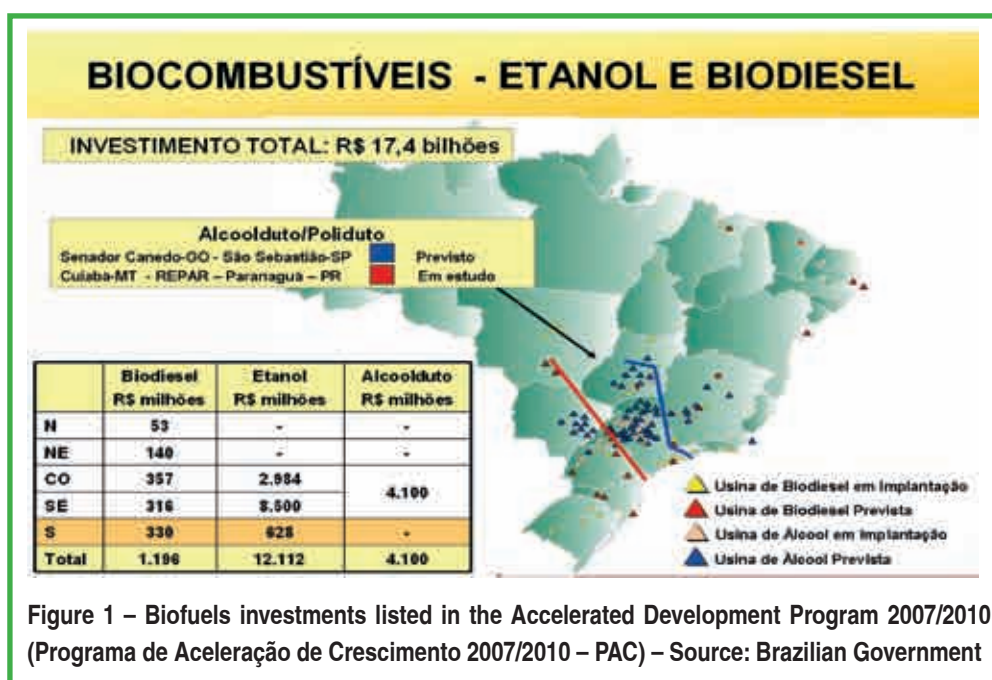


Figure 1 – Biofuels investments listed in the Accelerated Development Program 2007/2010 (Programa de Aceleração de Crescimento 2007/2010 – PAC) – Source: Brazilian Government



Figure 2 – Logistics projects under development by the Petrobras System for Biofuels

Source: Petrobras/Transpetro

half of this sum being destined to increase its logistics infrastructure for Ethanol exportation.

In the meanwhile Petrobras is searching for partnerships and developing studies that take into consideration groups of projects for multimodal transportation (pipelines, waterways, railroads and roads), to be implemented in synchronized pace with the production increase, with the goal of developing Ethanol exportation corridors to supply the growing world demand.

Among the on going studies in the Petrobras System, two new pipelines are being considered, as well as collecting centers dedicated exclusively to Ethanol. One of them will interlink the states of Goiás, part of Minas Gerais and the interior of São Paulo to the port of São Sebastião (SP), crisscrossing the major Brazilian sugarcane production areas, which hold the biggest number of installed and under construction mills. There is another project that considers the construction of both a multi-product pipeline for clear products and an Ethanol dedicated pipeline, running parallel from Cuiabá (MT) towards Paranaguá Port while passing by Campo Grande (MS).

The waterway corridor of the Tietê-Paraná river is also being considered for the movement of Ethanol using barges going from the south of Goiás and Southwest of

Mato Grosso do Sul state until a new terminal is built and linked by pipeline to the refinery of Paulínia (REPLAN) so that it will integrate itself with all other Ethanol exportation corridors and allow exportation either by the terminal of Ilha d'Água in Rio de Janeiro or by the terminal of São Sebastião in São Paulo. For that, it will be necessary to built 30 pushers and 120 barges.

Besides that, investments for improvement and adaptations of the existing installations of Transpetro are under way, so that a significant increase in the Ethanol exportation capacity by Ilha d'Água Terminal located in Rio de Janeiro can be achieved, reaching volumes of over 3 millions cubic meters of anhydrous ethanol starting next year.

However, even though all these projects and investments are reaching over 1 billion dollars until 2012, the Transpetro's ethanol exportation is already a reality with the use of its pipelines and terminals. Today's estimate is that the exportation will total over 1 million cubic meters of anhydrous ethanol until the end of this year.

Transpetro's leadership and expertise

In 1975, with the creation of the Pro-Alcool, the Brazilian ethanol program, Petrobras was called upon

Today, Petrobras Transporte S.A. - Transpetro - is present in 19 Brazilian states, with a total of 20 land farm terminals and 25 marine terminals, plus 7.000 Km of liquid pipelines and another 3.000 Km of gas pipelines, transporting energy to the whole country. It also owns 55 ships used to transport crude oil and its derivatives throughout the Brazilian coast and abroad.

to develop the logistics infra-structure for the new fuel. Even after the decline of the program, Petrobras remained moving ethanol through its logistics subsidiary, called Transpetro, which was created in June 12, 1998 to comply with the legislation that restructured the oil business in Brazil.

Today, Petrobras Transporte S.A. - Transpetro - is present in 19 Brazilian states, with a total of 20 land farm terminals and 25 marine terminals, plus 7.000 Km of liquid pipelines and another 3.000 Km of gas pipelines, transporting energy to the whole country. It also owns 55 ships used to transport crude oil and its derivatives throughout the Brazilian coast and abroad. While storing crude oil, oil derivatives, biofuels and natural gas as well as transporting them to different parts of Brazil, the company acts as an element of national integration in operations that are in accordance with the Petrobras System business strategy to boost social and economical development.

The biggest technological advances of Transpetro during these 32 years of experience with biofuels logistics is its ability to transport ethanol using pipelines that transport fossil fuels and biofuels simultaneously, without the need of any special interruption.

Now shifting our analyses to the ethanol market, we will find out that for years it has counted on trucks, trains and

chemical tankers as ways of transportation. However the increasing demands for bigger volumes and lower costs started to require a new alternative. To fulfill these needs, Transpetro brought to the ethanol market the same concept developed for other fuel commodities, which is to substitute the land transportation of roads and rails by pipelines and the marine transportation by big size ships, achieving this way a cost reduction in logistics while increasing the volumes moved.

Transpetro's expertise turns it into the main logistic and transportation company in the country with stored knowledge of over three decades in ethanol transportation. All this time allowed Transpetro to develop competences and abilities capable of offering, with excellence, ethanol transportation services through pipelines and ships with the same quality and costs offered to other commodities.

Petrobras Transporte has full control over the technology needed for exportation of Ethanol while using pipelines as land transportation as well as marine transportation and terminal operations.

Among these technologies, its expertise spans from product quality control, specifications and standardization, as well as full domain over issues related to corrosion inhibitor use, types of coatings and inner painting both



in pipelines and storage tanks, standards for pipeline integrity control, water contamination control, ethanol content preservation and electric conductivity, not to mention, specific operational procedures for ship loading according to the different classes and types of ships, as well as keeping its pipelines system compatible with other products transported by pipelines, treatment and proper discharge of the generated interfaces.

On top of all this acquired technology, the Petrobras system is always in search of new challenges, continuously investing in improvements and new sources of energy, like all the on going investments being put into the lignocellulosic ethanol which will be produced from sugarcane biomass and where Petrobras has several patents already and new routes for the production of Biodiesel.

Nowadays, Transpetro has over 500 Km of multi-product pipelines that transport ethanol batches for exportation with a capacity of over 1 million cubic meters per year, while at the same time, is looking into investments of over 1 billion dollars to expand its infra-structure capacity to over 1.000 Km of pipelines dedicated to ethanol exportation, and thus following the growth of the Ethanol market.

This way, Transpetro is answering the call, made upon her by Petrobras and by its commercial partners to assist its Ethanol exportation program through technology transfer agreements and supplying technical assistance. Besides that, Transpetro has been offering pipeline and

marine transportation services looking to ethanol as a commodity instead of a high value product like the rest of the market. In the same way it does with the fossil fuels, which are commodities as well.

By implementing its new logistics concept, Transpetro achieves:

- High supply reliability, allowing countries and clients to safely diversify their energy supply,
- Transportation cost reduction,
- Demurrage reduction in terminal and ports,
- Green House Gases emission reduction and development of carbon credits business opportunities,
- Perform marine transportation of ethanol using large vessels, with cargos of over 300.000 m³ (190.000 barrels).

This way, with the capability of transporting ethanol straight from the Brazilian production areas to any part of the world, in a safe way with the required quality and still develop transportation and distribution solutions at the country of destination, Petrobras Transporte S.A. is the world leader in biofuels logistics, offering the best cost benefit relationship that only pipelines, waterways and big ships can offer.

Thus, the Petrobras system demonstrates its global contribution in the search for sustainable development, the quest for cheap renewable energy sources and the rational use of fuels while respecting the environment. 

CTDUT – A Shared Solution for the Development of Pipeline Technology

By Arthur J. F. Braga - CTDUT, Executive Manager and Sergio Damasceno Soares – Petrobras/CENPES, Engineer, MSC

The development of new technologies for oil and gas pipelines usually faces a great difficulty in carrying out data survey and field testing, which are fundamental in the technological process. These pipelines are so committed to the activities of conveyance and distribution of products that its operation must not suffer any interruption, being it intentional or even accidental, as a consequence of some test being undertaken. This aspect is particularly critical in the distribution of natural gas, as there is no possibility of storage in the consumption centers, and any paralyzation in the pipeline would mean an interruption in the distribution to the end consumer.

This obstacle results in the need for laboratory simulations and tests in pipeline segments of small length without product flow, characterizing actual oil and gas pipelines. The assessment of the functionality of PIGs (Pipeline Inspection Gauges) – which are fundamental inspection tools so as to ensure the integrity of the pipelines and to avoid accidents – is jeopardized and it is not satisfactorily solved with the widely employed resource of pulling the pig through a segment of the pipeline without any product, with the aid of a winch and a steel cable.

Not to mention the fact that carrying out a test battery through a 300Km pipeline means to do the test today, wait for a truck to bring the pig back and then do it all again. Small details which could be the object of a quick assessment and correction, typical situations in the development of the software of the electronics attached to the pig turn out to be costly and time-consuming.

On the other hand, building and operating an actual pipeline, even if in a reduced length scale, represents an extremely high cost, something around tens of million dollars. Taking into account the fact that the frequency of usage and undertaking of these tests is not high enough to justify the progressive operation of this testing pipeline, its cost becomes disproportionally high.

The current solution of carrying out the tests in laboratories and in pipeline segments without the product in



Arthur J. F. Braga - CTDUT, Executive Manager

order to 'guess' its validation in an actual pipeline afterwards is not fully satisfactory and does not mirror the current status of environmental awareness and growing importance given to new technologies for the assessment of the integrity of pipelines.

Philosophy of the CTDUT

The CTDUT - Pipeline Technology Center - was created in order to remedy the deficiency in this model of development and improve the competitiveness of the pipeline industry, with an innovative purpose in terms of Institution of Science and Technology (ICT).

Traditionally the ICTs count on a supporting institution, facing the well-known difficulties in keeping a research and development institution effectively engaged in these activities and which would be, at the same time, capable of financing its activities with the funds resulting from its own work. These supporting institutions can be companies which are interested in the technology developed there, therefore determining a bias in the course of research under development, or governmental agencies which support, through direct or indirect subsidies, the activities of the ICT.

When a member wants to perform a demonstration of a product and promote the maximum visibility of the fact, CTDUT can invite the main interested parties to attend the tests and verify the functionality of the product.

The CTDUT is a non-profit, private-owned company and was created with a different proposal, in which there are no 'supporting institutions', but Associate Members instead, who have no commitment to the financial output of the Center, nor individual power to define its courses of action and priorities. These Members pay a small annual fee, which is insufficient to cover all of CTDUT's expenses, and participate, through appointed representatives, of a General Assembly where the strategies and objectives of the company are decided.

The CTDUT was instituted by initiative of its three Founding Members (Petrobras, Transpetro and PUC-RIO) and today, 16 months after the official opening of its facilities, counts on 35 Associates, including the most representative pipeline sector companies in the country, universities and several institutions with acknowledged prestige and importance for the sector.

This model allows the onerous and occasionally-used installations to be shared by all, in accordance with their needs, besides enabling the synergy of interests between the Members for the development of new technologies.

However, the implantation of this model inevitably results in the necessity of being able to generate income by rendering technological services to ensure its survival and permanent improvement of its installations. On the other hand, there is a clear awareness that the Center should not, by any means, compete with any of its Members nor assist any sectors being already assisted by other companies, whether Members or not. Bearing this in mind, the products and services offered by the CTDUT are:

- Development of new technologies through the accomplishment of research projects;
- Tests of equipment or new products;
- Training and certification of skilled personnel;
- Certification of equipment or products.

CTDUT also helps encourage and divulge technology, having hosted several workshops in its installations, as well as a Seminar on cleaning pigs, and technological demonstrations from the part of its members to divulge their products, and so on.

An important aspect in the operations of CTDUT is the constant concern over the industrial property of the products under tests in the company. We understand that there are two very distinct situations and they receive different treatment. When a company wants to use CTDUT's installations for the development of a product which will eventually result in a patent, total discretion is offered in this respect and the tests can be carried out with the participation of their own staff only, without the presence of CTDUT's technicians. On the other hand, when a Member wants to perform a demonstration of a product and promote the maximum visibility of the fact, CTDUT can invite the main interested parties to attend the tests and verify the functionality of the product.

FINEP's Financing

The high investment necessary for the construction of installations of this nature would be a major obstacle for the constitution of the company, something which was made possible with the resources from CT-PETRO through the FINEP – Financiadora de Estudos e Projetos – an organ attached to the MCT – Ministry of Science and Technology.

This contribution was possible, initially, through non-refundable resources for the construction of the installations and, nowadays, through agreements with the financial consideration from PETROBRAS for the development of projects aiming at endowing CTDUT with a full-scale testing oil and gas pipeline, intended exclusively for testing, training and developing of new technologies.

This financial contribution was of fundamental importance to make CTDUT something real and to allow the



Picture 1 - Pull Test Unit

company to achieve its sustainability as far as costs of operation and maintenance are concerned, without any compromise of indemnification by the Members of the costs incurred in the implantation of the company's infrastructure.

Operational Installations

Today only part of CTDUT's installations is operational, with the construction of the oil and gas pipelines in its beginning.

The following are fully operational today: a 14" diameter loop for water and gas, an Integrity Assessment Laboratory, a set of pipeline sectors for winch-pulled Pig, a cathode protection system, workshops and classrooms.

The 14" diameter loop

It is a 100m-length aerial circuit with a pig launcher and receiver, capable of operating with water and inert gas and with several mapped defects in its course. In addition to it, it has several flanged reefs which allow the replacement for other reefs with different defect configurations, so that every passage of a pig is unique in terms of expected result as for defect and damage detection. This feature enables efficient usage not only for tests from the part of developers, but also for the validation from the part of users and buyers.

The configuration of pumps and valves was designed to represent a typical oil pipeline, which allows the training and certification of operators without environmental risk, since it operates with water.

The possibility of replacing reefs also allows other technological developments or demonstrations, such as trepanning, leakage repair under pressure, pig passage in reduced radius curves, or whatever configurations which might be added to the loop through specific reefs.

Moreover, CTDUT counts on facilities for the storage and conservation of Member's reefs in case of necessity of their reutilization in new tests.

Pull Test Unit

It consists of a device with pipes of several diameters located in the direction of a winch, allowing a pig to be pulled in the interior of the pipes with a steel cable. The pipes have mapped defects which enable a series of preliminary tests of the pig prior to its introduction in the testing pipeline with the product.

Integrity Assessment Laboratory

It consists of safe installations where a pipe may be pressurized until its destruction without any risk to the team conducting the tests or other personnel in the place. It has a rectangular trench of 17m x 4,1m with 2.6m depth, a 10-ton conveyor bridge and windows with masonry blinds, without glass, in order to avoid accidents.

Cathode Protection System

It consists of a buried 40-m pipeline segment, a rectifier and protection anodes, allowing several measurements for training purposes.

Workshops

The CTDUT counts on a workshop equipped with weight and area maneuver equipment for repairs and benchmark testes, besides a small workshop for assays and measurements.

Classrooms and Auditorium

As support for field installations, the company offers two classrooms and an auditorium for 70 people to host lectures and classes.



Picture 2 - Hands-on class at the rectifier of the cathode protection system

Submarine Pipeline

Feeler Snake Pig: A Simple Way to Detect and Size Internal Corrosion

By Claudio Camerini and Miguel Freitas

Submarine pipelines are traditionally inspected with the same technologies used for onshore pipelines. A good example of that is an inspection using instrumented pigs, which is usually based on same parameters, procedures, and tools used in onshore inspections. Under those circumstances, some conflicts, of course, are expected to happen. Onshore pipelines are usually easy to access, and that enables excavating for field verifications and correlations, thus allowing inspection quality measurement. The same is not true for submarine pipelines, in which a correlation of instrumented pig results implies very high costs or, in some cases, non-existent technology. During the 1980's and 1990's, onshore pipelines received strong investments in Brazil to be adapted to instrumented pig inspections, such as: removing small radius bends; installing launchers and receivers; unifying diameters; and removing obstacles. Some submarine pipelines received the same treatment, but those adaptations were not extended to the whole network, once the investments required were, at least, of a higher level. It is very common, therefore, to find submarine pipelines with various diameters and small radius bends, among other obstacles that prevent the use of conventional instrumented pigs.

Other equally relevant factors make the inspection difficult, like submarine pipeline wall thickness, which limits significantly the use of magnetic instrumented pigs – MFL – magnetic flux leakage. As oil production heads for deeper and deeper waters, pipelines become thicker for structural reasons, and that implies loss of MFL pigs

measurement capacity. Those pigs present reduced sensitivity from 15 mm-thick wall, with a practical limit of 20 mm. The problem increases even more in less than 14-inch diameter pipelines, which present large thickness and small internal volume, making magnetization very difficult, as the space available to place magnetizers is limited. With current technology, there are not enough compact and high-power magnetizers to be used on large thicknesses in such small space.

Another context of submarine pipelines inspections is that almost always those pipelines are accessed from outside, with visual inspection using ROVs – Remotely Operated Vehicles. Those vehicles are already periodically used to inspect Petrobras' submarine pipelines, to identify external damages, measure cathodic protection electrochemical potential, identify spans, etc. That external visual access is, compared to onshore pipelines, the greatest difference regarding submarine pipelines inspection.

Other aspects that favor submarine pipelines is that the main cause of deterioration is internal corrosion, which occurs in presence of produced water. External corrosion is easily prevented with cathodic protection, while damages caused by collisions or anchor action are, mostly, identified through ROV visual inspection. It is considered, therefore, that the main objective of inspecting oil and gas production submarine pipelines is to detect and quantify internal corrosion and, in a lesser degree, external defects related to diverse actions.

line Inspection

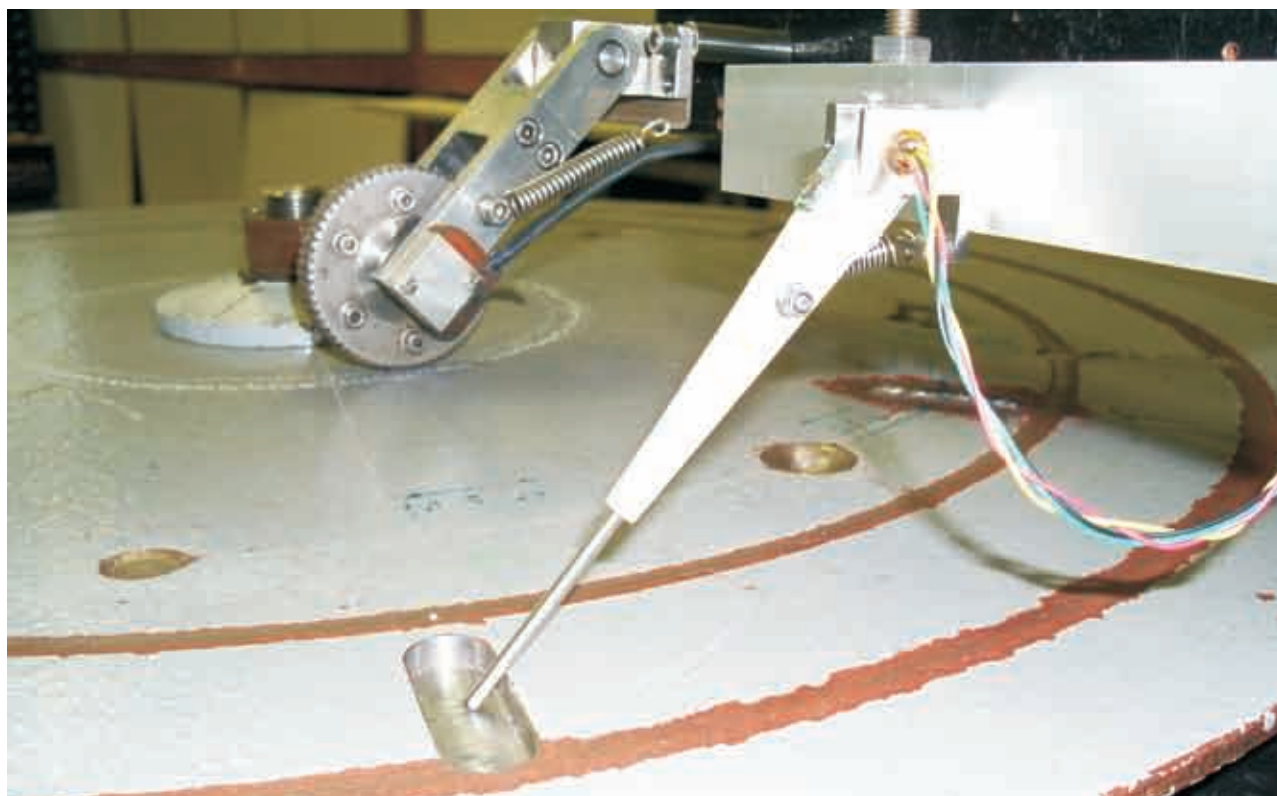


Figure 1 - Feeler pig measuring method. Corrosion effects (pits) are measured according to angle variation of sticks

An alternative found in the market to inspect pipelines subject to internal corrosion is the use of pigs with ultrasound technology. Depending on its mechanical design, the ultrasonic pig may tolerate variations in diameter, and does not present inconveniences for measuring large thicknesses. A severe limitation to that method is the need of a homogeneous liquid, with good acoustic properties, to serve as coupler. That limitation makes it more difficult to inspect gas pipelines, requiring introduction of a diesel batch, but with strong operational impact. Also, the fluid is not homogeneous in production pipelines with “live” oil (oil + gas + water), making ultrasonic inspection practically impossible.

In this context, Petrobras, together with PUC-RIO, developed a submarine pipelines inspection method to detect and size up loss of wall thickness associated to internal corrosion. A special pig was designed to bear large variations in diameter, have no practical limit of thickness to be inspected, and be able to navigate through

curves and geometric accessories with small bend radius. The pig was called feeler pig, as it consists of several feeler-type sensors that measure internal corrosion, as illustrated in Figure 1.

At first, the special pig was developed for small diameter production pipelines, however, because of its potential shown in field tests, a first prototype was constructed for large diameter pipelines, in this case, 22 inches. That prototype carried out an inspection of a submarine pipeline in Campos Basin, with excellent results, thus confirming tool’s potential in the field. Figure 2 shows the pig assembled and ready to use. Results delivered by the pig’s 250 sensors (sticks) were compared with a previous inspection performed with a commercial ultrasound pig. The new tool delivered results that were identical to those of the ultrasonic pig, confirming, therefore, under real conditions, the technical viability of the new internal corrosion detection and quantification method.

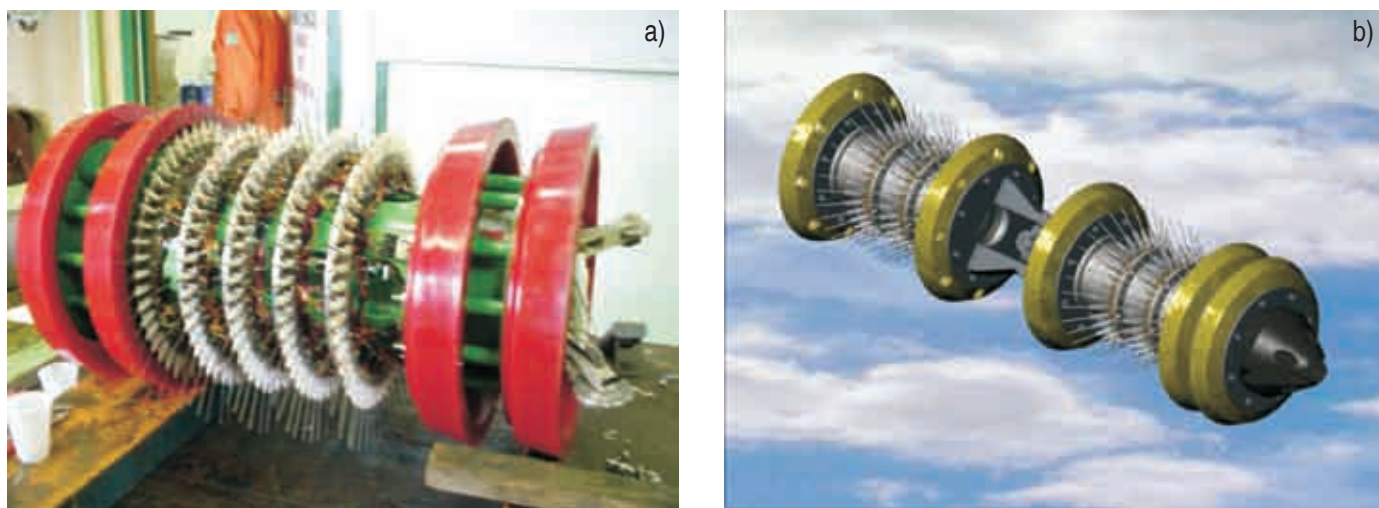


Figure 2 – a) Feeler pig for 22", with 250 sensors (sticks); b) Feeler pig for 16", with 180 sensors (sticks)

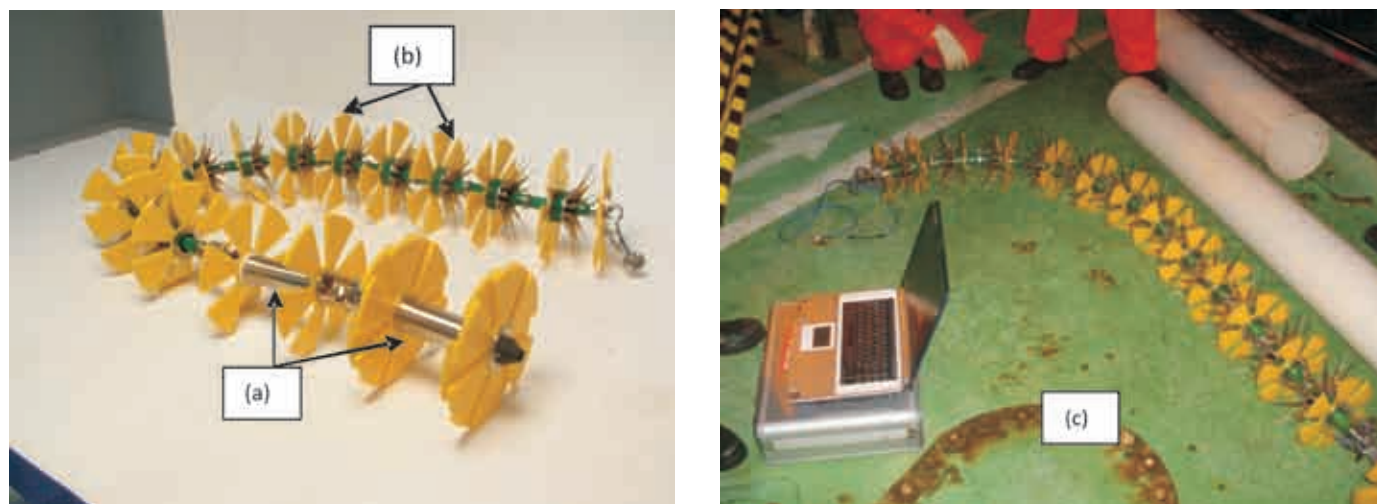


Figure 3 – Feeler Snake Pig – a new concept of instrumented pig, where sensors are mounted on a flexible base to allow inspection of usually non-piggable pipelines. (a) – batteries and electronics modules; (b) 12 sensor modules, totaling 144 sensors distributed across pipeline's perimeter; (c) general view of equipment during pre-launch check.

Based on the aforementioned results, several inspections using that system are being scheduled for 2006 to 2008, and include oil and gas pipelines with or without diameter variation, in addition to short and long pipelines with a wide range of flow speed. In July, 2006, an inspection was performed using a feeler snake pig, which is a fully innovative design using the above mentioned method. Figure 3 shows the new concept of instrumented pig, in which sensors (sticks) are mounted on a flexible base. That tool enabled a multi-size inspection, with small radius bends, a kind of inspection that tools commercially available cannot provide. As a result, 7.6 kilometers of a submarine pipeline were recovered.

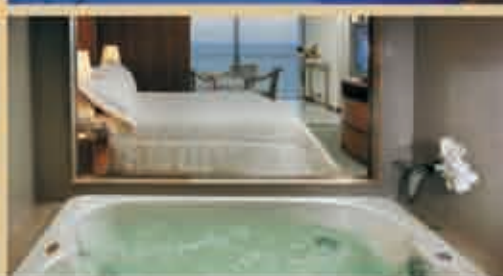
To consolidate the feeler pig technology and the feeler snake pig concept, Petrobras is changing its submarine pipeline inspection systematic, prioritizing that technology for internal corrosion control. The use of other pigs, like MFL and ultra-sound, will still occur whenever there is a suspect of external corrosion. With the new system, Petrobras intends to inspect the vast majority of its submarine pipelines, practically eliminating the expression "non-piggable line" from its offshore production fields. Therefore, Petrobras pioneers the inspection of production pipelines that were usually excluded from routine pigging inspections. ●

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Global W

Although, skeptics have become a minority, disinformation still surrounds the topic of Global warming. As part of a double feature, this article looks at the concept of climate change and how it can be minimized. In the second part, Dr. Andrew Spencer of the Scott Polar Research Institute, Cambridge University, England talks exclusively to ttnrg about the role of polar ice-caps in maintaining the global climate equilibrium.

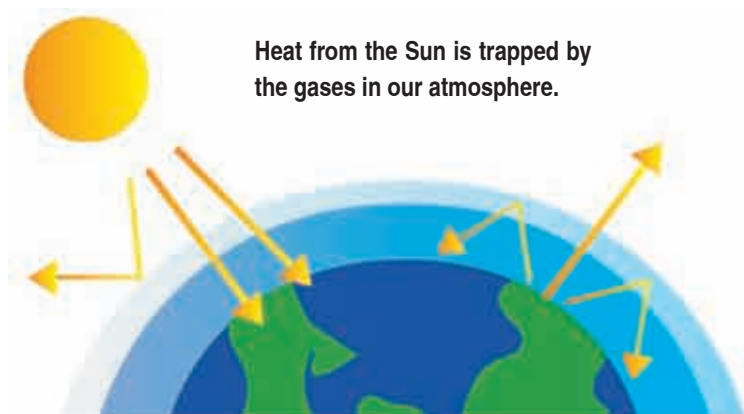
By Wajid Rasheed

Since the 18th century and the Industrial Revolution the temperature of the earth's lower atmosphere has been rising. Also known as the "near atmosphere", this part of the delicately balanced global climate is gradually being warmed through the greenhouse effect. The greenhouse effect is so termed because levels of certain gases in the atmosphere have increased which means that more heat is retained on the earth.

In normal atmospheric conditions, sunlight reaches the earth passing through a layer of gases such as water vapor, carbon dioxide, methane, nitrous oxide, and ozone. Here, infrared radiation reflects off the earth's surface but does not pass through the thermal layer as part of it is trapped keeping temperatures suitable to life, about 60°F (16°C).

If it were not for this heat trap, the average temperature of the earth would be below freezing.

The rapid industrialization of the 18th Century fuelled demand for agriculture, land development and transport. As more fossil fuels such as coal were burnt and as forests were cleared for development ever-greater quantities of greenhouse gases (GHG) were produced. Other types of gases such as Chlorofluorocarbons also led to rising temperatures. Consequently, this results in more heat being trapped and rising air and sea temperatures.



Warming

Since the industrial revolution, volumes of CO₂ in the atmosphere have increased from 270 ppm to 370 ppm (parts per million). This affects the natural CO₂ cycle which takes place between the atmosphere, oceans and forests. As greater quantities of CO₂ are generated, this leads to excessive loading of the natural cycle and a decreased ability of the earth's natural mechanisms (ocean and forests) to absorb CO₂ is reduced.

CO₂ has the greatest effect of GHG and projections show that emissions will continue to grow. For CO₂ emissions to stabilize at 550 ppm, there would have to be a major reduction in emissions complemented by new energy technologies that do not produce CO₂ at all. However, more than 80% of today's energy demands are met by fossil fuels, which makes replacement even more challenging.

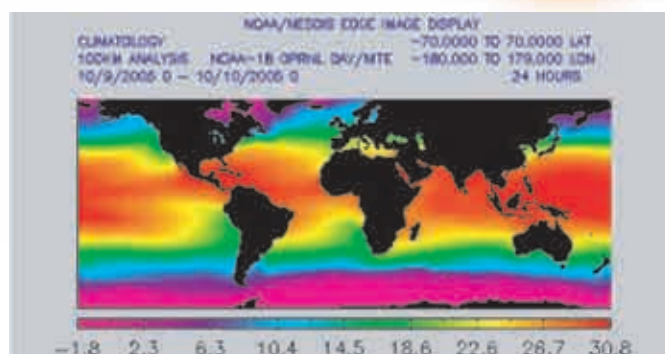
Temperature's up

Scientists keep track of global temperatures by registering air and sea temperatures. According to US environmental body figures, the global average temperature of the air at the Earth's surface has warmed between 0.3 and 0.6°C (about 0.5 and 1°F) since the late nineteenth century, while atmospheric temperature has risen 0.6°C (1.1°F), and sea level has risen several inches.

Little Boy

First noticed by fishermen in 1992, 'El Niño', which in Spanish means 'Little Boy' or the 'Christ-child', describes the arrival of a warm weather event coinciding with Christmas. La Niña means 'Little Girl' and is used to describe a cold weather event. El Niño is an alteration to the ocean-atmosphere system which starts in the tropical Pacific but has global repercussions. These include greater rainfall and flooding across the southern US and in Peru to drought and bushfires in the West Pacific.

El Niño can be seen in sea surface temperatures in the Equatorial Pacific Ocean, such as those shown in the



Global Sea Surface Temperature Chart.

Courtesy of the NOAA - US National Oceanic and Atmospheric Administration

image above, which were made from the NOAA's array of moored buoys.

Polar ice-caps

Some projected, longer-term results of global warming include melting of polar ice-caps, a rise in sea level and coastal encroachment; extinction of species as habitats disappear; higher intensity tropical storms; and an increased incidence of tropical diseases. This aspect of Global warming is covered in The Big Melt - *TTNRG Issue 9, which has an interview with Dr. Andrew Spencer of the Scott Polar Research Institute, Cambridge University, England.

Kyoto

In order to combat global warming, the UN held a meeting in Kyoto, Japan, in 1997. This resulted in an international agreement to reduce emissions of greenhouse gases by industrialized nations. Not all industrial countries, however, immediately signed or ratified the accord. In 2001, the United States Government announced it would abandon the Kyoto Protocol. At the time, this was considered a major setback as the US generates 25% of global GHG. However, 125 other Governments agreed to a binding international treaty which runs from 2005 to 2012. Further to this, many individual US States have committed to respecting Kyoto emissions levels at a local level.



Greenpeace activists stage a climate chaos protest. Eco-Groups and certain energy companies are increasingly sharing the same message: Combat climate change. Photo courtesy of StopClimateChaos/Morgan.

Montreal Climate Conference

In November 2005, Montreal, Canada, will host an environmental summit where 150 countries will be represented. Talks will centre on taking Kyoto beyond 2012. Deep divisions exist as to what should occur post Kyoto. The main objective will likely be to extend the treaty to include countries that currently have not signed such as the US, Australia and Russia. A major stumbling block is the exemption of so-called developing countries such as Brazil, China and India from Kyoto targets. These countries have argued that Western development was responsible for much of the CO₂ emissions and this also led to these countries gaining developed status. The argument continues that applying CO₂ emissions targets to developing countries would then hinder their progress.

The arguments and debates will continue.

Contributors to Climate Change

It is recognized that the main contributors of global warming are the burning of coal and petroleum products, deforestation, which increases the amount of carbon dioxide in the atmosphere, the production of cement which releases CO₂, increased livestock production which increases volumes of methane gas released in animal waste.

Skeptics argue that the climate cannot be modeled as it is too complex. They also contend that observed climate changes maybe normal fluctuations in global temperature. Despite this, most leading scientists agree that part of the observed warming is the result of human activity, and that the trend for warming has to be broken. This means finding other options to CO₂ emitting products and a raft of energy initiatives.

"Since the 18th Century and the Industrial Revolution the temperature of the earth's lower atmosphere has been rising. It is commonly accepted by leading scientists that the temperature of the 'near atmosphere' is gradually being warmed through a natural process called the greenhouse effect."

Energy Initiatives

Plans to reduce emissions include improving road transport mileage per gallon, reforestation projects, energy efficiency in construction and public transport systems.

More ambitious plans would include replacing fossil fuels with safe alternates, improving manufacturing and operational processes that generate CO₂, replacing chlorofluorocarbons with safe alternates and reducing deforestation.



Larsen B iceberg much reduced in size. Photo courtesy of Colm o Cofagh.

Emissions

In order to reduce GHG emissions, several initiatives have taken place. These include improved manufacturing and



BP's new CEO is pursuing a low CO₂ emissions policy

operational processes that would otherwise emit CO₂, a reduction of usage of emissions when energy is generated ie selecting less harmful options - LNG produces less GHG as it has a lower carbon content. (See TTNRG Issue 2* - hydrocarbon types).

Carbon capture

These types of technology have a crucial role to play in reducing CO₂ emissions. Essentially, carbon capture or sequestration relies on the prevention of CO₂ being released to the atmosphere. The CO₂ is captured and injected deep into geological formations which are known to have natural traps or seals. Carbon capture plants can be located close to power stations and oil and gas production facilities.

Currently, several oil companies are involved in existing carbon capture projects which is helping their acceptance from wider society.

To accelerate acceptance and reduce the costs of carbon capture, in 2000 a US\$25 million carbon capture Project was launched. This has funded research and development into carbon capture technologies and processes.

In terms of geologic storage, oil companies have already implemented CO₂ compression and injection into oil and gas reservoirs. CO₂ is readily soluble in water and oil and miscible with gas. Where producing oil and gas reservoirs are contemplated, the injected CO₂ could be used to maintain reservoir production. On production it would be separated from the oil, gas or water and re-injected.

Such reservoirs are an obvious choice as they already have a seal or cap rock in place. ((See TTNRG Issue 1* - Why Does Trinidad Have Oil and Gas).

In some gas producing provinces, as much as 10%-15% of the total gas in the reservoir is attributed to CO₂. In these cases, the CO₂ is not vented to the atmosphere but is compressed and injected into the reservoir. Around one million tonnes of CO₂ will be injected into the reservoir every year, which reduces GHGs by the equivalent of taking 200,000 cars off the road.

CO₂ can also be injected into deep saline aquifers and unmineable coalbeds.

References

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* Or visit www.ttnrg.com to review electronic interactive versions online.

A satellite map of South America at night, showing the continent's outline and internal landmasses. The map is illuminated with a blue and orange glow, with numerous small yellow and orange dots representing city lights and urban areas. The background is a dark blue gradient.

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