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The Floating Drilling, Production, Storage, and Offloading Vessel for the Large Deepwater Field Development

John Halkyard, Guibog Choi, Igor Prislin, Atle Steen* and Phil Hawley**
* *Aker Engineering, inc., USA*
** *Mentor Subsea Technology Services, Inc., USA*

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ABSTRACT: *A new alternative for large deepwater field development is described. This "Oil Box" (aka "Box Spar") is a multifunction vessel capable of floating drilling, production, storage and offloading (FDPSO). It is distinguished from other Floating Production, Storage and Offloading (FPSO) vessels by its unique hull form and oil storage system. It's main advantages are flexibility derived from the floatover deck option, use of proven top tensioned riser technology, and motion characteristics which make it operable in a wide range of environmental conditions.*

KEY WORDS: FDPSO, Oil Box, Box Spar, Large Deepwater Field Development

1. Introduction

Large oil and gas discoveries have been made in the ultra-deep waters of the Gulf of Mexico. These discoveries are on a par with those found in the other "hot" frontier areas of West Africa and Brazil. The high costs of drilling and producing these ultra-deep water fields using conventional approaches naturally yields an incentive to consider new methods and paradigms for field development. One approach being promoted by several contractors for West Africa is the "multi-function" vessel, which can do drilling, production, storage and offloading. These Floating Drilling, Production, Storage and Offloading vessels (FDPSO) have the advantage of reducing the need for costly MODU operations for development drilling and completions, and they allow dry tree operations and workovers. The FDPSO combines the functions of a wellhead platform and an FPSO, reducing the total costs for facilities.

A disadvantage of the FDPSO approach is that the vessel's schedule is driven by the longest lead time component, usually the process facilities. While combining all functions on one vessel might save some money, project economics might be improved if, for example, the drilling function could be fast tracked with a smaller wellhead platform. Some operators also perceive added risk in "placing all the eggs in one basket".

Most FDPSO designs are based on conventional mono-hull construction. These are suitable for subsea wells and flexible risers in most environments, but these hulls are not ideal for rigid risers and steel catenary risers in harsh environments or those subject to cyclonic events.

A new FDPSO design has been developed to address these issues. This "Oil Box" (formerly known as the "Box Spar") was originally intended for West Africa (Ref. 1). Recently, the configuration has been optimized for improved motions and is capable of operations in Brazil and the Gulf of Mexico as well.

This paper will present a description of the Oil Box as configured for West Africa and as modified for Gulf of Mexico applications. We will also present the current status of development and an economic assessment of the Oil Box for a typical field development scenario.

2. Design Criteria

Table 1 lists the design criteria used for designs described here.

Table 1 Design Criteria

Parameter	Value
Oil Production	200,000 BPD
Gas Production	
Oil Storage	2,000,000 BBL
Water Depth	5000 ft
Survival Environment	100 Year Return Period Storm
Operating Environment	. West Africa & Brazil: 100 Year Storm Gulf of Mexico: 10 Year Winter Storm Offloading SS4
Specifications	Hull ABS MODU Rules Mooring. API RP2FPS
No. of Dry Tree Wells	40
Drilling Rigs	2

Survival environments used for this paper are summarized in Table 2. Two 100-year environments are listed for each location. The environment labeled "current" corresponds to the 100-year current with a 10-year wind/wave environment, and similarly the 100-year "storm" corresponds to a 100-year wind/wave together with a 10-year current. These are "typical" environments and are not site specific. Typical current profiles have also been assumed.

Table 2 100-Year Environments

Region Dominent Env	100 year Environments					
	West Africa		Brazil		Gulf of Mexico	
	Current	Storm	Current	Storm	Loop	Hurricane
Sign Wave Hgt ft	10.5	12.1	20.7	24.9	15.0	44.3
Peak Period sec	15.0	15.1	12.1	12.7	9.0	14.6
Jonswap Shape	3.0	3.0	3.0	3.0	2.4	2.4
Wind 1hr @10m kts	33.8	41.8	4.96	57.0	30.0	84.2
Surface Current kts	2.00	1.79	3.79	3 15	4.00	2.10

The base case consists of 40 surface completions. There are two drilling rigs capable of simultaneous operations.

3. Oil Box Description

3.1 Hull and decks

The Oil Box is shown in Figure 1. The hull consists of a lower hull, four edge columns and a central upper hull to support the drilling module and centerwells. The edge columns provide support for the process module and the quarters/utilities module on either side of the drilling module. The lower hull is 600 ft. x 275 ft. x 105 ft. It contains fixed ballast and sufficient volume for storing 2,000,000 BBL of oil. The columns and the upper hull provide buoyancy. The centerwells pass through the upper and lower hulls. Oil storage in the lower hull is below the collision zone and does not require double hull construction.

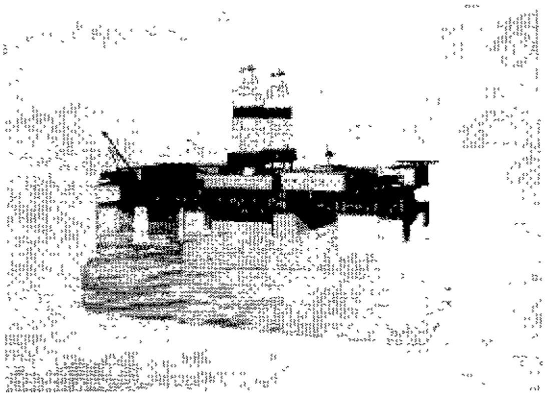


Figure 1 Oil Box

The topsides consist of three modules: drilling, process and quarters. Utilities are included in the quarters module. Figure 2 shows a layout of these modules. Module weights are given in Table 3.

Table 3 Topside Module Weights

Module	Operating Weight(Kips)	Dry Weight(kips)
Drilling	17,280	12,850
Process	29,557	26,625
Quarters/Utilty	43,135	31,639
Total	89,972	71,124

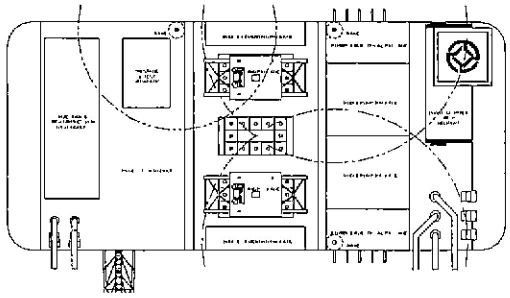


Figure 2 Main Deck Layouts

The hull outboard profile is shown in Figure 3. Hull dimensions are given in Table 4.

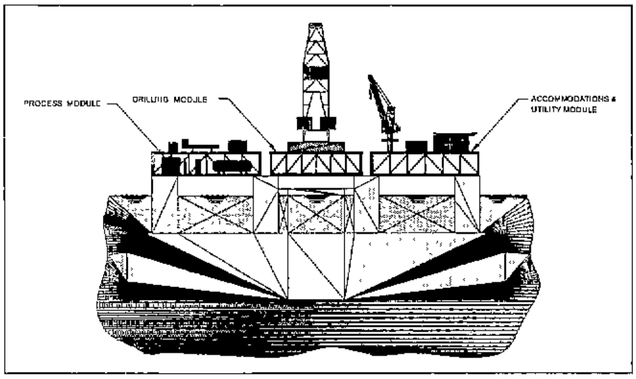


Figure 3 Outboard Profile

The hull form serves three primary purposes. It is designed to allow a floatover deck operation using a standard 100 ft. wide transportation barge. The hull form also results in lower motions due to its small waterplane area and deep draft. Finally, the deep draft/centerwell arrangement allows use of proven riser technology from previous Spar design experience.

Table 4 *Hull Dimensions*

	West Africa	Gulf of Mexico
Freeboard, ft	30	55
Edge Colum Height, ft	90	160
Total Height, ft	195	280
Draft, ft	165	225
Hull Wt.. kips	118,000	148,000

The inboard profile is shown in Figure 4. Oil stored in the lower hull displaces seawater under ambient hydrostatic pressure. The storage tank is always filled with either water or oil. The maximum pressure on the tank wall is equal to the difference in head between oil and water plus environmental (wave) loading.

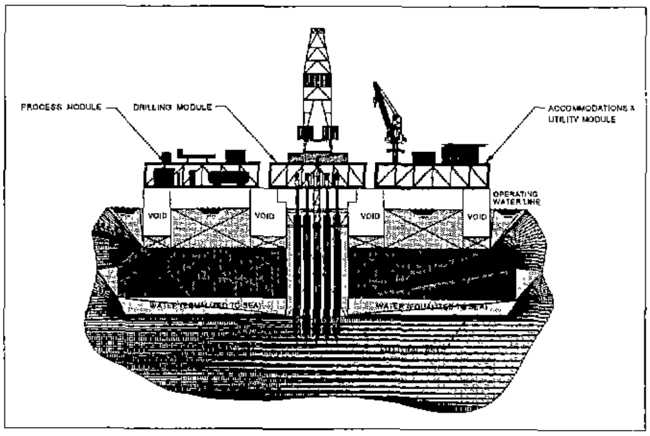


Figure 4 Inboard Profile

The principle of the crude oil storage is to store the oil on water in a 'wet storage' at ambient static sea pressure. Produced oil then displaces water during production, and water refills the storage compartments during offloading. Eight compartments of the lower hull are used for storage.

There will be a water buffer volume in the bottom of each storage compartment, as indicated in Fig. 4. An allowance of 13 ft. for the minimum water buffer is included for possible sediments, inlet outlet diffusers, interface measurement tolerances and motion of the oil/water interface due to vessel motions. This volume together with 5 ft. emulsion layer is subtracted from the compartment volume, to give the net crude oil storage volume. The amount of water buffer and tank baffling requirements need to be finalized by model tests after oil properties are verified.

This principle of the crude oil storage is similar to the Brent Spar and the Draugen GBS storage, and is chosen due to better cost performance and operational simplicity than other systems. Wet storage requires about 1/7th the amount of ballast pumping required for conventional dry storage in order to keep a constant draft during offloading. Also, steel oil storage tanks using this method were installed in the Persian Gulf in the late "60s and early 70s and are still in operation today. One difference between this design and conventional oil storage in an FPSO is the fact that the tanks are inaccessible for inspection. Experience on the Brent Spar and the other steel storage tanks built using this method indicate that little or no corrosion takes place on the inside of tanks exposed to stored oil, and that the internal areas in the water buffer zone can be cathodically protected. For our design, an additional corrosion allowance of 0.125" has been added to normal code requirements to allow for the lack of inspectibility.

3.2 Oil storage system

As for existing GBS's, the storage systems must be 'tailor made' for the crude oil at hand, and all necessary operable systems must be incorporated in the design from the very beginning. Utility systems for emulsion removal, possible heating and circulation systems, together with possible pipe insulation, will be determined and designed according to the results of laboratory tests of the processed crude oil.

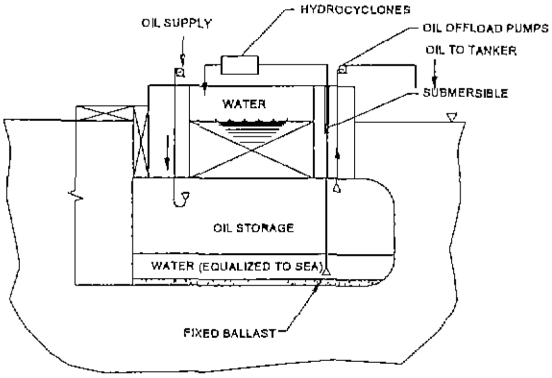


Figure 5 Oil Storage System

The crude oil storage system illustrated in Figure 5 consists of several subsystems

- fill system
- discharge system
- displaced water system
- instrument systems

Other systems, such as an emulsion removal system, may be added if crude properties dictate. The fill and discharge systems are keyed to 16"and 36" manifold lines, respectively, which run along the upper surface of the cargo tanks (lower hull). A cargo pump located on the cellar deck of the process module feeds the fill manifold. This pump receives "dead" crude from the process plant. Crude may be delivered to one or more cargo tanks through a diffuser to mitigate turbulent mixing during loading. Crude could also be diverted to directly to the offloading stream.

Each fill line is designed to take full production flow. An emergency shut down valve is located at cellar deck in the fill line, to prevent the storage to overflow by gravity. The 30" discharge manifold delivers crude for offloading to a sump located in a corner column of the hull. Three deep well offloading pumps are located in the sump. The cargo pumps are vertical turbine pumps operating at a fixed speed of 900 RPM Flow control is achieved by a throttle valve on the discharge, or by a bypass valve.

The offloading pump characteristics are·

capacity	31500 BPH (5 000 m3/h)
head	132 psi (9 bar)
power	1200 kW

Offloading may be performed from a single or multiple compartments to achieve full capacity. Total offloading capacity is then 63000 BPH (10000 m3/h) at a power consumption of 2.4 MW.

The offloading is performed directly to a tanker by means of a dynamically positioned buoy. This buoy design is not described here. Offloading could also take place to a calm buoy with a moored tanker.

A 24" pipe is run from above the solid ballast at the bottom of each storage compartment to a 36" manifold installed above the lower hull for removal of the displaced water below the oil. This 24" pipe also serves as a conduit for a submersible pump used for deballasting in preparation for a tow. The manifold terminates in a common water inlet/outlet, to allow water to flow freely in and out of the compartments by gravity. In this way no operational malfunction of the crude oil storage system can influence the integrity of the structure. The pipe termination within each storage compartment will be elevated about 5 feet above the floor, to allow some bottom sediments. Displaced water may optionally be pumped to a water treatment plant on the process module.

The displaced water system is used during platform towing as part of the temporary ballast system. The discharge manifold is connected to the fill manifold for flooding of these tanks for installation. During permanent operation there are no operable valves or equipment in the system needing maintenance or exchange, all pipes being embedded inside the compartments.

Two instrument systems are necessary to operate the crude oil storage:

- interface measurement system
- oil contamination of displaced water measurement

The interface measurement system consists of an echo sounder type instrument located at the bottom of each storage compartment 'looking up', and measuring the distance to the interface between water and crude oil (emulsion). Each transponder will be redundant, and the instrument in different compartments can be back up for each other when the compartments are operated in parallel. The instrument probe in each storage compartment is exchangeable by ROV

The system gives stored crude oil at all times together with high and low level alarms (empty and full storage respectively). A low level alarm will automatically shut down the fill line to prevent overfilling the compartment, if no reaction within a certain time span (say half an hour) is given after the low level alarm. The instrument also indicates the thickness of a possible emulsion layer.

3.3 Riser systems

The Oil Box top tensioned risers consist of single or dual barrier casing strings with premium connectors. Tension is provided by buoyancy cans installed in the center well. The well system includes a surface tree and mudline tie-back connector. This configuration has been used on three spar platforms in the Gulf of Mexico and is fully compatible with the Oil Box design.

The drilling riser is similarly configured with buoyancy can support or top tension may be augmented with active tensioners.

Steel Catenary Risers (SCRs) pass through slots in the centerwell and are supported at the keel. Further information on these riser systems can be found in Reference 2.

4. Global Motions and Mooring

Model tests were recently carried out on a 67.5:1 scale model. These tests were conducted at the Offshore Model basin in Escondido, California from August 27 to September 8, 1999. Figures 6 to 8 show the model as tested.

Figure 9 shows heave RAOs for the Oil Box, Classic Spar, and semisubmersibles. Oil Box RAOs were derived from the recent tests. The classic and truss spars were computed from SPLASHT, a frequency domain program. The "classic" spar represents the state of the art in deep draft drilling and production vessels (Ref. 3, 4). The semi motions were taken from Reference 5. The Oil Box valves are based on the West African design.

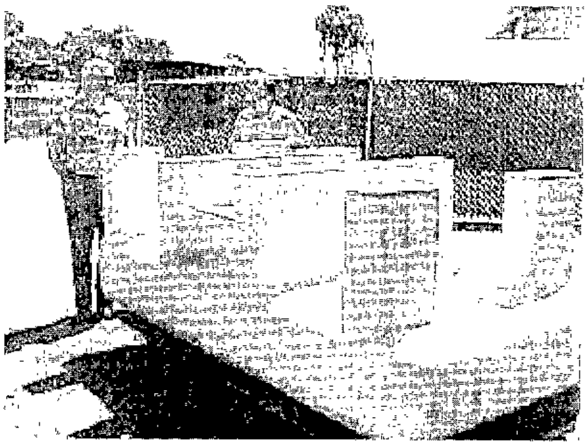


Figure 6 1:67.5 Scale Model of Large Oil Box

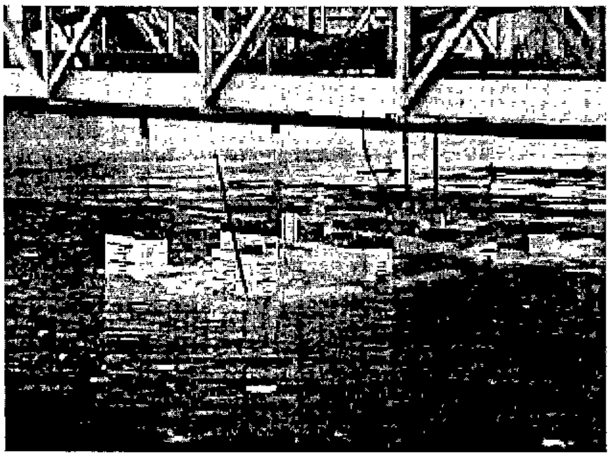


Figure 7 Oil Box Model Being Tested in a West African 100-Year Storm

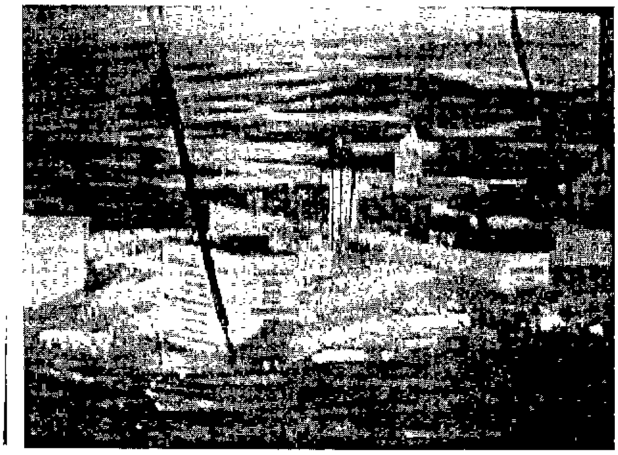


Figure 8 Oil Box Being Tested in a Brazilian 100-Year Storm

Figure 10 shows a comparison of the Oil Box, Classic and Truss Spars roll/pitch RAOs. The Oil Box RAO for pitch is for head seas, the RAO for roll is for beam seas.

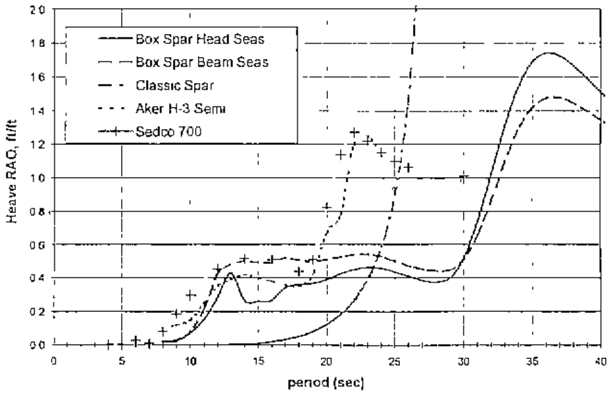


Figure 9 Heave Motion RAO Comparisons

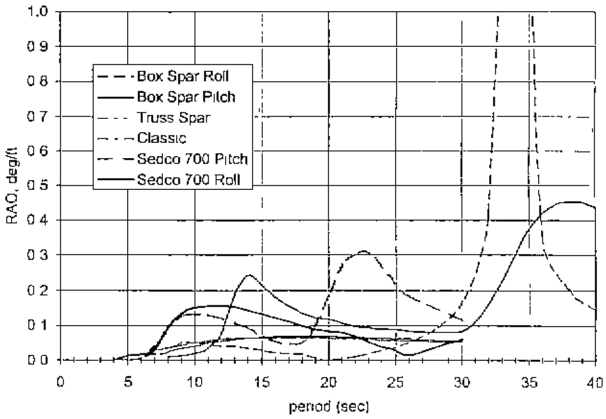


Figure 10 Roll and Pitch RAO Comparisons

Responses to irregular, 100 year seas are tabulated in Table 5. Pitch and roll values are the mean plus extreme single amplitude dynamic responses. Heave is total range, i.e. double amplitude. Oil Box and classic values are measured in model tests. The "typical" semi values have been computed for an eight column, 3rd generation semi design and are included for reference only.

The Oil Box motions are favorable for drilling and dry tree completions in all of these environments. One issue which is important for economic operations in deep water is the utility of using steel catenary risers (SCRs) for flowlines and export risers. Vessels with large heave motions such as ship shaped FPSOs are not easily compatible with SCRs because of the dynamics at the mudline, and because of fatigue due to vessel heave induced Vortex Induced Vibrations (VIV). This phenomenc, discovered in recent large scale tests, results when vessel heave motions result in a large change in SCR catenary shape near the seafloor. This cyclic motion may cause cross flow velocities large enough to induce VIV and result in fatigue damage.

Table 5 Dynamic Responses to 100 year Storm

Vessel type		Oil Box			Classic Spar	Semi (typ)
Environment		West Africa	Brazil	Gulf of Mexico	Gulf of Mexico	Gulf of Mexico
Hs	ft	14.0	22.0	40.0	40.0	40.0
Tp	sec	16.0	14.0	14.0	14.0	14.0
Heave Range Head Range	ft	7.7	10.5	17.1	4.0	31.0
Heave Range Beam Range	ft	12.9	15.8	30 4	4.0	24 0
Max. Pitch Head Seas	deg	3.3	4.3	7.3	9.0	9.0
Max. Roll Beam Seas	deg	1.6	2.2	5.1	9.0	13.0

Table 6 SCR Fatigue Life

Condition Riser Attachment	Gulf of Mexico	West Africa	Brazil
Head Seas Bow (x=+300′, z=0′)	23,960	Infinite	Infinite
Head Seas Amidships (x=z=0′)	3,444,800	Infinite	Infinite
Head Stern (x=300′, z=0′)	22,209	Infinite	Infinite
Beam Seas Port (x=0′, z=-137.5′)	4,802	Infinite	48,675
Beam Seas Amidships (x=z=0′)	24,403	Infinite	Infinite
Beam Seas Starboard (x=0′, z=137.5′)	18,432	Infinite	175,417

Results of an analysis of SCR fatigue life due to this effect are shown in Table 6. These lives are well in excess of the customary requirement for 10 times the design life.

The Oil Box mooring system depends on water depth and environment. Typical mooring systems in 5,000 ft water depths are

West Africa: 250', 3 3/4" chain at platform
(8 lines) 6,600', 3 7/8" strand
250', 3 3/4" chain at anchor

Brazil: 250', 6"chain at platform
(12 lines) 7,500', 5 7/8" strand
250', 6" chain at anchor

Gulf of Mexico (same as Brazil)
(16 line)

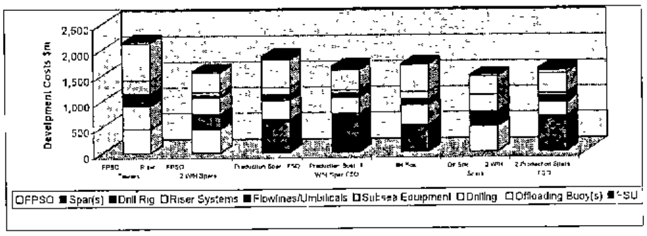
These chain-wire-chain systems are semi-taut systems similar to those used on other spar projects. The Oil Box is capable of being moored in water depths up to 10,000 ft using wire. Polyester moorings could also be used.

5. Economics

The Oil Box hull may be built in a dry dock or suitable fabrication yard. Hull specifications were recently reviewed with several Southeast Asian shipyards. Hull fabrication cost estimates were received from three yards with capacity to build the Oil Box. Costs for the outfitted hull range from $125-160MM. The schedule for hull construction from the end of FEED engineering is about 20 months. This is about 12-14 months sooner than the estimated schedule for the facilities module. This suggests that it would be economic to build and install the Oil Box with drilling and utilities modules pre-installed on a fast-track schedule. This would minimize MODU time required for development drilling and completions. Also, if a small process module were installed, early production could offset much of the drilling costs. Economic analysis indicates that this approach to field development could greatly improve the Net Present Value of large fields. This scenario is made possible by the provision to remove and install decks at the drilling site.

In order to evaluate the Oil Box a cost model was developed for a typical large field. This model included CAPEX costs for the facilities, subsea and risers and drilling costs. The drilling costs were adjusted to include the difference in current MODU day rates and drilling from a production platform using a platform rig. The field evaluated included three drilling sites and nominally 61 wells including producers, water and gas injection wells. Alternative development scenarios ranged from an FPSO with all subsea wells to all dry tree cases with combinations of Spar systems and an Oil Box. The results are shown in Figure 11.

Figure 11 Relative CAPEX of Development Alternatives



While the FPSO option results in the lowest surface facility cost, drilling, subsea and riser costs result in a total cost which is over $500MM higher than the lowest cost option, an Oil Box and two wellhead spars. This difference does not take into account the time value of money, which would increase the differential NPV of these two cases considerably if the Oil Box were delivered early and the full process module added later.

These results are obviously very sensitive to specific reservoir conditions and MODU rates and should not be considered as representative of all cases.

6. Concluding Remarks

Work on the Oil Box over the past five years indicates that it is a feasible and very cost effective alternative for large field development in West Africa, Brazil and the Gulf of Mexico. It has the advantage of using proven spar riser technology, motion characteristics which make it feasible for the major deepwater areas of the world, and probably most importantly the flexibility to proceed with construction, installation, drilling and early production operations before delivery of the full process module. This has a major impact on project economics The West African design is under review by a Classification Society for issuance of an Approval in Principle. This design is ready for FEED engineering. Currently the hulls are being optimized for Brazilian and Gulf of Mexico operations and designs should be complete by Mid-2000.

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