A NEW DEEPWATER TANKER LOADING SYSTEM FOR WEST AFRICA

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Abstract

With the prospective development of a large number of deepwater fields in West Africa using non-weathervaning floating production units, there is a need for a reliable means of offloading processed crude oil to ocean-going tankers. Most development studies to date for fields in West Africa have considered the use of a large displacement catenary anchor leg mooring (CALM) terminal to support the export flowlines and to provide a single point mooring for the ocean-going tankers. However, detailed analyses of the system has shown that the flowlines are exceptionally susceptible to fatigue damage, caused by the high frequency, low amplitude motions of the CALM buoy in waves. Concerns, both financial and operational, exist regarding the feasibility of repairing and/or replacing the CALM buoy and/or the flowlines during the life of the field.

This paper presents a new tanker loading system developed for deep water that dramatically reduces the fatigue damage to the steel or flexible flowlines, and provides a conventional offloading interface for the ocean-going tankers. The system also provides improved reliability of the offloading system over the life of the field by de-coupling the flowline support system from the single point mooring, allowing for repair and/or replacement of the SPM in the event of damage by accident. An additional benefit is that the new offloading system allows the use of larger diameter, smaller wall thickness steel flowlines than would be suitable when supported directly by the large displacement CALM buoy. This provides a major improvement in flow performance and allows further optimization to the pumping system. This system should be of interest to operators looking for a deep water tanker loading solution in mild and moderate environments.

Background

Multitudes of high yield oil reservoirs have been discovered recently in relatively benign environments in deepwater offshore West Africa. There are exciting prospects for similar finds in ultra-deepwater. The benign environment and the directionality of prevailing forces allows non-weathervaning floating production systems to be considered as the preferred option for development of these oil fields.

Permanent mooring of a non-weathervaning facility in these environments presents few problems and allows great flexibility in selecting the production riser system. Issues do, however, arise when there is a requirement to offload the produced oil to a trading tanker unlike, for instance, the North Sea where purpose built, sophisticated and dedicated shuttle tankers are viable to lift comparatively small parcels at frequent intervals. The nature of the trade from West Africa dictates that the production facility can offload to large (VLCC or even ULCC) non-dedicated tankers of opportunity. Not only are these vessels much larger than the North Sea shuttles, having twice or even four times the carrying capacity of the shuttles, but they also are not equipped with station keeping aids such as thrusters which are the norm in the North Sea.

The Challenge

In many areas of the world, including West Africa, tandem offloading is the primary method of offloading turret-moored (weathervaning) and spread-moored (non-weathervaning) FPSOs. However, for spread-moored production vessels with large throughputs requiring frequent offloading, and with long field life, tandem offloading is not considered to provide the desired offloading operability. This is true even in a benign environment like offshore West Africa. The close proximity between the offloading tanker and the production vessel during offloading (approximately 100 meters) is a safety concern that has caused tandem offloading to be a secondary means of offloading.

In shallow waters offshore West Africa, and elsewhere in the world, a very usual and efficient method of loading ocean-going tankers is through an offshore catenary anchor leg mooring (CALM) marine terminal. Numerous units are currently in operation offshore West Africa. The current practice for deepwater spread-moored production vessel offloading is to consider the use of a marine terminal located at a distance where the risk of collision between platform and shuttle tanker is minimized.

A CALM terminal enables the ocean going tanker to achieve rapid connection and disconnection and to weathervane while connected. As a rule of thumb a tanker is able to connect to a CALM buoy in sea states that approximate to a significant wave height of 2.5 meters and to remain connected in seas up to 4.5 meters. Another rule of thumb is that the terminal should be able to load a million-barrel parcel of oil in 24 hours, including time for the tanker to connect and disconnect.

Due to the shuttle tanker weathervaning about the CALM terminal, it needs to be located in an area where the tanker is free to move through a 360 degree arc without any risk of collision with the production units or other field traffic. When this requirement is applied to other structures in the vicinity the horizontal clearance should be in the region of one nautical mile (approximately 1,850 meters).

With a few exceptions, the world's population of CALM terminals is located in water depths of less than 100 meters. Product is transferred through the terminal via marine hoses that are brought up from a manifold on the seabed in a configuration that results in small loads on the CALM buoy (approximately a 10 metric ton vertical load). The terminal is moored using chain in a four to eight leg catenary arrangement, designed to restrict the buoy motions during offloading, and in extreme seastates to ensure the integrity of the marine hoses and anchor chains.

As the marine hoses are very flexible and primarily exert a vertical load on the CALM terminal, the hoses do not have a large effect on the displacement and motions of the buoy. In most marine operations the marine hoses are replaced every five years or so, and thus the fatigue life of the hoses are not a major issue. The systems are designed to allow efficient replacement of the hoses when required.

Can a conventional CALM type terminal be designed for deepwater application?

The main issues are identified as:

- ***Water depth:*** The buoy and its anchoring system must be selected to perform adequately for the greater water depths. The buoy displacement and mooring system arrangement must be properly designed to offset the loads exerted by the flowlines. Analysis techniques are readily available for this adaptation.
- ***Flow assurance:*** Since diameter of the flowline must be limited for this type application, precise flow assurance design and analysis is critical to developing a viable economic solution that accounts for the desired flowrate, pumping system costs and the possible need to perform pigging during life of field operations.
- ***Flowline type and configuration:*** Currently, only large diameter steel and flexible flowlines are available for this service. Composite flowlines may become available in the future. Since available fatigue life is decreased by diameter increase, selection of flowline configuration is critical to project economics. As it is not viable to run the flowline from the platform to the seabed and then back up to the offloading terminal, the mid-water wave configuration is used. Three flowlines may be required in some cases to provide a system capable of a typical industry standard throughput of one million barrels per day. Overall design of the complete offloading system is imperative for selecting the optimal flowline type solution.
- ***HSE Integrity***: It is desirable that the system employ proven components that provide a high level of integrity towards HSE issues. Other than the requirement for flowlines to be suspended in the water column, the type of system being discussed herein presents no new HSE issues compared to conventional shallow water CALM terminals.
- ***Repair and Maintenance:*** The export system should be user friendly for repair and maintenance. No additional requirements are imposed upon the CALM for deepwater in this regard, however, inspections required to fulfill flowline maintenance needs requires attention. In either case, no interruption of loading is anticipated.
- ***Service Life:*** In many cases CALM buoys for shallow water are designed to provide uninterrupted service over the life of the field (20 to 30 years) in terms of

> bearing, structure and anchor leg fatigue. For deep water systems with mid-water flowlines, it must be demonstrated that the flowlines have adequate fatigue life over the life of the field.

To extend the shallow water CALM terminal concept to deepwater, the first approach has been to design a single large displacement CALM buoy and the associated mooring system. The large distance required between the producing platform and the offloading point (~1,850 meters), and the weight of the large flowlines suspended results in large reaction loads at the buoy (approximately 300 metric tons vertical and 250 metric tons horizontal). These loads are reacted by designing an asymmetric mooring system to react the horizontal load, and increasing the displacement of the buoy to support the riser and mooring load. This results in a buoy that has a displacement approximately four to five times that of a conventional shallow water buoy. The heavy flowlines also impact the motions of the buoy and must be accounted for when assessing the dynamic response of the buoy system.

The flowlines (both steel pipe and flexible riser) must be designed to require no change-out for the life of the field due to the great expense and offloading downtime that will be experienced if this were required. Thus the flowlines must have adequate fatigue life for a duration of twenty to thirty years. As the flowlines are directly connected to the buoy, they respond dynamically to any motions the buoy itself may exhibit in response to the wave environment, and are thus susceptible to the accumulation of fatigue damage. Detailed analysis of this complex system have shown that the fatigue life of the flowlines attached to a large displacement CALM buoy can have unacceptable levels for a twenty year application. This will be discussed and quantified in a section later in this paper.

This paper presents a new offloading system that will alleviate the fatigue damage of the flowlines by separating the support and offloading functions of the offloading system. With the performance offered by the addition of the Flowline Termination Buoy (FTB) as discussed herein, more than adequate service life for the flowlines can be achieved. Risk of insufficient fatigue life for the flowlines is lowered significantly by adapting this system configuration in place of the large displacement CALM buoy, and it will be shown that the system provides several opportunities to optimize the entire offloading system, resulting in reduced capital and operational expense.

Description of the New Offloading System

The offloading system presented in this paper has been designed as a solution for deepwater offloading from offshore platforms either fixed (e.g., jacket structures), or floating (e.g., FPSOs, Semi-submersibles, or Spars). Figures 1 through 3 provide an illustration of the proposed offloading system.

As can be seen in Figures 1 and 3 the offloading system is comprised of two major components:

1) a submerged Flowline Termination Buoy (FTB) moored 75 to 100 meters below the water surface that serves as the support point for the mid-water flowlines, and
2) a conventional CALM-type buoy (SPM) on the surface that serves as the marine terminal for offloading to the shuttle tankers.

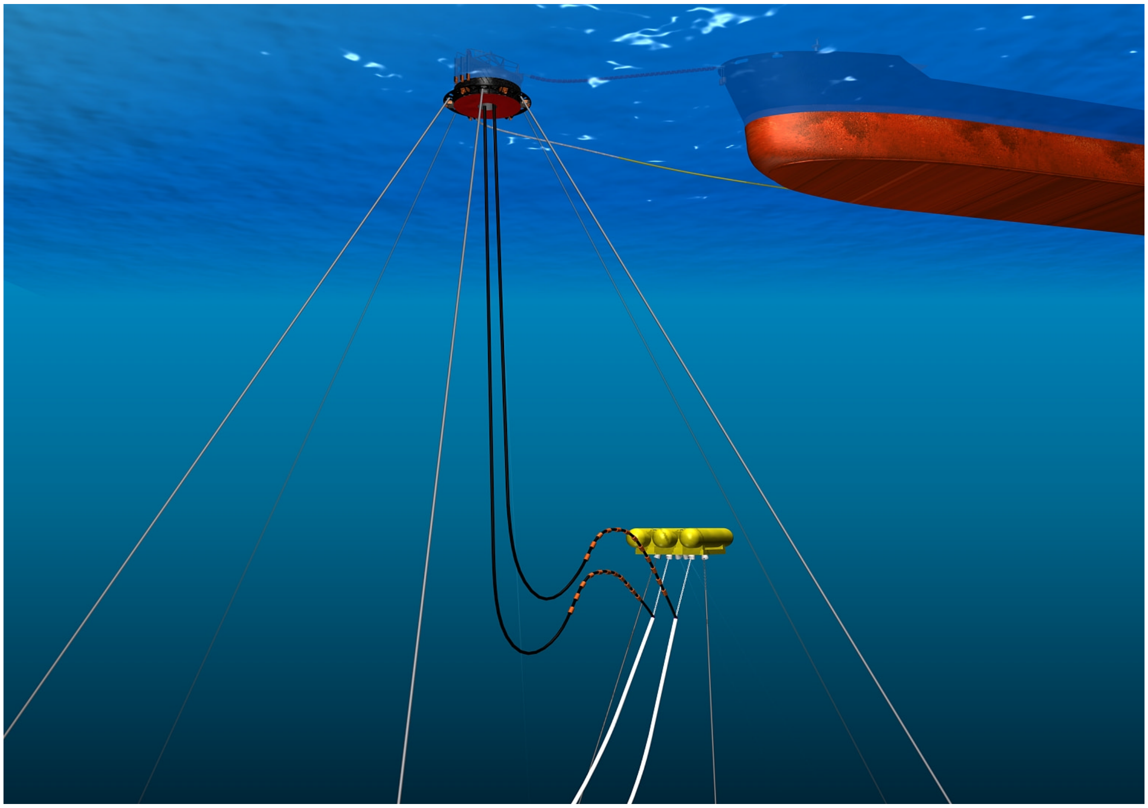

Figure 1: The Flowline Termination Buoy and CALM Buoy Offloading System.

The two buoys are independently moored, with standard marine hoses or flexible jumpers connecting the flowlines at the FTB to the SPM buoy using a configuration that is flexible enough to effectively de-couple the two buoys. Motions of the SPM on the surface do not affect the flowlines, and the FTB is deep enough to minimize the effect of wave loading. This drastically reduces dynamic loading on the flowlines from the offloading system and results in a significant reduction in fatigue damage of the flowlines. This is a major advantage over the large displacement CALM buoy serving as both the support mechanism for the flowlines, as well as the marine terminal for offloading.

The following paragraphs provide a description of the individual components of the FTB-SPM offloading system.

The Flowline Termination Buoy (FTB): The flowline termination buoy is designed to provide a reliable support system for the flowlines at the offloading location. As shown in Figures 2 and 3, the FTB is moored by a four-leg mooring system at a depth of approximately 75 to 100 meters. The four-leg mooring system is designed to counteract the horizontal loads from the flowlines, as well as provide the desired vertical stiffness to maintain the FTB at the desired location. To ensure the reliability of its mooring system for the life of the field the FTB mooring system may be constructed from sheathed spiral strand wire with short sections of chain at either end.

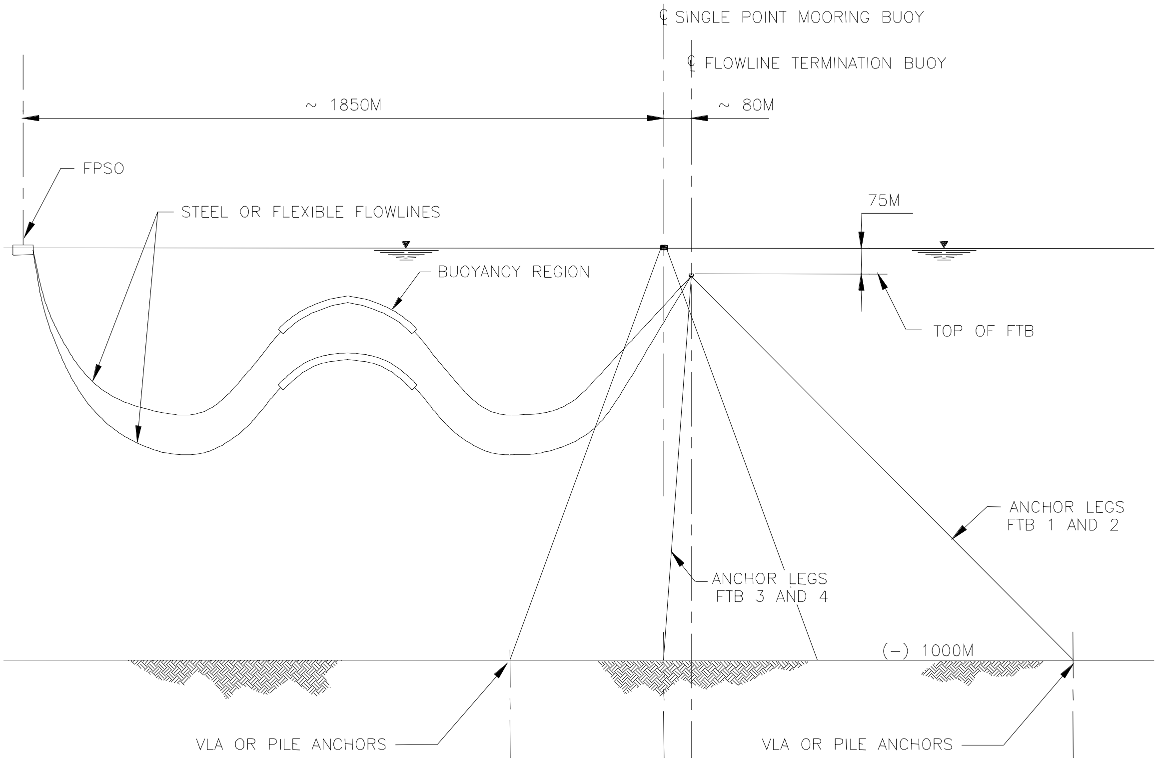

Figure 2: Schematic of the FTB-SPM Offloading System with Flowlines.

The FTB is a multi-compartment buoy, designed to be positively buoyant and is relatively insensitive to density changes of the fluid in the flowlines (e.g., from oil to water). The FTB has been designed to provide a reliable support in the event of accidental damage of an anchor leg, or loss of one compartment in its buoyancy tanks. The buoyancy of the system has also been designed to support the flowline loads during installation, operational and damaged conditions. The FTB buoy could be constructed with a hermetically sealed steel buoyancy system, an open bottom steel buoyancy system, or using syntactic or polyurethane foam buoyancy. The FTB buoy and flowlines can be installed by either jacking the buoy down using submersible chain jacks on Legs 3 and 4, or by controlling the ballast of the buoy. Once installed, the FTB does not require an active ballasting system to maintain its position.

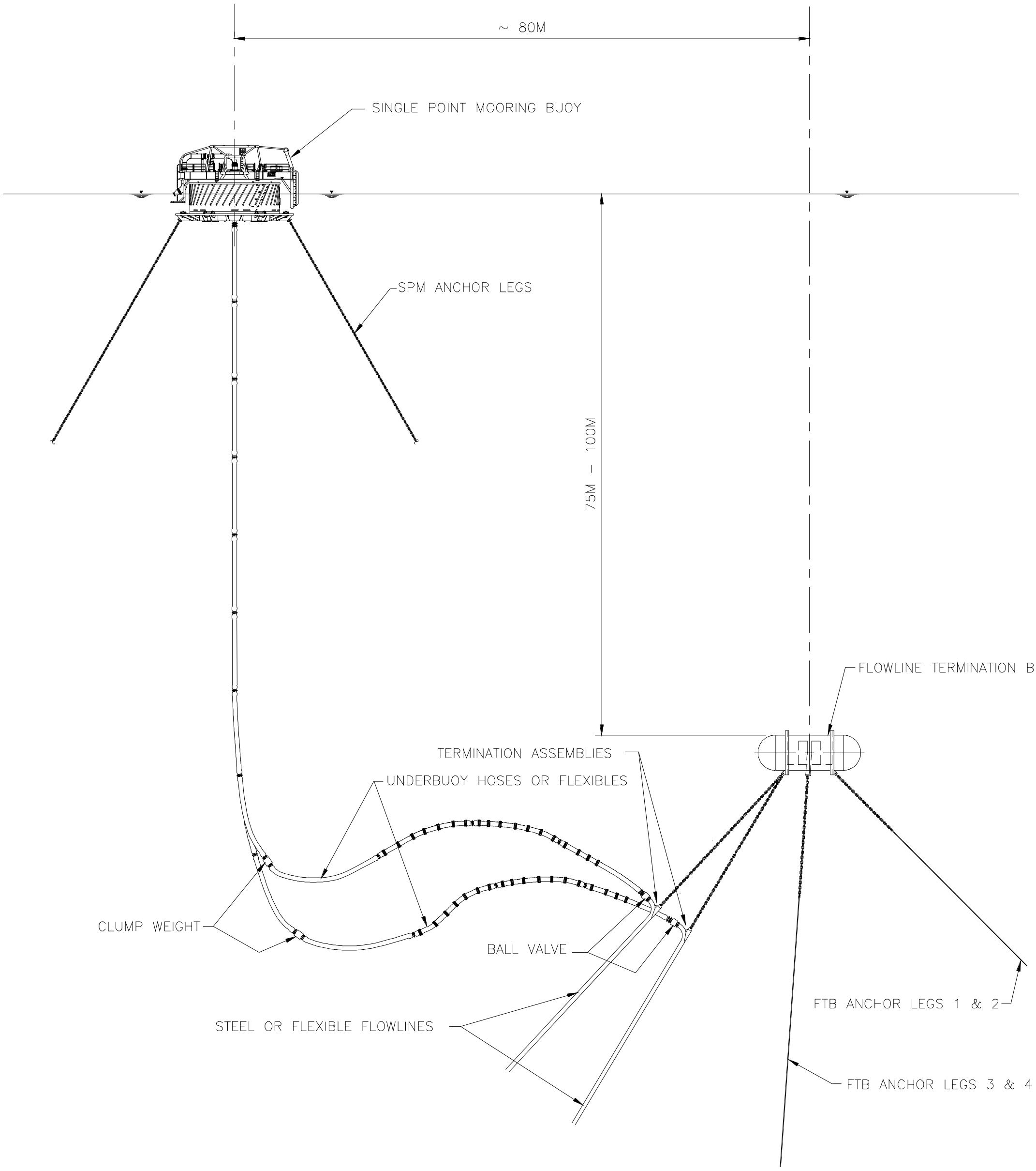

Figure 3: Illustration of the FTB and SPM Arrangement.

The flowlines are connected to the FTB via a specially designed gooseneck flowline termination assembly that allows connection of the flowline to the FTB with an adjustable chain element. The chain segment eliminates the need for expensive flexjoints at the flowline/FTB interface, and allows for easy installation of the flowline. Marine hoses or flexible pipe (depending on required diameter) are connected from the gooseneck to the SPM in a lazy wave configuration. Ball valves and breakaway couplings can also be provided at the marine hose-gooseneck interface if required.

The SPM: The SPM is a conventional CALM buoy moored by a 6-leg mooring system as illustrated in Figures 1 through 3. The centerline of the SPM is located approximately 80 meters away from the FTB, and the mooring legs are arranged to ensure no interference with the FTB and its mooring, the flowlines, and the connecting hoses or flexible jumpers. For an application in approximately 1,000 meters water depth, the CALM buoy has a diameter of 12 meters, and a depth of 5.8 meters. Of course, the dimensions of the CALM buoy can be varied to provide whatever level of buoyancy required to support the mooring legs in various water depths. Likewise, for the FTB. All rotating parts are located above the waterline and all equipment can be serviced in situ. Standard marine hawsers are used to moor the offtake tanker to the SPM and standard marine floating hoses carry the product from the SPM to the offtake tanker manifold as in conventional offloading systems in shallow water. The system may also be designed to allow round trip pigging from the FPSO.

Key Features and Advantages of the Proposed Offloading System

The offloading system described in the previous session has key features that have many advantages over the large displacement CALM buoy and flowline system.

De-coupling the flowlines from the offloading buoy

The proposed offloading system separates the flowline support and product offloading functions to two independent buoy systems: the FTB and SPM buoys. This feature provides several advantages and increased reliability for the life of the field over the large displacement CALM buoy-flowline system.

De-coupling the flowlines from the surface buoy and supporting them by the submerged FTB essentially reduces the highly dynamic loading on the flowlines to static loading. The complex response of flowlines attached to a large displacement buoy are due to the high frequency motions of the buoy in both the local waves (4 – 10 second period range) and the swell waves (12 – 16 second period range). These small motions result in low amplitude, high cycle fatigue damage of the flowline, leading to unacceptable fatigue damage over the life of the field. Reference 1 provides an in-depth analysis of the complex dynamic response of steel flowlines attached to a large surface buoy and its sensitivity to various parameters. Reference 2 provides details of a case study in the Campos Basin where the high frequency response of an actual CALM buoy in deep water is described along with the flowline failures associated with that motion.

The FTB provides a reliable support mechanism for the flowlines, positioned 75 to 100 meters below the surface. At this depth the wave kinematics of the local waves approach zero, while those for the swell waves are reduced by 90 percent. The taut mooring system coupled with the weak environmental loading on the FTB-flowline system, results in very small motions of the FTB. This results in the FTB providing an essentially static support for the flowlines with most of the dynamic excitation from the FPSO end and that due to vortex-induced vibration (VIV). The VIV is minimized by the appropriate application of strakes along portions of the flowline. This reduces the fatigue damage of the flowline over a twenty-year life by at least two orders of magnitude as presented in the next section.

In addition to reducing the fatigue damage of the flowlines, the proposed offloading system also enhances the integrity of the flowline support/offloading system by reducing the risk of shuttle tanker or support vessel collision with the offloading system and its impact on the flowlines. With the FTB and flowlines 75 meters below sea level there is no risk of collision between shuttle tankers and the flowlines themselves. If a collision does occur between the shuttle tanker and the offloading buoy, the damage is localized to the buoy and has no effect on the flowlines. The use of a conventional marine terminal allows for easy replacement without the concern of supporting the flowlines in the absence of the offloading buoy, as would be the case in the large displacement CALM buoy-flowline system.

Another important advantage of the FTB system over the large displacement CALM buoy is the lower hawser loads during offloading. For a given shuttle tanker and environment, the maximum hawser load varies as a function of the offloading buoy size (due to the change in motions). The maximum dynamic hawser loads for a large displacement buoy can be significantly higher than that for a smaller buoy. This can have a major impact on the offloading efficiency of the system, as the bow stoppers on most tankers of opportunity are limited to a 200 metric ton maximum load. In some sea conditions this implies that the hawser loads for the large displacement CALM buoy could exceed the tankers bow stopper capacity while the hawser load for the FTB-SPM system will not, thus allowing offloading to continue.

Optimization of the Mid-Water Flowline System

The FTB-SPM offloading system also allows greater optimization of the product export system (flowline and pumping equipment on board the platform) than the large displacement CALM buoy system. This is due to the reduction of dynamic response of the flowline and the insensitivity of the FTB system to changes in flowline loads.

Impact on flowline construction: The reduction in dynamic loading of the flowline for the FTB-SPM system allows a smaller wall thickness than that required for a large displacement CALM buoy. Typically a reduction in wall thickness of 25 to 33 percent is possible for steel pipe of approximately 20 to 24 inches in diameter. In addition, the reduction in fatigue damage eliminates the need for expensive forged thickened sections used in some applications to provide additional fatigue resistance.

The reduction in wall thickness results in a much lighter pipe that requires less buoyancy along the length of the flowline to provide the desired “wave” configuration. This results in lower pull-in and porch loads at the platform end and reduced vertical and horizontal loads to be reacted at the FTB. For the FTB, this relates to a reduction in net buoyancy and in mooring components required to react the loads. Further optimization can be made in trading-off the buoyancy on the flowline (expensive) with buoyancy in the FTB (cheap) to provide the most cost-effective solution.

Impact on flowrate and pump requirements: The insensitivity of the flowline to fatigue damage and the associated reduction in wall thickness and pipe weight also allows the use of a greater bore pipe than that for the large displacement CALM buoy. This has a major impact on the head loss experienced by the product along the length of the flowline. Higher flowrates with lower pumping pressures, and associated required pump power, are possible using the FTB-SPM offloading system.

The above discussion outlines many aspects of the product export system that could be optimized by utilizing the FTB-SPM offloading system. This results in a more efficient and cost-effective total offloading solution than one based on the surface termination of the flowlines to a large displacement CALM buoy. The next section provides a quantitative assessment of various parameters of the FTB-SPM offloading system as compared to a large displacement CALM buoy.

Quantitative Assessment of the Large Displacement CALM Buoy and FTB-SPM Offloading Systems

To provide a quantitative comparison between the large displacement CALM and FTB-SPM offloading systems, a hypothetical field in approximately 1,000 meters water depth offshore West Africa was considered. The offloading system was assumed to be located approximately 1,850 meters away from the FPSO with two steel flowlines arranged in a midwater wave configuration.

Table 1 provides a summary of buoy, mooring and flowline characteristics for the two systems. To make a direct comparison between the two systems 22-inch O.D. (0.559 meter) steel flowlines were assumed for both systems, with the FTB-SPM flowlines having a wall thickness of 0.75 inch compared to 1.0 inch for the large displacement CALM buoy. Table 2 illustrates the advantage of further optimizing the flowlines for the FTB-SPM system by utilizing a 24-inch O.D. (0.61 meter) diameter flowline with a wall thickness of 0.75 inches.

Table 1 provides a comparison of the buoy and mooring system properties for the two offloading systems. The total weight of the FTB-SPM system is approximately 60 percent that of a large displacement CALM with one to four additional anchor legs (typically with smaller components). This implies that though there may be a cost saving from the weight of the FTB system, there may be additional costs incurred for installing the extra anchor legs. Preliminary analysis has shown the differences in system cost to be minimal. As discussed earlier the maximum hawser load for the FTB-SPM system is approximately 70 percent that for the large displacement CALM buoy.

The bottom half of Table 1 compares the particulars of the 22-inch O.D. flowlines for the two systems. Reducing the wall thickness for the flowlines on the FTB-SPM system provides a net reduction in steel weight of 75 metric tons per flowline and 70 metric tons per flowline in syntactic foam buoyancy. The loads at both ends of the flowline are reduced by approximately 25 percent. The FTB solution also results in the elimination of expensive flexjoints, replacing them with a gooseneck-type flowline termination assembly as described in an earlier section.

In comparing the flow performance of the flowlines, it is seen that the small (0.5-inch) increase in inner diameter has a noticeable impact on the flow performance of the 22-inch O.D. flowline. The 0.75-inch wall thickness flowlines reduce the flowline head loss by 12 percent resulting in a 5 percent increase in flowrate for the same pump pressure (255 psi).

Table 1: Comparison between Large Displacement CALM Buoy and FTB-SPM Offloading Systems (22-inch O.D. flowlines)

	Large Displacement CALM Buoy	**FTB - SPM Buoys**	**Units**
Buoy Particulars			
CALM Buoy:			
Diameter	19.5	12.5	m
Height	10.0	5.8	m
Weight	800	310	MT
FTB :			
Displacement	N/A	750	MT
Weight	N/A	160	MT
Total Weight:	**800**	**470**	MT
Mooring System			
CALM Buoy:	3X2 (6 legs) or 3X3 (9 legs)	3X2 or 6X1 (6 legs)	
Construction	Chain/Wire or Chain/Polyester	Chain/Polyester	
Static Vertical Load	600	160	MT
FTB:	N/A	4X1 (4 legs)	
Construction	N/A	Chain/Wire	
Static Vertical Load	N/A	360	MT
Hawser Loads			
Maximum Load, 340 kDWT tanker	330	225	MT
Steel Flowline Particulars			
Outer Diameter	22 (0.559)	22 (0.559)	in. (m)
Wall Thickness	1.0 (25.4)	0.75 (19.1)	in. (mm)
Total Length	2,200	2,200	m
Total Weight of Steel	735	560	MT
Total Buoyancy Required	255	185	MT
Total Vertical Load/Flowline on Buoy	160	115	MT
Total Horizontal Load/Flowline on Buoy	120	85	MT
Interface with Buoy	Double Flexjoint	Gooseneck/Chain	
Flowline Characteristics			
Head Loss @ 7,500 m^3/hour	120	105	psi
Pump Pressure @ 7,500 m^3/hour	240	210	psi
Flowrate @ 255 psi pump pressure	8,100	8,520	m^3/hour
Time to Offload 1,000,000 bbls	19.6	18.7	hours
Estimated Flowline Fatigue Life	**10 - 200**	**1,000 - 10,000**	years

Table 2 compares the flow performance of a 24-inch O.D. flowline (wall thickness of 0.75-inch) with the 22-inch O.D. flowline (wall thickness of 0.75-inch) in Table 1. The weight of the flowlines has minimal impact on the FTB and its mooring. However, the table illustrates the advantage of the 24-inch O.D. flowline on the flow performance of the system. For a 7,500 cubic meter/hour flowrate the required pump pressure and platform power is reduced by 21 percent compared to the 22-inch O.D. flowline. If the pump pressure was maintained at 255 psi the flowrate is seen to increase by almost 20 percent, reducing the offloading time by 3 hours per million barrels of oil.

Table 2: Impact of Flowline Size on FTB-SPM Solution.

	FTB - SPM Buoys 22-inch O.D. / 0.75-inch w.t.	**FTB - SPM Buoys 24-inch O.D. / 0.75-inch w.t.**	**Units**
Buoy Particulars			
CALM Buoy:			
Diameter	12.5	12.5	m
Height	5.8	5.8	m
Weight	310	310	MT
FTB :			
Displacement	750	790	MT
Weight	160	170	MT
Total Weight:	**470**	**480**	MT
Mooring System			
CALM Buoy:	3X2 or 6X1 (6 legs)	3X2 or 6X1 (6 legs)	
Construction	Chain/Polyester	Chain/Polyester	
Static Vertical Load	160	160	MT
FTB:	4X1 (4 legs)	4X1 (4 legs)	
Construction	Chain/Wire	Chain/Wire	
Static Vertical Load	360	380	MT
Hawser Loads			
Maximum Load, 340 kDWT tanker	225	225	MT
Steel Flowline Particulars			
Outer Diameter	22 (0.559)	24 (0.61)	in. (m)
Wall Thickness	0.75 (19.1)	0.75 (19.1)	in. (mm)
Total Length	2,200	2,200	m
Total Weight of Steel	560	610	MT
Total Buoyancy Required	185	160	MT
Total Vertical Load/Flowline on Buoy	115	125	MT
Total Horizontal Load/Flowline on Buoy	85	95	MT
Interface with Buoy	Gooseneck/Chain	Gooseneck/Chain	
Flowline Characteristics			
Head Loss @ 7,500 m^3/hour	105	65	psi
Pump Pressure @ 7,500 m^3/hour	210	165	psi
Flowrate @ 255 psi pump pressure	8,520	10,180	m^3/hour
Time to Offload 1,000,000 bbls	18.7	15.6	hours
Estimated Flowline Fatigue Life	**1,000 - 10,000**	**1,000 - 10,000**	years

Figure 4 provides a comparison of the estimated fatigue of similar 22-inch O.D. steel flowlines used with the large displacement CALM buoy and the FTB-SPM offloading systems. The fatigue life estimates account for the damage due to buoy and FPSO motions only and not damage due to installation and VIV. It is seen that the fatigue life of the flowlines reduces by at least two orders of magnitude when used with the large displacement buoy. A typical rule of thumb is a minimum fatigue life with damage from all contributions of 10 to 15 times the design life of the field is acceptable. This would result in a desired fatigue life of 300 to 500 years when all contributions to damage are accounted for. Figure 4 and Tables 1 and 2 indicate that the FTB-SPM system provides a fatigue life that greatly exceeds this requirement while the large displacement buoy solution is marginal at best, resulting in system that is neither reliable or robust.

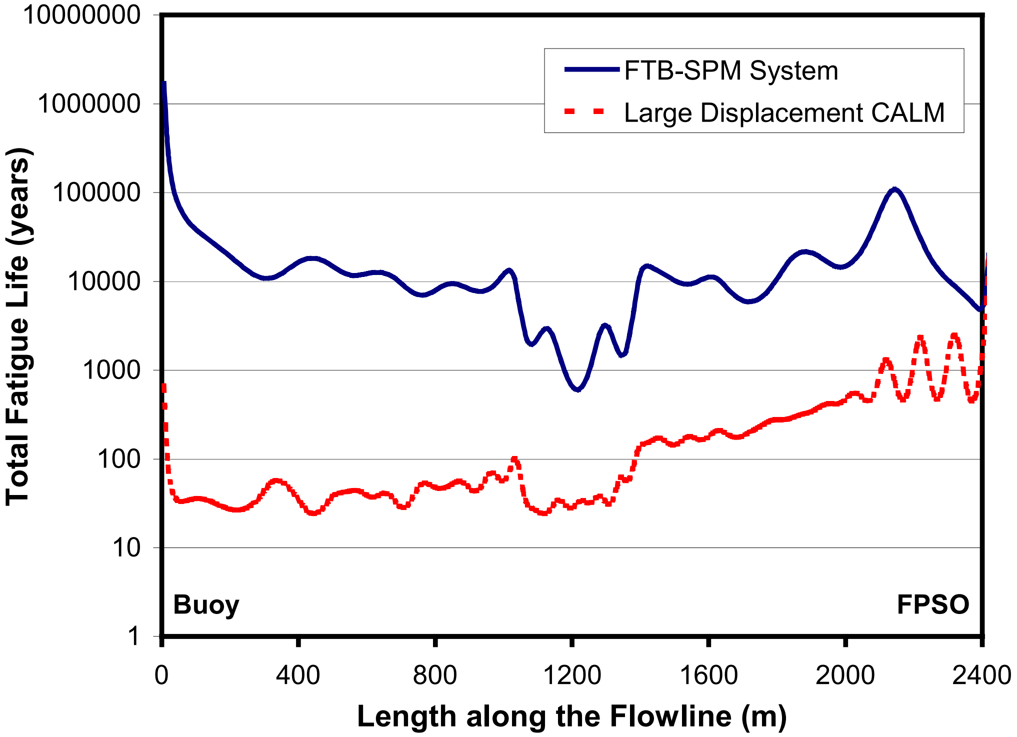

Figure 4: Comparison of Estimated Fatigue Life for Large Displacement CALM Buoy and FTB-SPM System.

Conclusions

The flowlines used for deepwater offloading systems must demonstrate adequate fatigue life over the life of the field. Flowlines attached to large displacement CALM buoys have been shown to have marginal fatigue life at best and failure of the lines can have a dramatic environmental and operational impact.

The FTB-SPM offloading system described in this paper is shown to effectively eliminate the fatigue damage of the flowlines by using two independently moored buoys to separate the support and offloading functions of the offloading system. The FTB, located 75 to 100 meters below the sea level, provides a static support for the flowlines, while the conventionally sized CALM buoy provides a conventional marine terminal offloading interface. As demonstrated in the paper, the FTB-SPM system provides a more robust and reliable deepwater offloading system than a large displacement CALM buoy. It has also been shown that the FTB-SPM offloading system can result in an optimized product export system with savings in overall project CAPEX and OPEX.

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