OTC 19365

Surge Pressure Analysis for Bijupira and Salema Water Injection System

Patricia Meliande, Elson A. Nascimento, Universidade Federal Fluminense Civil Engineering Department; João P. Dandoulakis, SHELL Brazil; André L. L. Massa, Universidade Federal do Rio de Janeiro Oceanografic Department;

This paper has been prepared for presentation at the 2008 Offshore Technology Conference held in Houston, Texas, U.S.A., 5–8 May 2008.

Abstract

Anticipating and controlling transient response is a critical design activity for ensuring both safety and integrity of the operational subsea system. Predicting transient effect, commonly known as surge pressure, is of high importance for offshore industry. It involves detailed computer modelling that attempt to simulate the complex interactions between flowline and fluid, aiming at efficient flow assurance and consequently flowline and riser systems integrity. Bijupirá and Salema water injection systems, located in the Campos Basin, offshore Brazil, have been operating since 2003. The operational teams have raised concerns, whether the system is adequately designed to protect the subsea system against possible surge pressures during the event of sudden closure of a valve. Researches, referred to transient effects, clarify that is necessary to evaluate the system performance under current and desired operating conditions. The main goal of this paper is to predict the surge pressure in flowline and riser of the water injection system due to valve closure. A supplemental simulation has been performed in order to evaluate conditions that would keep the water injection surge pressure below Maximum Allowable Operating Pressure (MAOP) of the subsea equipments. According to the simulations results, the maximum surge pressure occurs throughout the manifold and jumper region, and the worst case occurs when all valves are simultaneously closed in Bijupirá and Salema production fields. The maximum surge pressures verified in simulations may reach values greater than the operating desired pressure, which may cause damage to the water injection system integrity. In order to avoid surge pressures greater than MAOP, which corresponds to 255 bar, the simulations indicated that when a pressure of 230 bar occurred on the turret, injection flow rate should not exceed 12000 bbl/day. Therefore, conventional techniques to solve complex problems in this area need to be improved, and computational simulations may contribute to establish the operating control system and guarantee its integrity during operating life.

Introduction

One of the main reasons for offshore industry expansion is the development of sophisticated equipment for subsea oil and gas production fields operation. Operational procedures require advanced technology applied throughout operating life of equipments which includes flowlines, risers, manifolds, jumpers and other complex structures with capability for round trip pigging.

Techniques for assuring well production have been implemented, and one of them is known as “water injection”, which consists in applying water flow rates in injection wells to guarantee enough pressure to rise oil and gas flow from production wells.

Nowadays, flow assurance and consequently flowline and riser systems integrity are the great challenges for the offshore design development. Equipment failures may be responsible for disturbances in subsea systems operation. Fast closing valves and unplanned pumps operations are the most common reasons of transient problems, known as “Water Hammer” or “Surge Pressure” effects. These effects may cause severe enough pressure fluctuations resulting change of the steady-state operating conditions.

Pressures fluctuations are result of the interchange among the fluid kinetic energy, the fluid strain energy and the pipe wall. Such fluctuations are identified as oscillating, periodic, or pulsating disturbance waves, traveling at approximately sonic velocity, which are propagated to the fluid. Continuous surge pressure process may lead to structural damage due to uncontrolled large pressure oscillations acting in the piping system.

In the last years many researches and practical advances related to transient analysis have been achieved. Even so, in spite of all efforts, there are still many problems that need to be solved, mainly concerned with analytical methods employed to solve transient effects.

Although available computer programs with special routines have been implemented, the main challenge consists in their validation. These programs may help to provide procedures which can identify the mainly transient factors, as pump start-up and changes in operational position of control valves, and consequently ensure the optimization of system, and provide cost-effective solutions.

Transient analysis is a subject widely open to further improvements in offshore design. The purpose of this paper is to present a contribution to this analysis, showing how surge pressure in flowline and riser of the water injection system due to valve closure, could be estimated. Transient model analyses have been performed to evaluate surge pressure behavior in Bijupirá and Salema oil fields located in Campos Basin, offshore Brazil. In previous paper[1,2], flow assurance challenges have been discussed. This paper aims to highlight transient behavior aspects of Bijupirá and Salema water injection systems.

Analyses results indicate that when one valve is closed at Salema Field, surge pressure reaches 261 bar, and when two valves are closed at the same time, the maximum surge pressure achieves 282 bar. Both situations indicate that in Salema, surge pressure is higher than the design pressure established, equal to 255 bar.

Related to Bijupirá Field, analyses indicated that surge pressure would exceed the design pressure when more than three valves are closed at the same time. Besides, when all valves at Salema and Bijupirá are closed at the same time, results have shown that there is no influence of the surge pressure from one set of wells upon the other.

Supplementary simulation has been also performed in order to evaluate the operating conditions to keep the water injection surge pressure below the design pressure established for the entire system. Whereas results indicate that when the pressure on the turret corresponds to 230 bar, injection flow rate should not exceed 12,000 bbl/day; therefore, the water injection flow rate may be increased significantly, when the topside pressure is reduced.

Finally, some factors affecting transient analysis may be identified using advanced computer programs; one of them is when surge pressure is higher than the operating design pressure. Frequent transient problems (pressure fluctuations) may expose the pipeline system to fatigue process.

Bijupirá and Salema water injection system description

Bijupira and salema field is located in Campos Basin offshore Brazil. The two fields are developed as subsea tiebacks to an FPSO, positioned approximately in the middle of the field with offset distances between the subsea drill centers ranging from 2 to 3 km. The system comprises subsea manifolds, flowlines, risers and jumpers with capability for round trip pigging[2]. The water injection system consists of two lines between the FPSO Fluminense and the two subsea fields, Bijupirá and Salema.

Bijupirá field is composed of six producers wells and four water injection wells, while Salema Field comprises two producers wells and two water injection wells, and each water injection well is connected to two valves, wing and master valve, used to close the water injection well. For each water injection well there is one choke, used to control the injection rate from pumping station. Figure 1, below, presents Bijupirá and Salema water injection system layout.

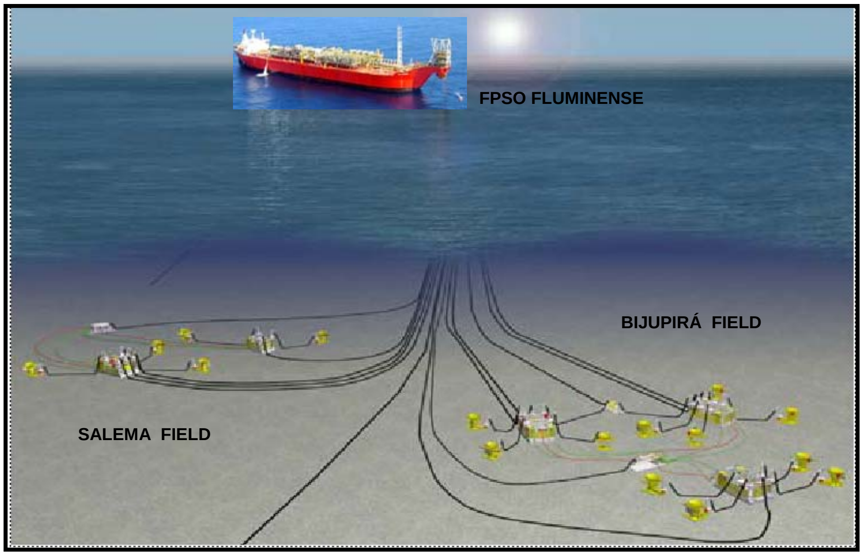

Figure 1. Bijupirá and Salema system layout

Operating water injection system

The measured topside pressure remains between 220 and 230 bar most of the time, as showed at Figure 2. Based on this, the turret pressure was assumed 230 bar, in order to validate the simulation model.

All the measured pressure data refer to piezometric pressure, which includes the hydrostatic pressure.

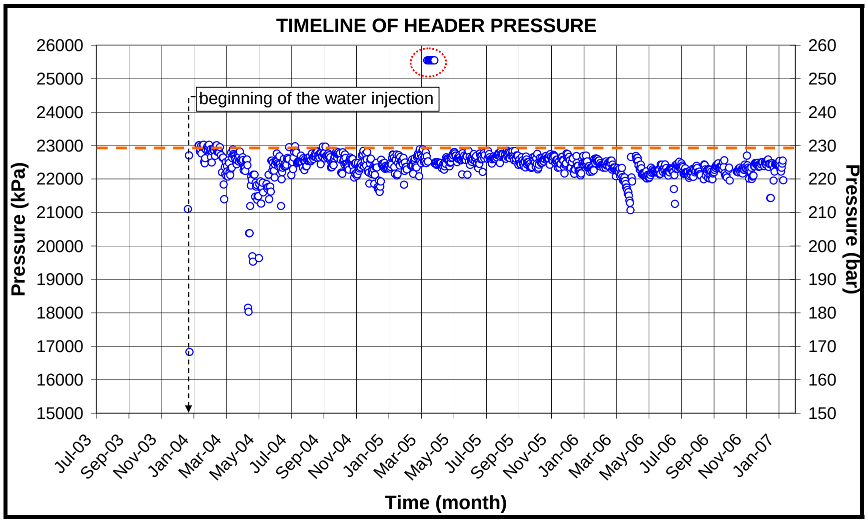

Figure 2. Turret pressure of Bijupirá and Salema water injection system

In hydraulic science, concepts about "head pressure" are fundamental for operational comprehension of the water injection system. Piezometric or hydraulic pressure corresponds to the head above a datum to which fluid rises in a tube connected to a tapping in a pipe or passage[3].

In Bijupirá and Salema systems, the pressure measured on the turret, in topside, has achieved 230 Bar. Bijupirá and Salema fields are located respectively 770 and 640 meters of water depth; therefore, the total head pressure, considering the subsea level as reference datum, is equal to the topside pressure added to the external overpressure. The external overpressure will be then ballanced with the internal pressure due to water transport. The value of 255 bar obtained for the operating pressure design (MAOP) is higher than the topside head and guarantees the operational system security.

Figure 3 shows the injection lines profiles from the turret on the FPSO Fluminense to both fields.

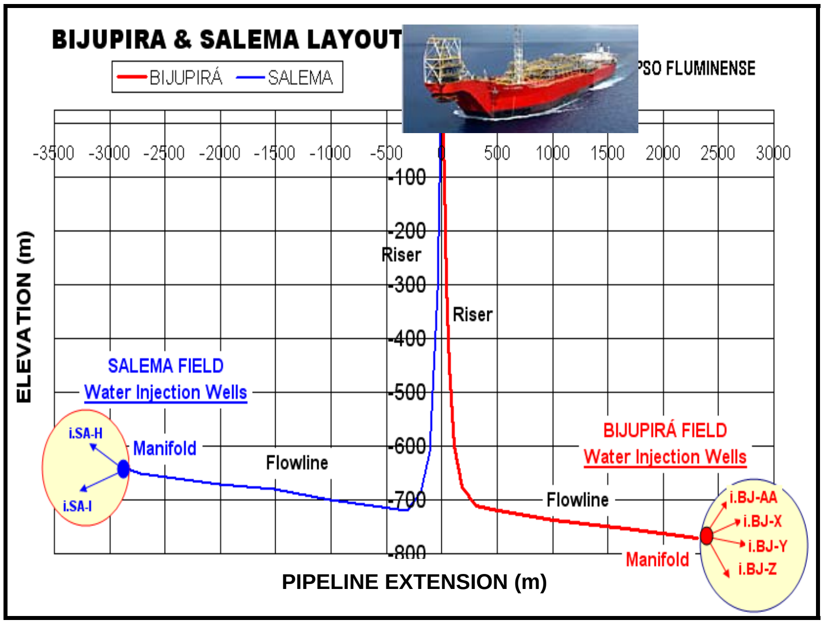

Figure 3. Bijupirá and Salema water injection system

Table 1 provides dimensions and properties of the flowlines, risers and jumpers. These informations have been applied to perform the transient analysis model.

Table 1. Piping dimensions and properties

LINE	PARAMETER	PRODUCTION FIELD	
		BIJUPIRÁ	SALEMA
Flowline/Riser	ID (in)	7.0	4.5
Flowline/Riser	Length (m)	2876	3440
Flowline/Riser	Roughness (mm)	0.005	0.005
Flowline/Riser	Modulus of Elasticity (PSI)	2,000,403.00	1,900,919.00
Jumper Piping	ID (in)	4.5	4.5
Jumper Piping	Length (m)	45	45
Jumper Piping	Roughness (mm)	0.005	0.005
Jumper Piping	Modulus of Elasticity (PSI)	29,000,000.00	29,000,000.00

The average operating conditions of September 2006, was used to validate the simulation analysis model. Validation consists in one of the most important procedures in computational modeling; i.e., it means compare the model results against the measured data by adjusting the model parameters in order to get the best approach between the model and the field data. In this sense, the pressure behavior and flow rates in the pipelines have been evaluated.

Table 2 shows the injection pressures, the water injection flow rates and the jumper velocities.

Table 2. Flow rates and Injection pressures

OPERATING DATA	UNIT	BIJUPIRÁ FIELD				SALEMA FIELD	
		I.BJ-AA	I.BJ-X	I.BJ-Y	I.BJ-Z	I.SA-H	I.SA-I
Injection pressure (Piezometric pressure)	Bar	247	192	268	276	180	222
	(PSI)	3,582	2,785	3,887	4,003	2,611	3,220
Flow rate to well	m^3/day	960	993	4,360	1,308	3,451	1,131
	Bbl/day	6,040	6,246	27,425	8,228	21,706	7,113
Jumper diameter	inch	4.5	4.5	4.5	4.5	4.5	4.5
Jumper velocity	m/s	1.08	1.12	4.92	1.48	3.89	1.28
Flow rate to field	m^3/day	7,622				4,582	
	Bbl/day	47,940				28,819	
Flowline and Riser diameter	inch	7.0				4.5	
Flowline and Riser velocity	m/s	3.55				5.17	

Transient flows basic concepts

Valve operation, the starting and stopping of pumps, and other events may provide alterations in liquid flow velocities causing transients. During a transient event, the kinetic energy of a flow is converted to pressure energy due to a reduction in the flow velocity. Considering a valve closing and the resulting pressure wave that propagates up and down the pipe, the maximum pressure change occurs at the location of the disturbance and is given by the Joukowsky equation[4].

$$\Delta H = \frac{a}{g} \cdot \Delta v$$

$$a = \sqrt{\frac{1}{\rho\left(\frac{1}{k} + \frac{d \cdot \phi}{t.E}\right)}}$$

Pressure changes due to disturbances are classified as three distinct types dependent upon the relationship between the time taken for the change in flow velocity to be complete, T, (e.g. closure time of valve) and the pipeline period, 2L/a, (i.e. the time for a pressure wave to propagate to a point of reflection and return).

RAPID EVENT

$$T \leq \frac{2L}{a}$$

A rapid event is one in which the change in the flow occurs in less than one pipeline period. The magnitude of the resulting maximum pressure change is given by the Joukowsky equation[4]. The pipeline should be simulated as an elastic pipe model.

SLOW EVENT

$$\frac{2L}{a} \leq T \leq 500\frac{2L}{a}$$

A slow event is one in which the change in flow occurs between 1 and 500 pipeline periods. For "slow" events the maximum pressure change is a proportion of the full pressure change predicted for a rapid event. In the case of flow changes which occur in 2-3 pipeline periods the pressure reduction is negligible. For events of greater than 10 x (2L/a) it may be appropriate to assume rigid column behavior and use the rigid pipe model.

VERY SLOW EVENT

$$T \leq 500\frac{2L}{a}$$

A very slow event is one in which the change in flow occurs in a time greater than 500 pipeline periods. For these events the magnitude of the maximum pressure change is proportional to the rate of change of flow velocity and independent of wave speed. Consideration should be given to use the rigid pipe model.

Conceptual Model

Each field is joined to FPSO Fluminense through an injection line. There are four water injection wells at BIJUPIRÁ and two at SALEMA. The water injection well systems are compounded of one choke used to control the injection rate, and two valves - wing and a master valve - to close the injection wells.

Figure 4 shows a scheme to represent the network of the water injection system in BIJUPIRA e SALEMA fields.

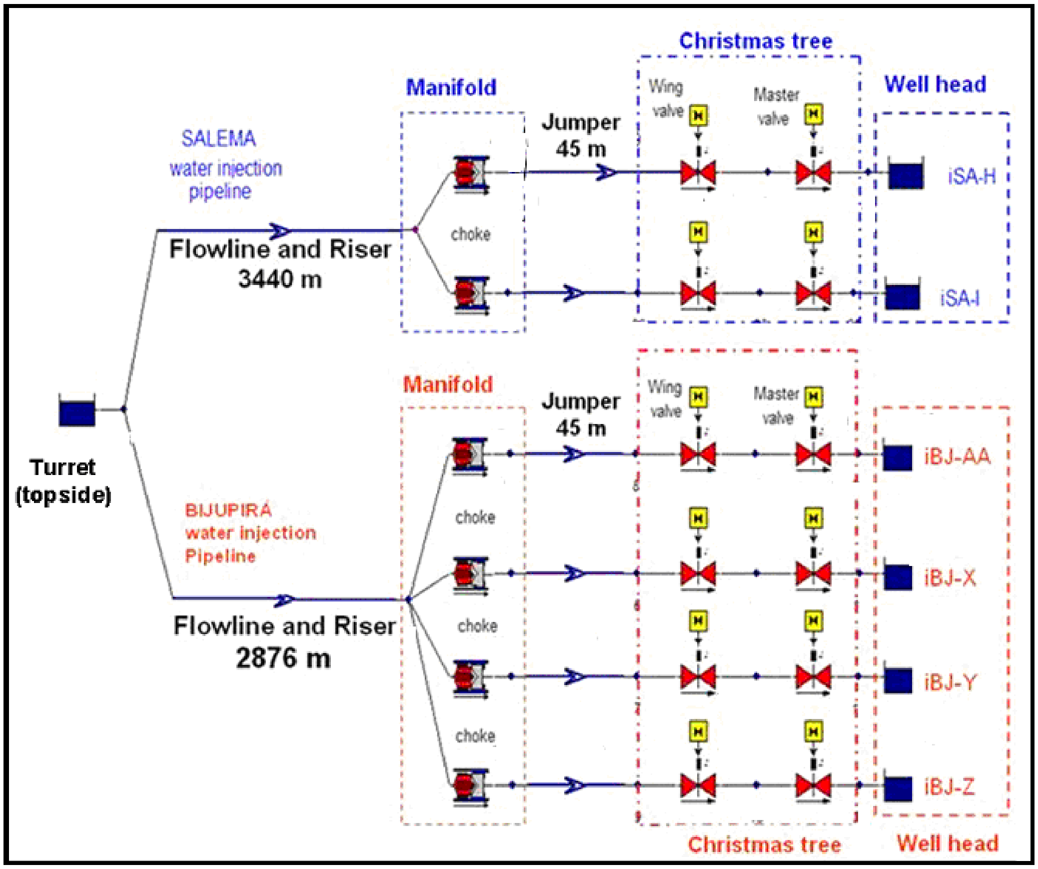

Figure 4. Conceptual Simulation Model

The conceptual model has been performed according to the available field data and the basic assumptions on transient analysis. All the main features of the network have been considered in the simulations. Flowline and riser systems have been simulated as elastic pipe model due to their great extension, while jumpers have been modeled as rigid pipe model.

Analyses development

The first analyzed scenario was related to the closure of one well on Salema, which led to a surge pressure of 261 bar. When closing two wells simultaneously at Salema the surge pressure reached 282 bar, which represented the highest simulated surge pressure.

Related to the Bijupira scenarios, the simulation of closing one, two and three simultaneous wells led to the following surge pressures: 246 bar, 253 bar and 259 bar, respectively.

When closing all wells at Bijupira the surge pressure reached 265 bar, which, is still less than closing all wells at Salema. This may be explained by the Joukowisky equation once the flow velocity in the Salema water injection line (5.17 m/s) is higher than that at Bijupira (3.1 m/s).

Even though all valves at Salema and all valves at Bijupira are closed at the same time the simulation shows that the surge pressures are 282 and 265 bar, respectively. There is no influence of the surge pressure from one set of wells upon the other. The main reason is the pressure control from turret, which maintains the operating pressure constant.

Figure 5 presents comparisons between the design pressure and resultant surge pressure for all analyzed scenarios.

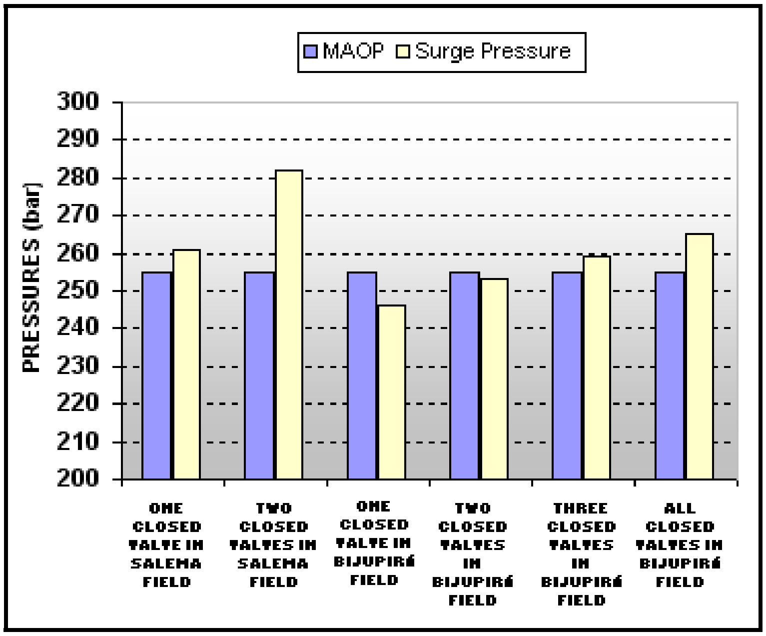

Figure 5. Pressure profiles for all scenarios

Modelling results indicated that the worst condition was obseved in Salema Field, due to higher flow rates wells. Therefore, when all wells are closed, the higher flux velocities will provide surge pressures which will surpass the design pressure. Similar scenarios occurring frequently may cause to the system dangerous consequencies as resonance frequencies due to changes in liquid flow velocities; this may cause fatigue process, and consequently commit the integrity of the pipeline structural system.

Supplementary simulation

For calibration purposes it has been applied the average value of both, flow rates and pressures related to the two periods, as per the following, June 2006 and August 2006 were applied. Based on these periods, the surge pressure reached 264 bar when the valve on the Salema - H (i.SA-H - water injection at Salema H well) has been rapidly closed, therefore higher than the Maximum Allowable Pressure (255 bar).

To keep the eventual hydraulic transient pressure below the design pressure (255 bar) the following operation conditions were simulated:

- When the turret (topside) pressure is 230 bar the allowable injection flow rate is 12000 bbl/day. For 240 bar at the turret the allowable flow rate drops to 7000 bbl/day.

- If the turret pressure is 217 bar, the simulation shows that for a flow rate of 20000 bbl/day the manifold pressure will be 255 bar.

- If the turret pressure is 210 bar, the simulation shows that for a flow rate of 25000 bbl/day the manifold pressure will be 255 bar.

Another set of simulations has been developed taking into account the smallest pressure at the turret. In this sense turret pressures of 217 bar and 210 bar were considered which result in 20000 bbl/day and 25000 bbl/day, respectively, for a maximum allowable pressure of 255 bar at the manifold.

Table 3 shows the simulation results for each case evaluated.

Table 3. Injection flow rate within Maximum Allowable Pressure

Salema – H			
Turret Pressure (bar) / (psi)	**MAOP (bar) / (psi)**	**Local**	**Maximum Water Injection Flow Rate for MAOP (bbl/day) / (m^3/s)**
230 / 3336	255 / 3698	Manifold	12000 / 0.0221
240 / 3481	255 / 3698	Manifold	7000 / 0.0129
217 / 3147	255 / 3698	Manifold	20000 / 0.0368
210 / 3046	255 / 3698	Manifold	25000 / 0.0460

Conclusions

In order to avoid surge pressures in Salema and Bijupirá fields greater than MAOP, which corresponds to 255 bar, the simulations indicated that when a pressure of 230 bar occurs on the turret, injection rate should be less than 12000 bbl/day. The simulation model applied to Bijupirá and Salema water injection systems was consistent with the operational data, and water injection procedure was effective in increasing oil production levels. Results showed that the water injection flow rate can be significantly increased when the topside pressure is reduced. It should be also remarked that every flow circuit has to be checked for potential fluid transients. Advanced transient computational models, when properly validated, may provide mechanisms to improve the operational pipelines systems efficiency, and identify susceptible failures due to transient effects throughout pipeline systems.

Acknowledgements

The authors would like to thank the managements of SHELL Brazil and the indispensable contribution to perform the transient analyses.

Nomenclature

ΔH = Magnitude of the head rise (m)
v = Flow velocity (m/s)
a = Wave speedy (m/s)
g = Gravitational acceleration (m/s^2)
ρ = Liquid density (kg/m3)
k=- Bulk modulus the liquid (N/m^2)
Φ = Pipe restraint factor
t= Pipe wall thickness (m)
E = Young's Modulus/ pipe (N/m^2)
T = Pipeline period (sec)
L = Pipeline length (m)
MAOP = Maximum Alowable Operational Pressure
FPSO = Floating, Production, Storage and Offloading

References

1. Davalath, J. and Hurtado, M, FMC Kongsberg Subsea, Keig, R., "Flow Assurance Management for Bijupirá and Salema Field Development", OTC 14052, Offshore Technology Conference, Houston, TX, May 6-9, 2002.
2. Davalath, J. and Patni S., FMC Kongsberg Subsea, Chen T., Shell Int´l E & P, Bryson B., Shell Brazil, "Bijupira Salema : Flow Assurance Analysis to support Operating Strategy", OTC 16692, Offshore technology Conference, Houston, TX, May 3-6, 2004.
3. Miller, D. S., "Internal Flow Systems", 2nd ed, BHRA, 1990.
4. Kossatz, H., Ladeia, R., C., C., "Reflection and dampening of pressure waves in marine terminal pressure surge analysis", IBP1074_05, Rio Pipeline Conference and Exposition, 2005.
5. DNV OS F101, "Submarine Pipeline Systems", 2007.
6. FLOWMASTER Manual, Version 7.4.1.
7. API RP 17 B, "Recommended Practice for Flexible Pipe", 2002.
8. VUUREN, S. J., "Theoretical Overview of Surge Analyses", University of Pretoria, 2001.

Metric

10^5 Pa = 1 Bar = 14.5038 PSI (lbf/in^2)
1.84013e^{-6} m/s = 1 bbl/day
1 m = 39.3701 inches