The Problem of Inert-Gas Venting on FPSOs and a Straightforward Solution

D. de Vos and M. Duddy, Single Buoy Moorings, and J. Bronneburg, Gusto MSC

Abstract

As an FPSO continually loads stabilised crude oil to the cargo tanks, the inert gas (IG) blanket within the tanks is compressed. At a certain pressure, below that which could cause damage to the vessel structure, this mixture of now IG and volatile organic compounds (VOC’s), emanated from the loaded crude, has to be vented safely to atmosphere, by some means.

From the very first FPSO that Single Buoy Moorings operated, the FPSO II in 1980, errant inert gas (IG) has resulted in a number of emergency shut downs (ESD’s) whilst venting the cargo tanks during calm weather. With no wind to disperse the heavier-than-air gas, the result is the mixture falling onto the vessel main deck or the process modules, triggering the FPSO gas detection system and subsequently causing an ESD.

The cost due to loss or delay of production in this manner can quickly become considerable. More importantly, whilst venting the cargo tanks, personnel are relocated to a safe area to ensure their safety and any hot-work being undertaken is postponed. Crane and helicopter operations are also suspended. There is, of course, a cost associated with the loss of personnel productivity during these events.

To prevent reoccurrence of IG venting related incidents, a number of operational measures are used. These usually consist of:

- delaying venting during low wind periods (<2ms⁻¹)
- employing the downstream vent mast (if two are fitted, one either side of the vessel)
- monitoring the lower explosive limit (LEL) via the gas detection system. As a high LEL is attained (usually around 40%) venting is stopped until the gas has been dispersed. Typically, the alarm is activated at 20% LEL and the executive action, in this case an ESD, is set at 60% LEL.

With FPSO’s becoming larger, production rates correspondingly so – sometimes over 300,000 bbls/day – the financial penalties resulting from an unplanned shutdown are even more significant. Although using operational means can be a successful way of mitigating against both the safety and production risks associated with IG venting, a system that would obviate the need for such procedures has been sought by SBM since their first operating FPSO, over 25 years ago. This paper describes the evolution of the inert gas arrangements onboard SBM’s units, past and present systems that have been employed with varying degrees of success and the recent (July 2005) retrofit of an IG eductor to two SBM FPSO’s operating West of Africa. The details of the patented IG eductor, from conception, design, safety studies, construction, installation and operational success are also presented.

Introduction

Many of the problems associated with IG venting can be attributed to the design of the IG facilities being a copy of those employed onboard crude oil and product tankers. This was an affliction of a number of early North Sea FPSO’s, necessitating expensive reparation offshore once the unit was operating. Typical difficulties encountered were:

- insufficient isolation to allow safe tank entry
- a poorly located vent mast, dispersing IG and VOC’s onto the process area during IG venting
- pressure vacuum (PV) breakers being installed on every tank
- inadequately located and sized PV breakers, that on losing the liquid seal cause a gas release and eventual ESD
- offshore personnel being unfamiliar with a marine system
- the capability of isolating a cargo tank and the subsequent possibility of over or under pressurising the vessel structure

With subsequent FPSO’s, more attention was paid to this critical system in the design and the construction phases and how it was to be operated.

IG System Evolution within the SBM Fleet

Kuito FPSO, which began operation in 1999, had a vastly improved IG layout compared to that of FPSO II and was the
result of 20 years of SBM Fleet experience. It contains characteristics that the most recent SBM FPSO designs still feature.
The P&ID for the *Kuito FPSO* IG system is shown in Figure 1. This configuration consists of two headers, namely supply and vent, with each header connected to every cargo tank. There are two vent masts, one either side of the vessel – *Kuito FPSO* is spread moored – providing redundancy if maintenance is required to the pipework of either of the main headers. Each header and vent mast has the necessary capacity to allow the FPSO to remain in operation without the other header. Both vent masts are equipped with high velocity (HV) valves and purging/ gas freeing covers. The HV valves discharge cargo tank vapour at a velocity greater than 30ms⁻¹, this being above the velocity that a flame front would travel at if the gas plume was ignited. In fact, the HV valves have a variable discharge rate, dependent on the available pressure within the cargo tanks, but this is always above the critical 30ms⁻¹ limit. The gas freeing/ purging covers have a considerably lower discharge velocity, approximately 23ms⁻¹, increasing the opportunity of gas returning to the FPSO in still weather conditions. A screen prevents a flame from entering the cargo tank via the gas freeing/ purging cover. Purging a cargo tank is the interlock, which exists between the valves on the supply header and the tank cannot be damaged by over or under pressure.

When entry to a cargo tank is necessary, however, both headers must be in operation as one is used to supply clean (hydrocarbon free) IG to the tank that is to be entered (TTBE), while the other is used to vent off the other tanks and the displaced vapours from the TTBE. Double valves, linked together, are used on each branch. An important safety feature is the interlock, which exists between the valves on the supply branch and those on the vent branch on each tank. This ensures that there is always a path to the venting system via the header and the tank cannot be damaged by over or under pressure.

The venting system on each mast consists of a remote controlled butterfly valve and an HV valve set at a low opening pressure (500 mmWG) in series to allow controlled release. A second HV valve at a higher opening pressure (1700 mmWG) is provided as redundancy if there is a failure of the low opening setting HV valve or if the operator fails to vent the tanks sufficiently. Two vacuum valves (-250 mmWG) are provided on each header in case a tank does encounter an over or under pressure, while as a final measure, a water filled pressure-vacuum (PV) breaker (2400 mmWG, -600 mmWG) if there are multiple valve failures. Although superior to that of the *FPSO II*, limitations of the system as shown are:

- if a slip spade is inserted in the incorrect location or inadvertently left in place, the possibility exists for over pressurising or under pressurising the tank when the tank is returned to service
- neglecting to insert a slip spade could allow migration of flammable vapour from another tank to enter the gas freed tank

Vast improvements in computation fluid dynamic (CFD) analysis over the last 20 years have assisted, during the design phase, in sizing and locating the vent masts. A smoke and gas dispersion study is undertaken at the early stages of a project and this can predict whether there will be difficulties in IG venting or during the purging cycle of a tank entry operation. Consistently, the studies have shown that during tank venting or purging in low wind conditions (<2ms⁻¹), vapour can fall back onto the vessel main deck and production facilities. Raising the height of the vent masts allows undisturbed wind flow, and the *Kuito FPSO* had this modification late in the construction phase, as shown in Figure 2. Originally the masts were 15.6m in height, and were extended to 18.6m. Due to the large modules required for increased production rates, the minimum height for a vent mast in the SBM fleet is now 18m.

Ostensibly, safety studies ensure that escapeways, lifeboats, helidecks and safe refuges are not impaired in the event of a major incident, and ‘obvious’ operational clashes are sometimes not noticed, such as that shown in Figure 3.

The port vent mast is only 10m from the intakes of the 2 x 13MW gas injection compressors. This placement renders the vent mast inoperable.

For the sistership of the *FPSO Falcon*, *FPSO Serpentina*, the port vent mast was situated forward of the gas compressor. In addition, to enable venting in low wind conditions, an HV valve was situated at main deck level, followed by an in-line flame arrestor before the pipework was led overboard and 3m below the level of the main deck. The arrangement is shown in Figure 4, and was the first time a method such as this has been used, requiring approval from the Classification Society. In practice, a flexible duct was attached to the end of the pipe to distribute the vented gas at sea level. Even when employing this system, it was found that when the wind velocity was low, gas could still quickly migrate back onto the vessel causing an ESD. It had become evident that the overboard dump was not a remedy to the problem of inert gas venting.

At this time, *FPSO Falcon* was producing 120,000 bbls/day while *FPSO Serpentina* was producing around 110,000 bbls/day. This is comparable to the 100,000 bbls/day that will be produced by the *FPSO Capixaba* when installed in the Campos Basin in March 2006, and other FPSO’s/ FSO’s in the SBM fleet as shown in Figure 5.

Figure 6 shows the arrangement of the *FPSO Capixaba* IG system. The few differences from the *FPSO Falcon* and *FPSO Serpentina* arrangement are as follows:

- the double valves have been replaced by single valves with a painted and polished disc and Viton seals. On both
**FPSO Falcon** and **FPSO Serpentina**, all of the IG valves failed due to torn seats. The unprotected valve discs pitted and were a contributory factor. Also, the linking mechanism between the valves was troublesome, with one valve closing prior to the other.

- the test facility between the double valves has been removed
- the carbon steel spectacle blinds have been replaced by lighter and easier to swing Tufnol

On most SBM Vessels, IG systems have the spectacle blind next to the downstream valve, but interfaces with the pressurized. On the supply header, the spectacle blind does not cargo tank would then be in danger of being over or under closed and the valves on the supply branch being closed. The avoid the vent valve(s) being open, the vent spade being open position, the spade must be too. This is necessary to against the downstream valve so that when the valve is in the open position, the spade must be too. This is necessary to avoid the vent valve(s) being open, the vent spade being closed and the valves on the supply branch being closed. The cargo tank would then be in danger of being over or under pressurised. On the supply header, the spectacle blind does not rest next to the downstream valve, but interfaces with the cargo tank lid, so that when the spade is closed, the cargo tank hatch must be in an open position. In this way, the tank is able to ‘breathe’ and is positively isolated for safe personnel entry.

Throughout the evolution of the IG system, subsequent SBM vessels maintained the twin vent mast arrangement for disposal of IG, since FPSO II, and therefore all the associated shortfalls too.

**Available methods for dealing with IG and VOC’s**

Tank venting is a difficulty all FPSO operators encounter and today a number of solutions are available on the market place. Mostly, these involve a system of gathering the VOC’s, processing and then reincorporating them into the cargo tanks. Unfortunately, these systems are large (sometimes requiring a complete new module), complex (using delicate machinery) and operationally intensive. As a result, they are expensive in terms of capital expenditure (CAPEX), maintenance and operator time. If an FPSO did have the available deck space to install such a system, the production shutdown time required to effect the necessary piping and instrument changes would be onerous.

**Options Investigated within SBM to Safely Vent IG**

As well as exploring the available options for dealing with IG proposed by external companies, SBM earnestly began creating their own designs. This creativity being fuelled by the increase in production rates of existing FPSO’s, and the requirement for large FPSO’s with a production capacity greater than 250,000 bbls/day. Some schemes drew from knowledge gleaned from the oil and gas industry, while others were quite radical.

**Incorporation into the gas compression system**

Investigations were undertaken to understand if the IG/ VOC mixture could be led to the suction of the booster compressor before feeding it forward to the main gas compression system. The booster (or flash gas) compressor normally takes low-pressure (LP) gas from the LP separator vessel and raises it to the pressure of the high-pressure (HP) separator. This gas is then led to the suction of the main gas compressor train, and after further compression is re-injected to the well, used for gas-lift purposes or exported to shore for sale.

After some effort, it was found that this option was not feasible for a number of reasons:

- difficulty in sourcing a booster compressor that could operate on the low suction pressure that would be available from the IG system – typically between 500 mmWG and 1500 mmWG (0.5 and 1.5barg)
- the variations in the molecular weight and properties of the IG/ VOC mixture caused operating problems for the main (centrifugal) gas compression train – examples of IG consistencies due to different process conditions are shown in Figure 7. The composition of the IG will also vary considerably when the cargo tanks are empty (mostly IG) and when they are almost full (mostly HC)
- gas from the well is used as fuel gas to drive the FPSO main power generators, water injection pumps, boilers and gas compressors as well as being used in the gas dehydration process. The Nitrogen (N2) and Carbon Dioxide (CO2) components within the IG/ VOC mixture were detrimental to the operation of the gas turbines
- the high CO2 content of the IG plus the large amount of moisture caused concerns with material suitability in the gas compression train – rendering a retrofit to an existing FPSO impossible (or very expensive)

In order to circumvent the above problems, a quite different approach was used.

**Using Fuel Gas instead of IG**

Most of SBM’s vessels use the boilers in the engineroom, burning LP fuel gas, to generate IG. The exceptions are *Kuito FPSO* and *FSO Oguzhan*, which use a dedicated IG generator mounted on a process module, again operating on LP fuel gas. As an alternative to using a non-combustible IG mixture with an Oxygen (O2) content of less than 5%, blanketing the cargo tanks with fuel gas to give an over rich, non-combustible atmosphere was studied. This mixture could then be brought to the booster compressor suction as described in the previous section. Although most of the problems associated with compressing IG are now not applicable, a few still exist:

- difficulty in sourcing a booster compressor that could operate on the low suction pressure that would be available from the IG system
- operational problems associated with having a potentially combustible gas in the cargo tanks compared to an inert atmosphere
Using fuel gas as an alternative to IG should not be discredited as there are numerous financial and operation advantages in implementing such a system. However, it is a topic that would benefit from a greater discussion, but is a little too large to be satisfactorily detailed in this missive and perhaps merits a paper in its own right.

**Air dilution within the vent masts**

A Graduate Engineer within SBM proposed that by adding air to the vent masts prior to discharging the IG, the velocity of the ejected plume would be increased, the dilution effect improved, and the probability of HC gas dropping back onto the LP flare reduced.

An air-powered fan would be installed in both of the cargo vent masts, drawing in air from a duct that encloses the mast and discharging the mixture (35:1 of air:IG) of gas at a high velocity. This arrangement, although requiring two fans (and possibly mixers) has a number of advantages but was not pursued further in preference of the solution discussed later.

**Disposal via the flare system**

The flare system on a production plant is the safety scheme with the highest integrity. When there is an unplanned process event, such as a gas compressor suddenly stopping, the gas that was being injected into the well now cannot be and has to be vented and safely disposed of. SBM FPSO’s have separate LP and HP flare systems and the intention was to vent the cargo tanks via the low-pressure arrangement, as this had the lowest operating pressure.

On most FPSO’s, the LP flare has an operating pressure of around 1.8 bar(g). This is higher than that available in the cargo tanks – the high pressure vent being set at 1700 mmWG and the PV breaker being set at 2400 mmWG – making a direct connection between the cargo tanks and the flare system impractical.

A method of boosting the pressure of the inert gas to overcome the back-pressure within the LP flare system was needed.

An adaptation of the inert gas fans used to supply the cargo tanks and the APL VOC recovery system was initially investigated, and took the form of an electrically driven Roots blower connected to both of the inert gas headers and to the LP flare.

As well as being expensive (~500k USD for just the compressor), complex and requiring intensive maintenance, this solution had a number of other drawbacks:

- a gas-tight double-sealing arrangement around the shaft of the blower
- materials of construction. Bronze or Duplex stainless steel being required
- an inlet scrubber to protect the positive displacement machine. A 2 stage centrifugal machine was investigated as an alternative, but due to its low stiffness, ensuring a gas-tight seal at the shaft was very difficult
- sound enclosure to limit the noise levels below 85 dB (A)

At the same time, SBM had also been enquiring whether the booster compressor in the gas compression train could be replaced by an eductor driven from the main gas compressors. The main disadvantage is that the eductor, although very cost effective compared to a screw compressor, is very inefficient and requires a large increase in the power of the main gas compressors. It is for this last reason that SBM did not pursue this possibility, but adapted it for service in the IG system.

**Vent gas eductor**

Eductors have been used on cargo vessels for many years, from stripping cargo tanks to priming pumps. They are simple, virtually maintenance free and cheap.

Instead of using a machine to increase the pressure of the IG so that it could be injected into the LP flare, an eductor with a suitable motive fluid was employed instead.

As mentioned previously, SBM vessels use boilers to generate power, IG, water and provide heating to the production plant. Steam is also used to drive the cargo pumps (used when offloading the FPSO), deck machinery and tank preservation dehumidifiers. Being available via already installed pipework and having excess capacity, steam was the ideal choice as the driving liquid to power the eductor. It is almost a free commodity on an FPSO, as it is generated using low-pressure gas from the well. Care must be taken to ensure an adequate level in the low-pressure steam generator (LPSG) and that the correct water treatment is maintained.

There will be an expense due to the loss of the treatment chemicals, but this is very minor. A typical SBM FPSO will have three freshwater generators (evaporators) of 50m³/day each, with one intended as a spare, and the additional load of the eductor does not cause the redundant evaporator to be brought into service. The eductor would be used intermittently, only when low wind speed would make conventional venting via the masts difficult, and the total amount of water used would be less than 12 tonnes per day.

A PFD of the steam driven eductor is shown in Figure 8. SBM designed an eductor driven IG venting system, initially destined for the FPSO Marlim Sul, as an import of 75,000 bbls/day is possible from the production platform, P40. Although never fitted prior to sailaway from the conversion yard (the import from P40 was reduced to an intermittent 40,000 bbls/day), a mature design was achieved, and an area reserved on the Vessel to place the skid. Piping spools were modified during the construction phase to allow easier integration if the equipment is retrofitted while the vessel is in operation.

In the engineering office, additional safety studies and design reviews were conducted and Classification Society Approval later obtained.

The P&ID of the eductor system is shown in Figure 9, isometric views in Figure 10 and some details in Figure 11. Some areas of interest, resulting from the engineering effort are described as follows:

- a corrosion coupon upstream of the connection to the flare header to monitor the corrosion rate in the flare system resulting from eductor use. The gas is wet, hot and laden with CO₂ and corrosion in the flare pipework was a concern
• a removable spool to inspect for corrosion upstream of the flare connection. Locked open (LO) valves and a spectacle blind are provided for isolation during this task. Corrosion rates were calculated according to NORSOK standards at 0.57mm/year
• a pressure indicator is present in the driving steam line to ensure that there is motive flow prior to opening the suction from the IG headers.
• 2 high integrity non-return valves (NRV’s) are provided to ensure no backflow of gas to the LP SG in the engineroom
• an interlock is provided to prevent a connection between the deck seal of the IG system and the eductor.
• venting via the eductor is not permitted during offloading or purging
• purge and drain points provided for maintenance
• a low low (LL) and high high (HH) pressure trip on the gas been drawn from the cargo tanks. The LL pressure trip at 300 mmWG ensures that the vacuum valves and the PV breaker on the IG headers do not operate, allowing air into the cargo tanks and the possibility of reaching the flare via the eductor

Although designed for FPSO Marlim Sul, later events conspired to have the eductor installed on both FPSO Falcon and FPSO Serpentina in June and July 2005.

**FPSO Falcon Volume Improvement Project**

Beginning production in December 2002, FPSO Falcon was originally envisaged as an Early Production System (EPS) to serve on the Yoho Field offshore Nigeria for 2.5 years. Her design production capacity being 90,000 bbls/day, she was debottlenecked in 2003 to provide 120,000 bbls/day. Due to the late arrival of the production platform that is to replace her at the Yoho field, the Client requisitioned an engineering effort to establish the possible capacity of the FPSO. By splitting the 3 stage process train (HP, IP and LP) into two separate trains, using the test separator in an HP mode, and by tying in two other platforms via a subsea manifold, production capacity was increased by an additional 45,000 bbls/day.

With the extra production capacity and the high relative vapour pressure (RVP), Yoho crude necessitated a method of disposing of the inevitable vented IG and VOC’s from the cargo tanks.

The eductor was installed, mostly prior to the actual shutdown of the process plant, on the piperack adjacent to the central walkway. The FPSO Falcon has a 7m wide piperack and this available space was used instead of a modular format. Tie-in to the LP flare header, upstream of the LP flare KO drum was performed during the shutdown, but all other work was completed while the vessel was producing.

Approximately 14 days of pre-shutdown work was required for the eductor system, while during the shutdown itself, 1 day was necessary to complete the connection to the LP flare.

The P&ID for the FPSO Falcon eductor is shown in Figure 12.

A number of differences exist between this arrangement and that originally intended for the FPSO Marlim Sul.

These are summarised as follows:
• the driving medium is gas from the HP (previously test) separator, instead of steam. The increase in production brought the gas produced above the compression capacity (100Mscf/day) of the FPSO and therefore gas (43Mscf/day) would be constantly flared. Therefore the decision was made to use the gas that would be disposed of to power the eductor. As a back-up in case the test separator train is shutdown, gas from the HP separator can also be directed to the eductor.
• a shutdown valve (SDV) is incorporated in the driving gas stream
• a permissive has been added to the SDV on the vent gas from the cargo tanks to only allow opening once pressure is detected in the motive gas stream from the HP separator
• an electronic interlock between the SDV on the vent from the cargo tanks and the SDV after the non-return valve on the main IG supply header. This prevents the SDV in the line from the cargo tanks to the eductor opening if the main IG supply header SDV is open.
• a silencer is provided after the eductor to limit the noise levels below 85 dB (A) and both are acoustically insulated
• a fail-closed (FC) pressure control valve (PCV) is provided in the driving gas from the HP separator to provide capacity control of the eductor. The PCV can be automatically or manually controlled to match the rate of evolved gas from the cargo tanks
• single NRV’s are installed in both lines to the eductor
• the tie-in to the LP flare system is upstream of the LP flare KO drum. On the FPSO Marlim Sul design, the connection was after the LP flare KO drum and the meters
• the pressure class of the pipework has been increased to ANSI #300
• the eductor nozzle is constructed from stainless steel

At the time of writing this paper, the eductor has been functioning successfully for over 6 months.

**FPSO Serpentina import from FPSO Zafiro Producer**

The FPSO Serpentina has been producing 110,000 bbls/day since May 2003 on the Zafiro Field offshore Equatorial Guinea. Although originally designed to accept importation of stabilised crude oil of up to 180,000 bbls/day from the FPSO Zafiro Producer, a change in the crude quantity and quality from the ZP required the installation of a vent eductor. The import was enlarged to 210,000 bbls/day and the RVP of the ‘stabilised’ crude increased to 22 psi, in cases of a process upset on the ZP. Evidently, the FPSO Serpentina would be venting for 9 hours per day from her IG masts, in comparison to the 5 hours before the import. Critically, production would have to stop when approaching the full capacity of the tanks during an electrical storm, as it would be impossible to vent the tanks.
Similarly to her sistership, the FPSO Falcon, the FPSO Serpentina has a large central piperrack and walkway suitable for installing the eductor. The arrangement is similar to that of the FPSO Falcon, with gas from the original HP separator being used as the driving medium.

A shutdown was already planned to allow the pulling-in of the import line from the ZP, and it was at this time the installation of the eductor took place. One day was necessary to connect upstream of the LP flare KO drum and the original shutdown schedule was unaltered. 10 extra personnel were onboard to perform this work, and 20 days were spent in pre-installation preparation for the shutdown.

The P&ID of the eductor on the FPSO Serpentina is shown in Figure 15. This installation differs to that of the FPSO Falcon in the following manner:

- the high CO₂ content and the high pressure of the produced gas (HP separator) necessitates that the pipework to the eductor, and the gas nozzle of the eductor itself, are fabricated from Super Duplex Stainless Steel
- in some cases, the low LP flare pressure allows the cargo tanks to vent without the assistance of the eductor
- the pipework and the eductor are ANSI #150 rated

Originally designed to vent the IG/VOC’s of the cargo tanks when the wind velocity was insufficient to disperse the gas from the masts, the eductor is in constant use onboard the FPSO Serpentina. After adjusting the setting of the PCV to control the driving gas, the system can be left to continually boost the cargo tank gas to the LP flare. In fact, the standard mode of operation for the eductor is to let the cargo tank gases vent automatically to the LP flare without the use of the motive gas from the HP separator.

**Summary**

Operation of the cargo vent eductor is a simple and effective way of disposing of IG and VOC’s from the vessel tanks. Being of compact size (3350 x 1500 x 2400 mm) and a low weight (less than 4000 kg) it can be installed on an FPSO under construction or already operating, without constructing a new module and is easily transportable. The small capital expenditure ~75k USD –when installed in the fabrication yard) is returned if one ESD is prevented – it was calculated that FPSO Serpentina would have suffered a full day of lost production per year if she were not equipped with the eductor. Other activities, previously postponed during tank venting by conventional means, can continue and this has contributed to both FPSO Falcon and FPSO Serpentina achieving operational availabilities of 99.8% and 99.7%, respectively. Flexibility in the design allows numerous possibilities for incorporating the cargo tank gas into the process gas stream, without large and expensive VOC recovery units.

**Acknowledgements**

The activities of the companies in the SBM Offshore group include the design and supply of floating offshore systems including FSO’s, FPSO’s and TLP’s. A large number of FPSO’s and FSO’s are owned by the group and leased to oil companies on long-term contracts. In addition to the design, construction, installation and operating activities for FPSO’s and FSO’s, the group also designs drillships, jack-ups, semi-submersible drilling rigs, crane vessels, etc.

Thanks to the engineering efforts of those at Gusto MSC who brought the original concept to fruition, to SBM-Imodco who designed the installed systems on both FPSO Falcon and FPSO Serpentina, to all the personnel of SBM who contributed in the early stages of the design and to the Clients who believed in the idea.

**References**

2. ES47110 DFV92051 X1 FPSO Falcon Vessel Inert Gas system PFD. SBM-Imodco, 22nd July 2005.
Figure 1. *Kuito FPSO IG System P&ID*
Figure 2. *Kuito FPSO* mast extensions

Figure 3. *FPSO Falcon* port mast next to gas compressor intake
Figure 4. FPSO Serpentina IG system PFD (before eductor installation)
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<td>FSO Yetagun **</td>
<td>2000</td>
<td>16,000 – 2,540</td>
<td>16,000 – 2,540</td>
<td>11,600 – 1,840</td>
</tr>
<tr>
<td>FSO Okha</td>
<td>1999</td>
<td>90,000 – 14,300</td>
<td>90,000 – 14,300</td>
<td>80,000 – 12,720</td>
</tr>
</tbody>
</table>

* Hydrogen Sulphide gas (H₂S) present
† Capacity increased as part of the Volume Improvement Project in July 2004
‡ Includes 180,000 bbls/day import from FPSO Zafiro Producer
‖ Includes 40,000 bbls/day import from P40
** Crude contains benzene

Figure 5. SBM Fleet Production Capacities
Figure 6. FPSO Capixaba IG system design PFD

<table>
<thead>
<tr>
<th>Component</th>
<th>Low Arrival Temp. Case (35°C)</th>
<th>High Arrival Temp. Case (67°C)</th>
<th>Liquid Density (g/cm³)</th>
<th>Molecular Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oxygen</td>
<td>0</td>
<td>0.8</td>
<td>1.1377</td>
<td>32</td>
</tr>
<tr>
<td>Water</td>
<td>5.88</td>
<td>9.28</td>
<td>0.8006</td>
<td>34.1</td>
</tr>
<tr>
<td>Hydrogen Sulfide</td>
<td>0</td>
<td>0</td>
<td>0.2997</td>
<td>16</td>
</tr>
<tr>
<td>Carbon Dioxide</td>
<td>3.94</td>
<td>6.69</td>
<td>0.3562</td>
<td>30.1</td>
</tr>
<tr>
<td>Nitrogen</td>
<td>0</td>
<td>13.8</td>
<td>0.507</td>
<td>44.1</td>
</tr>
<tr>
<td>Methane</td>
<td>33.41</td>
<td>31.68</td>
<td>0.5629</td>
<td>58.1</td>
</tr>
<tr>
<td>Ethane</td>
<td>11.4</td>
<td>6.73</td>
<td>0.584</td>
<td>58.1</td>
</tr>
<tr>
<td>Propane</td>
<td>22.4</td>
<td>13.41</td>
<td>0.6244</td>
<td>72.2</td>
</tr>
<tr>
<td>I-Butane</td>
<td>4.83</td>
<td>3.29</td>
<td>0.6311</td>
<td>72.2</td>
</tr>
<tr>
<td>N-Butane</td>
<td>10.3</td>
<td>7.41</td>
<td>0.685</td>
<td>84</td>
</tr>
<tr>
<td>I-Pentane</td>
<td>2.87</td>
<td>2.38</td>
<td>0.722</td>
<td>96</td>
</tr>
<tr>
<td>N-Pentane</td>
<td>2.06</td>
<td>1.76</td>
<td>0.745</td>
<td>107</td>
</tr>
<tr>
<td>Hexanes</td>
<td>1.33</td>
<td>1.2</td>
<td>0.764</td>
<td>121</td>
</tr>
<tr>
<td>Heptanes</td>
<td>0.93</td>
<td>0.91</td>
<td>0.778</td>
<td>134</td>
</tr>
<tr>
<td>Octanes</td>
<td>0.47</td>
<td>0.47</td>
<td>0.789</td>
<td>147</td>
</tr>
<tr>
<td>Nonanes</td>
<td>0.11</td>
<td>0.12</td>
<td>0.8</td>
<td>161</td>
</tr>
<tr>
<td>Decanes</td>
<td>0.03</td>
<td>0.04</td>
<td>0.811</td>
<td>175</td>
</tr>
<tr>
<td>Undecanes</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dodecanes</td>
<td>0.01</td>
<td>0.01</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tridecanes +</td>
<td>0</td>
<td>0</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Totals</td>
<td>100</td>
<td>100</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7. Composition of vented IG on FPSO Serpentina
Figure 8. PFD of vent gas eductor (steam driven)

Figure 9. P&ID of IG vent eductor (steam driven)
Figure 10. Isometric layouts of IG vent eductor (steam)

<table>
<thead>
<tr>
<th>Length (mm)</th>
<th>3350</th>
</tr>
</thead>
<tbody>
<tr>
<td>Breadth (mm)</td>
<td>1500</td>
</tr>
<tr>
<td>Height (mm)</td>
<td>2400</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>4000</td>
</tr>
<tr>
<td>Design Pressure (bar(g))</td>
<td>13.5</td>
</tr>
<tr>
<td>Operating Pressure (bar(g))</td>
<td>1.6 (discharge) / 12 (steam)</td>
</tr>
<tr>
<td>Design Temperature (°C)</td>
<td>210</td>
</tr>
<tr>
<td>Operating Temperature (°C)</td>
<td>120 (discharge) / 192 (steam)</td>
</tr>
<tr>
<td>Flow rate (kg/h)</td>
<td>1855 (vent gas) / 963 (steam)</td>
</tr>
<tr>
<td>Materials of Construction</td>
<td>Stainless Steel</td>
</tr>
</tbody>
</table>

Figure 11. General details of the vent eductor (steam)

Figure 12. P&ID of IG vent eductor as installed on FPSO Falcon
Figure 13. IG vent eductor as installed on the FPSO Falcon
Figure 14. IG vent eductor skid prior to installation on the FPSO Serpentina

Figure 15. P&ID of IG vent eductor as installed on FPSO Serpentina