FLOATING PRODUCTION STORAGE AND OFFLOADING UNITS AND TOPSIDE FACILITIES

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SUMMARY

Floating Production Storage Offloading (FPSO) units have been in use since 1970. The first FPSO unit was the Shell Castellon, built in Spain. Currently, about 270 FPSO units are operated around the world and generally used in Brazil, the North Sea, the Mediterranean Sea, and West Africa.

FPSO units are built to remain on location and continue operations during all their service life that is generally more than 20 years. FPSO Units should be properly designed and constructed to provide the prescribed operating life could be managed without any production interruptions.

Topsides of FPSO units have different types of equipment and machinery for production and process. Design and types of equipment selection can be changed depends on location, oil or gas quality, and buyer, etc. In this article, common topside process units are examined and their technical descriptions are made. This study will contribute to the literature by combining incomplete and/or insufficient information on FPSO units and topside facilities.

Keywords: FPSO, FSO, FLNG, FPSO Topside Units.

1. Introduction

FPSO units are built to remain on location and continue operations during tall their service life that is generally more than 20 years. FPSO Units should be properly designed and constructed to provide that the prescribed operating life could be managed without any production interruptions (Metzger, 2010).In the late 1990s, the Texaco Captain FPSO spilled around 3,900 barrels of oil because of the human error. (Rigzone, 2019).

Since late 1990s, the demand for FPSOs and other floating systems has been growing by 10% per annum, and is expected to continue, despite short term slowdowns in oil and gas investment. The future for FPSOs is looking more promising than even a few years ago. The main advantages are the ability to offer a 'fast track', all-in-one package in a single unit, which can be moved to different waters if necessary (MacGregor, 2009) .

Oil companies to produce and storage oil from oceans and deep seas use the Floating Production Storage and Offloading (FPSO) units. It is one of the best systems, which is improved for the oil industry to produce oil from oceans. Briefly, FPSO is a floating unit, which provides oil rigs not only storing oil products but also producing or refining it before finally offloading it for required industry, either by oil tankers or by the pipelines, which built underwater (Figure 1.1). The aim of this type of mechanism is used by oil companies due to no need to invest extra money for storage of crude oil to send it to a refinery, which located onshore. As a simply FPSO is beneficial for saving time and money effectively (Wikipedia, 2017).

Figure 1.1 FPSO Caraguatatuba.

A FPSO must provide the following functions (MacGregor, 2007):

- Method for bringing the reservoir onto the vessel (risers),
- Method for retaining the vessel in position relative to the risers (i.e. mooring system),
- Sufficient deck area, deck load capacity for the topsides,
- Topsides plant to process the well fluids, and sometimes provide reservoir support (water injection, gas lift),
- Sufficient storage capacity (weight and volume) for the produced oil,
- System for exporting the stored oil,
- Acceptable stability and motions during harsh environmental conditions,
- Sufficient strength to resist harsh environmental effects,
- Durability to resist fatigue and corrosion actions,
- Accommodation and related facilities (including safety systems) onboard for the people supporting the above operations,
- Power generation and other utilities required to support the above systems,
- Possible capabilities needed for well workover or drilling (not common so far),
- Capacity for future expansion (spare deck area and weight capacity),
- Mobility if needed (e.g. to avoid icebergs or typhoons).

The following steps, which explained below, will elaborate on the different functions performed by the FPSO as a system:

Production (P): The second word "P" in the FPSO refers to production. Production means developing crude oil from the deeper parts of the ocean. The FPSO is activated and equipped with equipment that would serve as a kind of refinery to distill oil extracted from the ocean along with the emitted gases. This is the main feature of an FPSO because only with the help of this feature can an FPSO achieve the reliability it enjoys today.

Storage (S): This is the second most important function and "S" in the abbreviation FPSO. It is second because it is also important to filter the extracted oil from its ocean reservoirs, it is equally important to store it well. For this purpose, FPSO is built in such a way that tubes and tanks are ideal for storing distilled products from raw materials. They are safe and durable to withstand any chance of unwanted oil spills and hence pollution of marine life forms.

Offloading (O): The third word "O" is an FPSO concept. The purpose of offloading is important, while the FPSO needs to move its contents to designed vessels as oil tankers or to pipelines. Typically, offloading means transferring the oil from the FPSO to another oil tanker or pipeline. The FPSO offloading process is very complex, as the process is carried out in the middle of the sea, so it requires deep concentration and motivation to avoid spills.
FPSO units can be defined as a type of oil refinery that has been in use since the seventies when a large-scale process of oil exploration in the oceans and seas began. Over the past four decades, the oil exploration industry has grown significantly, and the use and availability of FPSO units have increased even more. This system is perfect and cost-effective, so it becomes a very important oil asset when it comes to oil production in offshore areas (Marineinsight, 2017).

2. Working Principles of Floating Production Storage and Offloading Units

FPSO units are fundamental deep-sea oil extraction facilities that handle the processing and storage of produced hydrocarbons. Generally, the design of an FPSO is ship-shaped, which process the equipment or the upper side aboard the ship's deck and store the hydrocarbon down in the double hulls of the ship /Figure 2.1). After the production, the unit is storing oil or gas and before unloading shuttle tankers next to the unit or transfers, this processed oil via pipelines.

Figure 2.1 FPSO Topside Units.

FPSO units are moored by various mooring systems for both deep water and ultra-deep-water fields. When FPSO units use a central mooring system that allows FPSO vessels for rotating freely for acquiring the best way to weather situations because while using spread mooring type connections, it allows to the unit to anchor from different points on the sea bad (Rigzone, 2019).

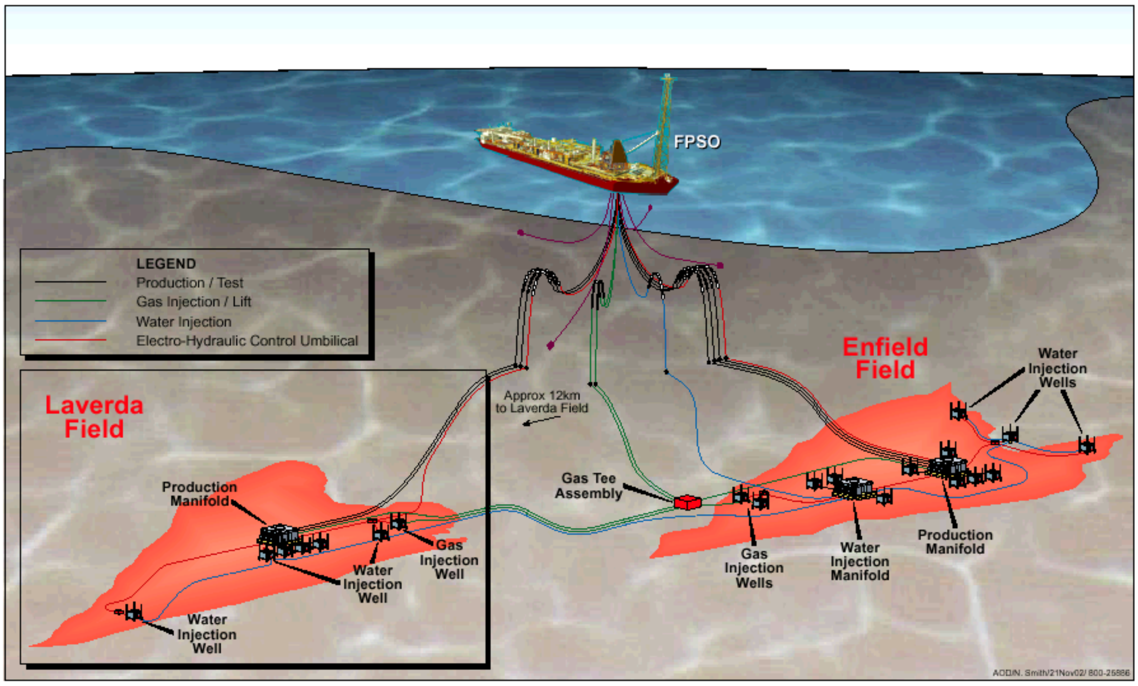

Figure 2.2 Real Field Layout Example - disconnectable FPSO moored centrally between two fields.

Generally, FPSO units are connected with various underwater wells to acquire crude oil from production wells via a pipeline. When the unit is tapped by subsea production wells, drilled hydrocarbons are transmitted by means of a flow line to risers that allows transportation of the gas and the crude-oil products from the ocean seafloors to the FPSO turret units and then transmission to the FPSO on the sea surface. Figure 2.2 shows disconnectable FPSO moored centrally between two fields.

When FPSO units are permanently moored, they are very effective developed solutions for deep-sea oil production purposes. FPSO units are suitable for disconnection from their mooring stations, and in that time, they are very viable for areas, which are experiencing heavy weather conditions. They are also optimal for disconnection their mooring and move when oil company is explored cheaper ways for more marginal areas, the FPSO unit could be transferred to different fields and reinstalled once the original field is exhausted.
Besides this, FPSO units are useful for when there are no pipelines or structures to transfer oil to shore. Due to these cost-effective and suitable advantages of FPSOs, existing oil tankers are generally have been converted to FPSO (Rigzone, 2019).

Topside process facilities of FPSO units are the same as the production platforms. Generally, they are consisted of modules and production systems which are water segregation, gas treatment plant, oil processing unit, water injection unit and gas compression unit and others. After that process oil is ready to transfer to the storage tanks. Stored oil is transferred to oil tankers via a loading hose, which goes to shore. Figure 2.3 shows topside facilities of one FPSO unit.

Figure 2.3 Overview of FPSO Topside Facilities (B&W Offshore).

1	Turret & swivel stack	**6**	Power generation	**11**	Risers and umbilicals
2	Flare tower	**7**	Switchgear room	**12**	Storage tanks
3	Gas compression	**8**	Accommodation	**13**	Fiscal metering
4	Process plant	**9**	Helideck	**14**	Offloading hose
5	Heating medium	**10**	Mooring lines	**15**	Central Control Room

3. Description of Topside Systems

This general process and utility description reflect the proposed topsides configuration. The primary systems associated with the FPSO process facility are:

- Oil Separation System and Oil Treatment System,
- Gas Compression System and Gas Treatment System,
- Water Production System,
- Seawater Injection System,
- Utilities.

The topsides process facility is designed to receive full well stream from production risers and provide separation of the gas, water and crude oil. Stabilized oil is stored in the hull storage tanks. Water discharged overboard as treated (Figure 3.1). Produced gas is compressed and treated (Dehydration). Gas will generally be dehydrated prior to export, in order to prevent freezing or hydrate formation. The treated compressed gas is used mainly for gas reinjection. A portion of the treated produced gas is consumed as fuel gas. Seawater is lifted, filtered, and then distributed for heat exchange with the cooling medium system and for freshwater production as well as for de-aeration and sulfate removal for water injection (Vmecompanies, 2019). A simplified process flow for FPSO Topsides is given in Figure 3.2.

Figure 3.1 Process Plant.

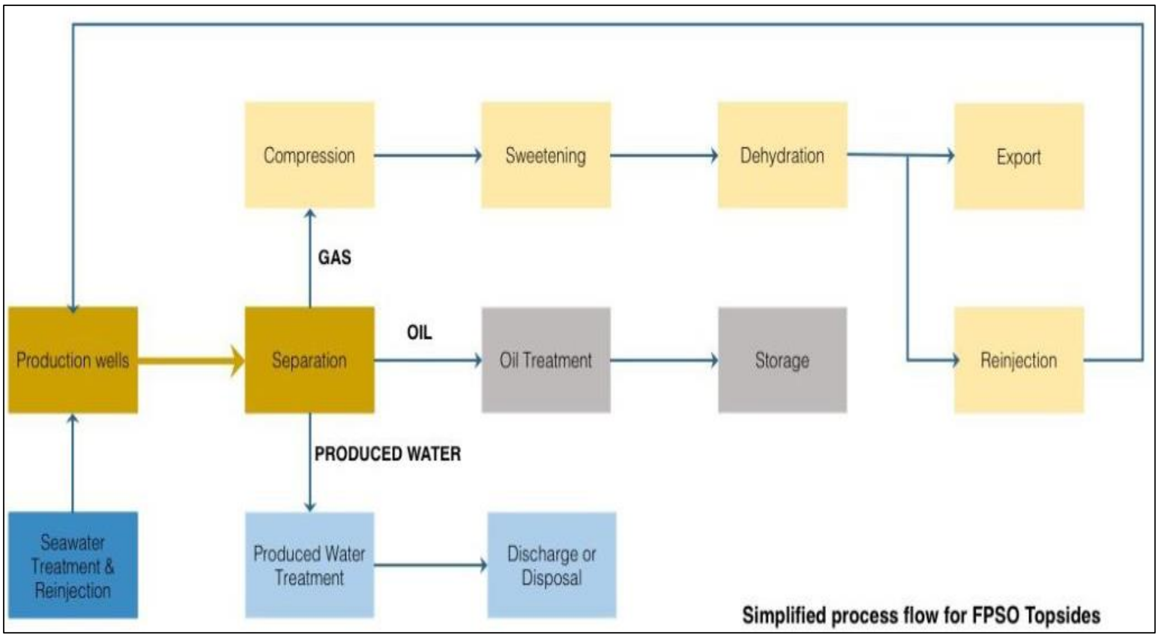

Figure 3.2 Simplified process flow for FPSO Topsides (Vmecompanies, 2019).

The topsides facility is designed to meet or exceed environmentally and safety standards. In order to reduce integration activities and accelerate pre-commissioning, equipment within each system is grouped by modules. The following considerations are incorporated into the topsides general arrangement (Mitsui Ocean Eng. Dev. Co., 2016):

- Hydrocarbon sources and inventory are located away from the accommodations module.
- Direct-fired heat sources are avoided in the process area.
- Hydrocarbon inventory is reduced in an emergency by depressurizing piping and vessels.
- Topside module arrangement and crane location(s) avoid lifting over pressure vessels and/or piping. All materials are transferred from/to a laydown area by monorail or wheeled vehicle(s) (working in Confined Space Guide, 2018).
- Equipment with an elevated risk of gas release (i.e. gas compression facilities) is separated from vessels/tanks containing liquid hydrocarbon.
- Power generation equipment is located away from process vessels.
- Deck plate serves as an initial fire barrier between equipment and cargo storage.
- The FPSO Topsides generally consist of the below components:
- Crude Separation/Stabilization Train with one Test Separator,
- Two 100 % Single-stage Process Vapor Recovery Units,
- Gas Turbine Generators,
- Single-stage Main A Gas Compression trains upstream of the gas treatment,
- Gas Dehydration System with molecular sieve adsorbents and regeneration equipment,
- Two-stage Main B Gas Compression train downstream of the gas treatment,
- Single-stage Reinjection Compression trains for injection of non-exported residue gas,
- Single-stage Lift Gas Compression trains for compressing import gas,
- Fuel Gas Conditioning System with 2 x 100% filters,
- Produced Water Treating System with rotating equipment spared at 2 x 100 % (except Hydro cyclone which could be configured as 2 x 50 % & still meeting sparing requirement during the turndown),
- One Chemical Injection System with 2 x 100 % Chemical Injection Pumps,
- One SRU Seawater Treatment System including Lift Pumps, suction caissons and hoses, Coarse Strainers, Cooling Medium/SW Exchanger Pre Filter, Multi-Media Filters, Vacuum Deaerator with associated vacuum pumps, SRU Feed Pumps, Cartridge Filters, SRU Membrane Trains, and Seawater Injection Pumps,
- Flare and Vent System with HP and LP Flare Knockout Drums and two 100 % pumps per drum,
- Closed Loop Process Cooling Medium System with Circulation Pumps and one Expansion Tank,
- One Closed Loop Heating Medium System with two 100% Circulation Pumps and one Expansion Tank,
- Waste Heat Recovery Units provided on each Main Generator,
- One Instrument, Utility and Nitrogen Air System, including three 4 x 33 % Instrument/Utility Air Compressors and 2 x 100 % Nitrogen Generation Units with one receiver for each system,
- One Fresh Water System, including 2 x 100 % Reverse Osmosis Units,

- One Closed Drain System, including piping headers to Closed Drain Drum and two 100 % pumps,
- One Open Drain System, consisting of segregated hazardous and non-hazardous drain headers on port and starboard side of the FPSO,
- One Flowline Circulation System, including two 50 % Flowline Circulation Pumps, two 100 % Leak Test Pump, two 50 % Diesel Injection Heaters,
- One PIP Heating System, consisting of one PIP Water Tank, one PIP Water Heater.

3.1 Oil Separation and Stabilization System

Oil separation and treatment system is to separate oil, gas, and water to produce stabilized crude oil that meets customer product specifications (Figure 3.3).

The Oil Separation and Treatment System consist of the following components:

- Free Water Knock Out Drum,
- Test Inlet Heater (1x100 %),
- Test Separator,
- Test Separator Oil Pump (2x100 %),
- Crude/Crude Exchanger Pre-Filter (2x100 %),
- Off-Spec Filter (1x100 %),
- Crude/ Crude Exchangers (3x50 %),
- Crude Preheater (3x50 %),
- Crude Heaters (3x50 %),
- Electrostatic Treater Flash Vessel First Stage and Electrostatic Treater First Stage,
- Electrostatic Treater First Stage Water Pumps (2x100 %),
- Electrostatic Treater Second Stage Feed Pumps (2x100 %),
- Electrostatic Treater Second Stage,
- Sales Oil Coolers (2x100 %),
- Dilution Water Heater (1x100 %).

The Oil Separation and Treatment System is designed and arranged to accommodate common operational issues associated with FPSOs. Extra attention to internals (cyclone internals) has been considered to mitigate the foaming tendency of the crude. No coalescing packs provided due to wax concerns. Heating coils are provided. All separators in the Oil Separation and Treatment System (Free Water Knock Out and Test Separator) are equipped with internals to improve separation efficiency by:

- Reducing splashing and internal motions,
- Improving separation quiescence, and minimizing foaming.

Each process vessel is also designed to achieve lower velocities and maximize retention times. Vane mist eliminators have been sized larger for lower velocities to help break foam and minimize liquid entrainment. Treaters operate at liquid full conditions, mitigating the susceptibility of the Treaters to internal turbulence motions.
The Figure 3.3 illustrates the designed system. Additional details on each component are presented in the following section.

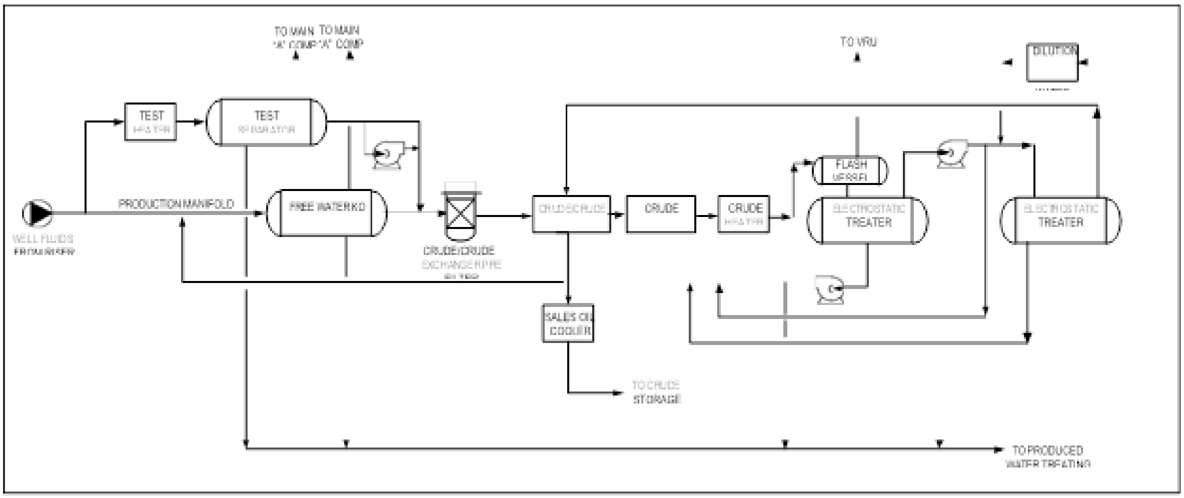

Figure 3.3 Oil Separation and Treatment System.

3.2 Gas Compression and Dehydration System

Gas Compression and Treatment System (Figure 3.4) is to compress and treat gas removed from in the oil separation and treatment system to use as fuel gas, lift gas, and gas injection (FPSO Technical Description, 2019).

The Gas Compression and Treatment System consist of the following components:

- Process VRU Compression (2 x 100%)
- Main Compression (A) (3 x 50%)–upstream of gas treatment
- Gas Dehydration by Molecular Sieves
- Main Compression (B) (2 x 100%)–downstream of gas treatment
- Reinjection Compression (2 x 100%)
- Gas Lift Compression (2 x 100%)

The figure below illustrates the Gas Compression and Treatment System. Additional details on each component within this system are presented in the following sections.

3.3 Produced Water Treating System

The produced water treating system is to remove oil from the produced water stream in order to comply with overboard discharge regulations. The system consists of all equipment from the water outlet of the three-phase separators and the electrostatic treater within the Oil Separation and Stabilization System to water disposal.

The Produced Water System consists of the following components:

- Water Collection/Skim Vessel,
- Water Collection/Skim Vessel Pumps (2x100 %),
- Hydro-cyclone (2x50 %),
- Flotation Unit Cell,

- Flotation unit Cell Pumps (TBD 2x100 %).

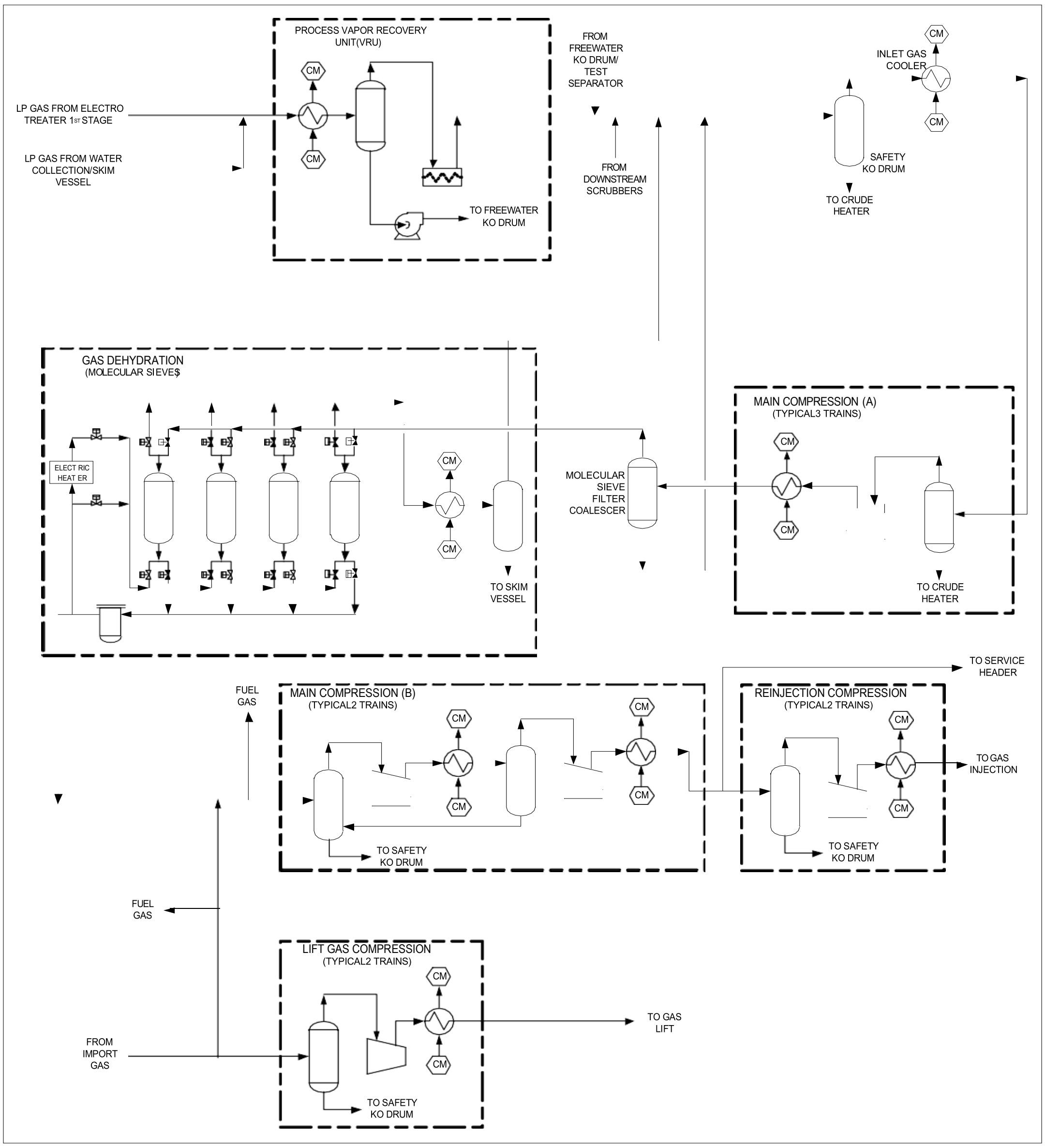

Figure 3.4 Gas Treatment System.

The Produced Water System is sized to process 16000-25000 m^3/day of produced water. A Produced Water System is given in Figure 3.5. Additional details on each component within this system are presented in the following sections.

3.4 Seawater (Distribution, Treatment, and Injection) System

Sea Water Injection System is for supply treated seawater to oil reservoirs as an injection, also providing supply water to other users on FPSO. This is used to increase the pressure in the oil reservoir and thus keep production rates high.

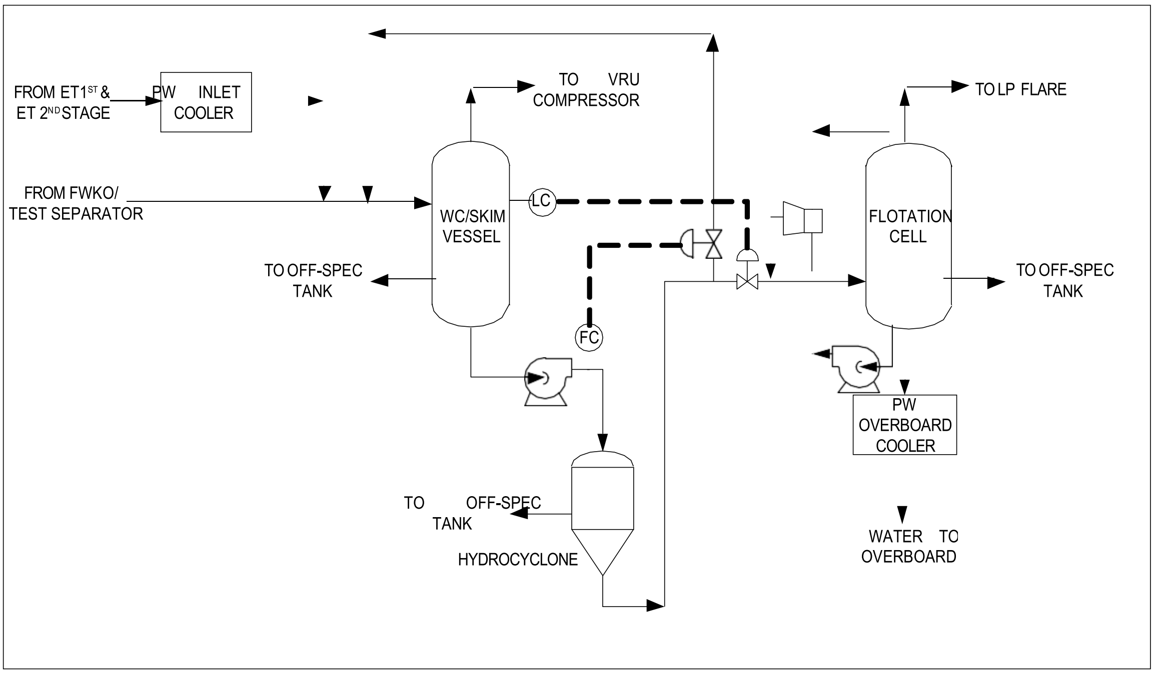

Figure 3.5 Produced Water System.

The Water Injection System consists of the following components:

- Seawater Lift Pumps (4x33 %),
- Electrochlorinator,
- Seawater Coarse Strainers (3x50 %, automatic backwash system),
- Cooling Medium/ SW Exchanger Pre-Filter (1x100 %),
- Multimedia Filters (4x33.3 %) (Hold),
- De-aerator,
- SRU Cartridge Filters (3x50 %) (Hold),
- Sulfate Removal System (3x50 % SRU Feed Pumps and 2x50 % membrane trains),
- Seawater Injection Pumps (3x50 %),
- Chemical injection system (integrated with subsea and topsides chemical handling system),
- Cleaning in Place System for membrane cleanup.

Figure 3.6 shows Water Injection System Additional details on each component within this system are presented in the following sections.

The seawater system provides seawater with the required treatment to meet the FPSO heat reject and reservoir injection demands. The amount of seawater to be lifted is based on the water injection requirements, the cooling demand, and other utility usages.

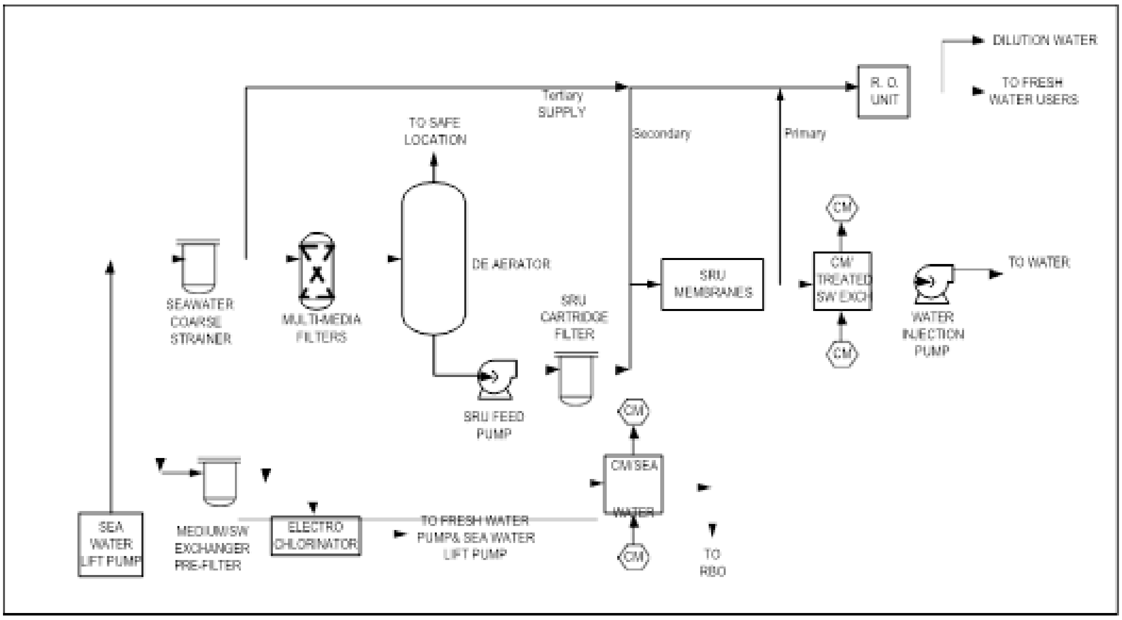

Figure 3.6 Water Injection System.

3.5 Utilities

The purpose of these systems is to provide utilities for topsides and hull systems. The utility systems consist of the following components:

- Flowline Circulation, Leak Test and Gel Mitigation System,
- Flare/Vent,
- Fuel Gas,
- Import Gas Conditioning,
- Heat Medium,
- Waste Heat Recovery Units (for the process heating and regeneration gas heating,
- Cooling Medium,
- Chemical Injection,
- Open/Closed Drains,
- Instrument and Utility Air,
- Fresh Water,
- PIP Water System.

3.5.1 Flowline Circulation, Leak Test and Gel Mitigation System

Diesel is used in the management of the subsea systems, including flushing manifolds and flowlines. The system includes two (2) positive displacement pumps. The pumps are used to circulate the diesel at 60 m^3/h each. The required discharge pressure is 25,000 kPa.

3.5.2 Flare System

The flare and vent system ensure a safe discharge of hydrocarbon fluids that are relieved during start-up or process disturbances of process equipment. Major equipment associated with the flare is listed below:

- HP Flare Scrubber,
- LP Flare Scrubber,
- Flare Tower-vertical flare tower located near the bow of the FPSO (Figure 3.7),
- Integrated HP and LP Flare Tips,
- Collection of relief, blowdown, and relief valves.

Figure 3.7 Flare Tower.

3.5.3 Import Gas Conditioning

High-quality gas may be imported onto the FPSO for used as fuel gas, gas lift and gas injection purpose. The CO_2 content and H_2S content of the imported gas are expected to be 3-5 %.

3.5.4 Fuel Gas System

There are two sources of fuel gas.
a) Dehydrated, associated gas, which contains about 15-40 % CO_2, and,
b) Import gas, which contains 3-5 % CO_2.

3.5.5 Heating Medium System

This system is designed for the capture and use of the heat from the generator turbine. Hot water is circulated by a pump around a closed system from an expansion tank to a combination of heat exchangers on the process modules and heating coils within the flare knockout drums. The system is divided into three distinct components:

Circulation: The circulation system consists of an expansion tank and circulating pumps. In its sizing, the Expansion Tank is assumed to be 25 % full at ambient temperature and 75 % full at the maximum operating temperature. There are two 100 % Circulation Pumps supplying heating medium throughout the system. The circulating heating water is supplied at a maximum of 160 ˚C to all heaters with an anticipated average return temperature of 120 ˚C.

Waste Heat Recovery: Recovery of the waste heat is achieved by circulating the medium through coils installed in the divertible exhaust duct stacks of the dual fuel gas turbine generators. Diverting turbine engine exhaust gas across the heating medium coil controls medium temperature by automated controls. One Waste Heat Recovery Units per turbo-generator is to be included in the system.

Heaters: The heating system consists of Crude Pre-heater, Crude Heater, Dilution Water Heater, Diesel Injection Heater, Test Inlet Heater, PIP Water Heater, Import Fuel Gas Heater, and Fuel Gas Super Heater as shell and tube type exchangers. Other end users are the heating coils in the hull tanks as well as at the bottom of the Free-water KO Drum, Test Separator, Electrostatic Treater First Stage, Electrostatic Treater Second Stage, Flare KO Drums and Closed Drain Vessel.

3.5.6 Cooling Medium System

This system is designed to meet cooling requirements of the end users: VRU Suction Coolers, Inlet Gas Cooler, Main Compressor (A) Discharge Coolers, Main Compressor (B) Discharge Coolers, Reinjection Compressor Discharge Coolers, Lift Gas Compressor Discharge Coolers, Regen Gas Cooler, Produced Water Inlet Cooler, Heating Medium Trim Cooler and, Sales Oil Coolers, and Auxiliary Exchangers. The system consists of a closed loop circulating inhibited fresh water, picking up heat from end users, and transferring heat to seawater via the seawater exchangers.

3.5.7 Chemical Injection System

The chemical injection system consists of all equipment and distribution piping (tubing) associated with chemical injection, including storage tanks, injection pumps, transfer pumps, and all required instrumentation up to the individual points of injection (or as the chemical leaves the FPSO for subsea injection points).

Chemical injection facilities provide a means of assisting the production facilities system to meet product specifications and disposed the fluid specifications as well as protect the production facilities from corrosion and hydrate plugging.
The chemical injection facilities supply specific chemicals through injection rate controlling devices at their identified injection points throughout the process facilities at the dosage rate

necessary for achieving the above. An injection rate-controlling device is also installed on the pipe manifold area to allow proper distribution to the end users.
The capacity of the chemical tanks and pump size are based on technical requirements defined in the specifications and the ppm dosage rate for each chemical per unit operations. The dosage rates are based on Client specifications and Supplier recommendations. Chemicals for subsea injection are ethanol or MEG, scale inhibitor, wax inhibitor, asphaltene inhibitor, and H_2S scavenger.

3.5.8 Drain System (Open and Closed)

Drain System is classified as the open and closed drain systems which shall be designed to receive drainage from:

- Maintenance drains from process equipment in hydrocarbon service,
- Liquid release streams from selected relief valves (e.g. thermal reliefs),
- Spillages on or around hydrocarbon service equipment (hazardous drains),
- Spillages and/or rainwater on or around non-hydrocarbon service equipment (non-hazardous drains),
- Spillages, deluge water, and/or rainwater on the vessel main decks,
- The drains system is integrated with the shipside storage tanks, including the crude cargo tanks, Off-Spec Tank(s), and the slop tanks. The following briefly describes the fluids that enter each storage tank.
- Crude cargo tanks: on-spec crude from the process,
- Off-spec Tank (designated tank in the hull): off-spec water which is the process, separated oil from the produced water system and closed drain fluids,
- Clean Slop Tank: rainwater, oxygenated seawater, non-hazardous open drain,
- Dirty Slop Tank: hazardous and non-hazardous open drains, rainwater and treated seawater.

The off-spec crude oil will be directed to a cargo tank at a sufficiently low volume so as not to contaminate the existing on-spec crude. Off-spec crude oil and produced water is further processed within the topsides facilities. Waters accumulating in the slop tanks and it is treated in a separate system before being drained overboard.

3.5.9 Instrument, Utility, and Nitrogen Air Systems

This system is to supply utility/instrument air for the regular operation of control and shutdown valves also for other various end users on the topsides.

3.5.10 Nitrogen

The system provides a source of low-pressure nitrogen for the purging of machinery which is under maintenance, also inerting topsides as a blanket, and separation gas for the compressor dry gas seals. Nitrogen is available at 880 kpa. As the generator is membrane based, a single 100 % unit with back-up bottles are provided.

3.5.11 Fresh Water System

This system is to supply fresh water, as treated and as required to FPSO users. In addition, the Fresh Water System provides dilution water to the Electrostatic Treater Second Stage to meet crude-oil salinity specifications. The system consists of all equipment associated with the production of fresh water for use in Process, Utility, and Accommodation areas.

3.6 Laboratory

The FPSO shall be equipped with a laboratory equipped to perform, as a minimum, the following analysis onboard:

- BS&W,
- Water Content in Oil,
- Sand content in Oil,
- API Gravity/Density,
- Salinity,
- Reid Vapor Pressure,
- Sand Content,
- Oil Content in Produced Water,
- O_2 Content of Injection Water,
- Gas Dew Point/Water Content,
- SDI of Injection Water,
- Humidity (Mitsui Ocean Eng. Dev. Co, 2016).

4. Conclusion

This article describes the process equipment in the topside modules of a typical FPSO along with the utility systems, presents, and includes information for the technical description of identified equipment and facilities on the FPSO topside.

Major structural components are, in the FPSO, Vessel side and Topside process modules (production, stabilization & utilities, gas compression, power generation, gas dehydration, H_2S removal, etc.).

As described in this study, process systems in an FPSO can be mentioned as Production Manifold, Separation, Treatment, and Stabilization of Crude Oil, Crude Oil Transport, Storage & Offloading, Produced Water (treatment & stripping), Lift Gas/Kick Off Gas Compression, Gas dehydration, Fuel Gas-Associated Systems, H_2S Removal from Gas, Chemical Injection, Flare, Vent & Blow Down. Utility Systems can be Fresh Water Generation, Sea Water for Topsides, Compressed Air-Nitrogen Generation, Antifouling (MGPS), Drains (open & closed).

Around 270 FPSO units in the world are still working and producing oil on different locations. Of course, producing oil from sea needs to more technology and costly than producing oil from shore, but due to high oil prices and politic problems nowadays seaside countries started to investigate different oil sources in their own lands and seas. Turkish government are searching oil at the Mediterranean and the Black Sea areas, expecting that FPSO, FLNG and FSO can be built Turkish Shipyards in the future.

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