Offshore Engineering

Ola Coats

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Chapter 1

Ocean Engineering & Marine Energy

Ocean Engineering

Ocean Engineering is an ambiguously defined discipline, but may refer to **Oceanographic Engineering** a term describing **marine electronics engineering** applied to supporting the work of oceanographers; or, may refer to **offshore engineering**, or **maritime engineering**, which is the branch of engineering allied to civil engineering, and concerned with the technical aspects of fixed and floating offshore marine structures and systems related to harnessing ocean resources. These include offshore oil and gas and the rapidly expanding area of ocean renewable energy, as well as other ocean resource activities such as sub-sea mining and aquaculture.

Fields of study

The Society of Naval Architects and Marine Engineers (SNAME) describes the work of "ocean engineers" as follows:

Ocean engineers study the ocean environment to determine its effects on ships and other marine vehicles and structures. Ocean engineers may design and operate stationary ocean platforms, or manned or remote-operated sub-surface vehicles used for deep sea exploration.

Although the term appears to describe one who designs, maintains, and operates oceans, the SNAME description bears a strong resemblance to a conflation of naval architecture, marine electronics, and offshore engineering.

As with all engineering disciplines ocean engineering should be concerned with the design and operation of systems — in the ocean; and should not be confused with oceanography — the scientific study of oceanic systems; nor marine electronics engineering (oceanographic engineering), which is concerned with the design and operation of remote sensing systems.

Ocean engineering is essentially a broad study of offshore civil engineering, naval architecture and marine engineering; as such it may encompass the study of man-made structures such as nearshore piers, breakwaters, groins, piles, and sewer outfalls as well as common offshore structures such as petroleum drilling, operating platforms, and ships.

Renewable ocean energy

The ocean environment presents a vast quantity of renewable sources of energy in the form of winds, waves, tides, currents and the density and thermal gradients between ocean water layers.

Ocean engineering education

The Accreditation Board for Engineering and Technology (ABET) established the following criteria for the curriculum of ocean engineering programs:

The program must demonstrate that graduates have: knowledge and the skills to apply the principles of fluid and solid mechanics, dynamics, hydrostatics, probability and applied statistics, oceanography, water waves, and underwater acoustics to engineering problems; the ability to work in groups to perform engineering design at the system level, integrating multiple technical areas and addressing design optimization.

Marine Energy

Marine energy or **marine power** (also sometimes referred to as **ocean energy** or **ocean power**) refers to the energy carried by ocean waves, tides, salinity, and ocean temperature differences. The movement of water in the world's oceans creates a vast store of kinetic energy, or energy in motion. This energy can be harnessed to generate electricity to power homes, transport and industries.

The term marine energy encompasses both wave power — power from surface waves, and tidal power — obtained from the kinetic energy of large bodies of moving water. Offshore wind power is generally confused as a form of marine energy, but is not as wind power is derived from the wind, even if the wind turbines are placed over water.

The oceans have a tremendous amount of energy and are close to many if not most concentrated populations. Many researches show that ocean energy has the potentiality of providing for a substantial amount of new renewable energy around the world.

Potential of ocean energy

The theoretical potential is several times greater than the actual global electricity demand, and equivalent to 4-18 million ToE.

Theoretical global ocean energy resource

Capacity (GW)	Annual gen. (TW·h)	Form
5,000	50,000	Marine current power
20	2,000	Osmotic power
1,000	10,000	Ocean thermal energy
90	800	Tidal power
1,000—9,000	8,000—80,000	Wave power

Forms of ocean energy

Renewable

The oceans represent a vast and largely untapped source of energy in the form of surface waves, fluid flow, salinity gradients, and thermal.

Marine current power

The energy obtained from ocean currents

Osmotic power

The energy from salinity gradients.

Ocean thermal energy

The power from temperature differences at varying depths.

Tidal power

The energy from moving masses of water — a popular form of hydroelectric power generation. Tidal power generation comprises three main forms, namely: tidal stream power, tidal barrage power, and dynamic tidal power.

Wave power

The power from surface waves.

Non-renewable

Petroleum and natural gas beneath the ocean floor are also sometimes considered a form of ocean energy. An ocean engineer directs all phases of discovering, extracting, and delivering offshore petroleum (via oil tankers and pipelines), a complex and demanding task. Also centrally important is the development of new methods to protect marine wildlife and coastal regions against the undesirable side effects of offshore oil extraction.

Chapter 2

Naval Architecture

Tahitian Princess in Tórshavn, Faroe Islands, August 2009

Naval architecture, also called **naval engineering**, is an engineering discipline dealing with the design, construction and repair of marine vehicles. Naval architecture involves basic and applied research, design, development, design evaluation and calculations during all stages of the life of a marine vehicle. Preliminary design of the vessel, its detailed design, construction, trials, operation and maintenance, launching and dry-docking are the main activities involved. Ship design calculations are also required for ships being modified (by means of conversion, rebuilding, modernization, or repair).

Naval architecture also involves formulation of safety regulations and damage control rules and the approval and certification of ship designs to meet statutory and non-statutory requirements.

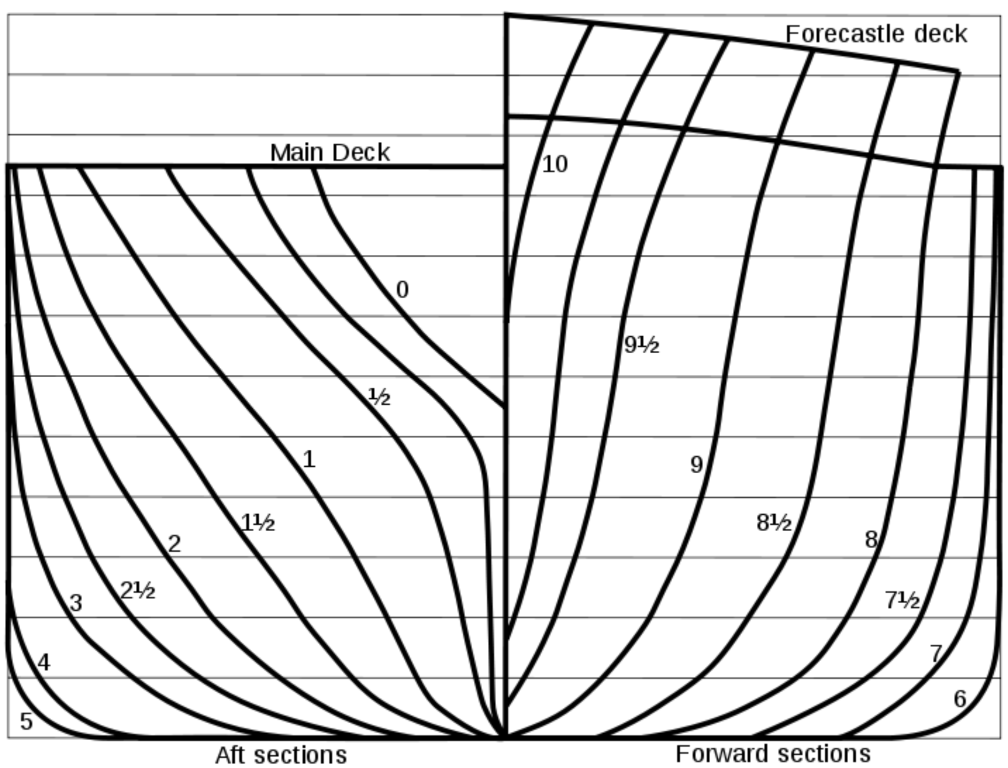
Overview

Due to the complexity associated with operating in a marine environment, naval architecture is a co-operative effort between groups of technically skilled individuals who are specialists in particular fields, often coordinated by a lead naval architect. This inherent complexity also means that the analytical tools available are much less evolved than those for designing aircraft, cars and even spacecraft. This is due primarily to the paucity of data on the environment the marine vehicle is required to work in and the complexity of the interaction of waves and wind on a marine structure.

Elements

The word "vessel" includes every description of watercraft, including non-displacement craft, WIG craft and seaplanes, used or capable of being used as a means of transportation on water. The principal elements of naval architecture are:

Hydrostatics



Body plan of a ship showing the hull form

Concerns the conditions under which the vessel is subjected to while at rest in water and its ability to remain afloat. This involves computing buoyancy, (displacement) and other hydrostatic properties.
Trim - refers to the longitudinal inclination of the vessel.
Stability - Ability of a vessel to restore itself to an upright position after being inclined by wind, sea, or loading conditions.

- **Hydrodynamics**

Concerns the flow of water around the ship's hull, bow, stern and over bodies such as propeller blades or rudder, or through thruster tunnels.
Resistance - resistance towards motion in water primarily caused due to flow of water around the hull. Powering calculation is done based on this.
Propulsion - to move the vessel through water using propellers, thrusters, water jets, sails etc. The energy to drive these is mainly provided by internal combustion engines. Some vessels are electrically powered using nuclear or solar energy.
Ship motions - involves motions of the vessel in seaway and its responses in waves.
Controllability (manoeuvring) - involves controlling and maintaining position and direction of the vessel

Deck of an oil tanker, looking aft.

- **Structures**

Involves selection of material of construction, structural analysis of global and local strength of the vessel, vibration of the structural components and structural responses of the vessel during motions in seaway.

- **Arrangements**

This involves concept design, layout and access, fire protection, allocation of spaces, ergonomics and capacity.

- **Construction**

Construction depends on the material used. When steel or aluminium is used this involves welding of the plates and profiles after rolling, marking, cutting and bending as per the structural design drawings or models, followed by erection and launching. Other joining techniques are used for other materials like fibre reinforced plastic and glass-reinforced plastic.

The craft of naval architecture

The air craft carrier USS Kitty Hawk (CV 63) at Naval Station Pearl Harbor.

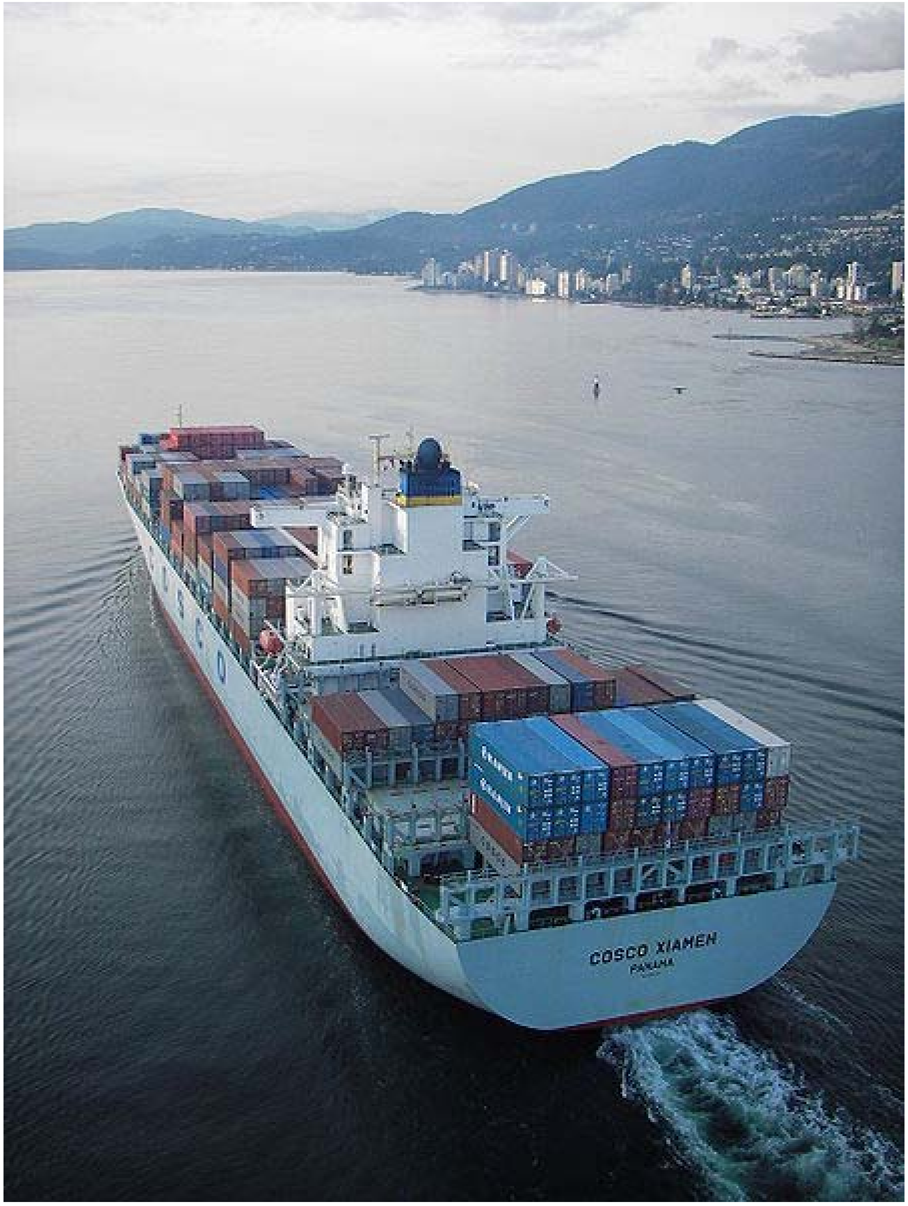
Traditionally, naval architecture has been more craft than science. The suitability of a vessel's shape was judged by looking at a half-model of a vessel or a prototype. Ungainly shapes or abrupt transitions were frowned on as being flawed. This included, rigging, deck arrangements, and even fixtures. Subjective descriptors such as ungainly, full, and fine were used as a substitute for the more precise terms used today. A vessel was, and still is described as having a 'fair' shape. The term 'fair' is meant to denote not only a smooth transition from fore to aft but also a shape that was 'right.' Determining what is 'right' in a particular situation in the absence of definitive supporting analysis encompasses the art of naval architecture to this day.

The science of naval architecture

Modern low-cost digital computers and dedicated software, combined with extensive research to correlate full-scale, towing tank and computational data, have enabled naval architects to more accurately predict the performance of a marine vehicle. These tools are used for static stability (intact and damaged), dynamic stability, resistance, powering, hull development, structural analysis, green water modelling, and slamming analysis. Data is regularly shared in international conferences sponsored by RINA, Society of Naval Architects and Marine Engineers (SNAME) and others. Computational Fluid Dynamics is being applied to predict the response of a floating body in a random sea.

The Naval Architect

A naval architect is an engineer who is responsible for the design, construction, and/or repair of ships, boats, other marine vessels, and offshore structures, both commercial and military, including:



Containership Cosco Xiamen exiting Burrard Inlet (Vancouver's harbour)

- Merchant ships - oil tankers, gas tankers, cargo ships, bulk carriers, container ships
- Passenger/vehicle ferries, cruise ships
- Warships - frigates, destroyers, aircraft carriers, amphibious ships
- Submarines and underwater vehicles
- Icebreakers
- Offshore drilling platforms, semi-submersibles
- High speed craft - hovercraft, multi-hull ships, hydrofoil craft
- Workboats - barges, fishing boats, anchor handling tug supply vessels, platform supply vessels, tug boats, pilot vessels, rescue craft
- Yachts, power boats, and other recreational watercraft

Some of these vessels are amongst the largest such as supertanker and most complex such as Aircraft carriers and highly valued movable structures produced by mankind. They are the most efficient method of transporting the world's raw materials and products known to man. Modern engineering on this scale is essentially a team activity conducted by specialists in their respective fields and disciplines. Naval architects integrate these activities. This demanding leadership role requires managerial qualities and the ability to bring together the often-conflicting demands of the various design constraints to produce a product which is fit for the purpose.

In addition to this leadership role, a naval architect also has a specialist function in ensuring that a safe, economic, and seaworthy design is produced. To undertake all these tasks, a naval architect must have an understanding of many branches of engineering and must be in the forefront of high technology areas. He or she must be able to effectively utilize the services provided by scientists, lawyers, accountants, and business people of many kinds.

Naval architects typically work for shipyards, ship owners, design firms and consultancies, equipment manufacturers, Classification societies, regulatory bodies (Admiralty law), navies, and governments.

Chapter 3

Floating Production Storage and Offloading

FPSO *Mystras* at work off the shore of Nigeria

FPSO *Crystal Ocean* moored at the Port of Melbourne

A **floating production, storage and offloading (FPSO)** unit is a floating vessel used by the offshore industry for the processing of hydrocarbons and for storage of oil. A FPSO vessel is designed to receive hydrocarbons produced from nearby platforms or subsea template, process them, and store oil until it can be offloaded onto a tanker or transported through a pipeline. FPSOs are preferred in frontier offshore regions as they are easy to install, and do not require a local pipeline infrastructure to export oil. FPSOs can be a conversion of an oil tanker or can be a vessel built specially for the application. A vessel used only to store oil (without processing it) is referred to as a **floating storage and offloading vessel (FSO)**.

History

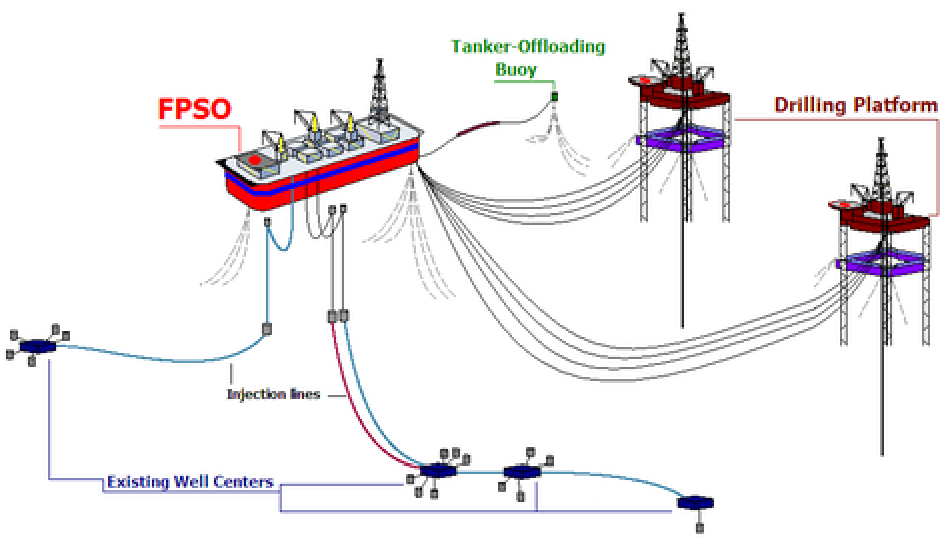
Oil has been produced from offshore locations since the late 1940s. Originally, all oil platforms sat on the seabed, but as exploration moved to deeper waters and more distant locations in the 1970s, floating production systems came to be used.

The first oil FPSO was the *Shell Castellon*, built in Spain in 1977.

The *Sanha* LPG FPSO operates offshore Angola, and is the first such vessel with complete onboard liquefied petroleum gas processing and export facilities. It can store up to 135,000 cubic meters of LPG while awaiting export tankers for offloading.

There are so far no LNG FPSOs. In the opposite (discharge and regasification) end of the LNG chain, the first ever conversion of a LNG carrier (Golar LNG owned Moss type LNG carrier) into an LNG floating storage and regasification unit was carried out in 2007 by Keppel shipyard in Singapore. An LNG FPSO works under the same principles an oil FPSO works under, taking the well stream and separating out the natural gas (primarily methane and ethane) and producing LNG, which is stored and offloaded. On July 29, 2009, Shell and Samsung announced an agreement to build up to 10 LNG FPSOs: Likely size and capacity: 456 meters in length and 74 meters in width, with a capacity of 450,000 cubic meters Estimated cost $5b. Already Flex LNG has four contracts for smaller units at the same yard.

Mechanisms



FPSO diagram

Oil produced from offshore production platforms can be transported to the mainland either by pipeline or by tanker. When a tanker is chosen to transport the oil, it is necessary to accumulate oil in some form of storage tank such that the oil tanker is not continuously occupied during oil production, and is only needed once sufficient oil has been produced to fill the tanker. At this point the transport tanker connects to the stern of the storage unit and offloads oil.

In the early days, the storage units consisted of decommissioned oil tankers, which were stripped down and equipped with process/production facilities (becoming therefore FPSOs), and were connected to a permanent mooring point. Today, there are two main types of FPSOs, those built converting an existing oil tanker, and those that are purpose-built. The FPSO design will depend on the area of operation. In benign waters the FPSO may have a simple box shape or it may be a converted tanker. Generally (but not always) the production lines (risers) are connected to a major component of the vessel, called a Turret, which allows the vessel to rotate in order to head into the wind and reduce environmental forces on the moorings. In relatively calm waters, such as in West Africa, turrets can be located externally to the ship structure, hanging off the bow of the FPSO. For harsher environments like the North Sea, the turret is generally located internally. The turrets and the mooring systems can be designed to be disconnectable or to remain permanently moored. Most ship-shaped FPSOs in the North Sea are purpose-built and are permanently moored.

While most FPSOs are ship-shaped, FPSOs may also be semi-submersible type platforms with storage or may have a cylindrical shape. These are moored in fixed orientation.

An FPSO has the capability to carry out some form of separation process. If the unit does not have such facilities, it is generally referred to as a Floating Storage and Offloading unit, and would be operated in conjunction with a production platform.

Advantages

Floating production, storage and offloading vessels are particularly effective in remote or deepwater locations where seabed pipelines are not cost effective. FPSOs eliminate the need to lay expensive long-distance pipelines from the oil well to an onshore terminal. They can also be used economically in smaller oil fields which can be exhausted in a few years and do not justify the expense of installing a pipeline. Once the field is depleted, the FPSO can be moved to a new location. In areas of the world subject to cyclones (northwestern Australia) or icebergs (Canada), some FPSOs are able to release their mooring/riser turret and steam away to safety in an emergency. The turret sinks beneath the waves and can be reconnected later.

Specific types

A **floating storage and offloading unit** (FSO) is a floating storage device, which is a simplified FPSO without the capability for oil or gas processing. Most FSOs are old single hull supertankers that have been converted. An example is *Knock Nevis, ex Seawise Giant*, the world's largest ship, which had been converted to an FSO to be used offshore Qatar.

At the other end of the LNG logistics chain, where the natural gas is brought back to ambient temperature and pressure, ships may also be used as FSRUs. A **LNG floating storage and regasification unit** (FSRU) is a floating storage and regasification system, which receives liquefied natural gas (LNG) from offloading LNG carriers, and the onboard regasification system provides natural gas send-out through flexible risers and pipeline to shore.

Vessels

Records

FPSO Firenze moored at Hellenic Shipyards, 2007

The FPSO operating in the deepest water depth is the Espirito Santo FPSO from Shell America operated by Brazilian Deepwater Production Ltd (a joint venture between MISC Bhd and SBM Offshore). The FPSO is moored at a depth of 1,800 m in the Campos Basin, Brazil and is rated for 100,000 bpd. The EPCI contract was awarded in November 2006 and first oil was achieved in July 2009. The FPSO conversions and internal turret were done at Keppel Shipyard Tuas in Singapore and the topsides were fabricated in modules at Dynamac and BTE in Singapore.

The world's largest FPSO is the *Kizomba A*, with a storage capacity of 2.2 million barrels (350,000 m^3). Built at a cost of over US$800 million by Hyundai Heavy Industries in Ulsan, Korea, it is operated by Esso Exploration Angola (ExxonMobil). Located in 1200 meters (3,940 ft) of water at Deepwater block 200 statute miles (320 km) offshore in the Atlantic Ocean from Angola, Central Africa, it weighs 81,000 tonnes and is 285 meters long, 63 meters wide, and 32 meters high (935 ft by 207 ft (63 m) by 105 ft).

The world's smallest FPSO is the Crystal Ocean, operating in 137 m of water in the Bass Strait between Australia and Tasmania on the Basker Manta Field. It is leased by Roc Oil

(Sydney-based international petroleum exploration and production company) from Rubicon Offshore and is operated on their behalf by AGR Asia Pacific; it is currently producing 5,000 bpd.

The FPSO in the shallowest water depth of just 13 m is the Armada Perkasa in the Okoro field in Nigeria, West Africa, for Afren Energy. This spread moored (fixed orientation) vessel uses 100 mm, 150 mm and 200 mm bore DeepFlex non-steel flexible risers in a double lazy wave formation (with weights and distributed buoyancy) to accommodate the large motion offsets in an environment of extreme waves and currents.

The **Skarv FPSO**, developed and engineered by Aker Solutions for BP Norge, will be the most advanced and largest FPSO deployed in the Norwegian Sea, offshore Mid Norway. Skarv is a gas condensate and oil field development. The development will tie in five sub-sea templates, and the FPSO has capacity to include several smaller wells nearby in the future. The process plant on the vessel can handle about 19 MSm3/d (670 MScf/d) of gas and 13,500 Sm3/d of oil (85,000 bbl/d). An 80 km gas export pipe will tie in to Åsgard transport system. Aker Solutions (formerly Aker Kvaerner) developed the front-end design for the new floating production facility as well as the overall system design for the field and preparation for procurement and project management of the total field development. The hull is an Aker Solutions proprietary "Tentech^{tm}975" design. BP also selected Aker Solutions to perform the detail engineering, procurement and construction management assistance (EPcma) for the Skarv field development. The EPcma contract covers detail engineering and procurement work for the FPSO topsides as well as construction management assistance to BP including hull and topside facilities. The production start for the field is scheduled for August 2011. BP awarded the contract for fabrication of the Skarv FPSO hull to Samsung Heavy Industries in South Korea and the Turret contract to SBM. The FPSO has a length of 292m, breadth of 50.6m and is 29m deep and accommodate 100 people in single cabins. The hull will be delivered in January 2010.

Current FPSOs

Data on operating FPSOs is reported each year in an annual survey.

FPSO Vessel Name	Oilfield	Current Location	Field Operator	Newbuild or Conversion	Startup year	Vessel Designer /Operator
Abo FPSO	Abo	Gulf of Guinea, Nigeria	Agip	Conversion	2003	Prosafe
Agbami FPSO	Nigeria		Star Deep Water Petroleum	Newbuild	2008	Chevron
Akpo FPSO	Akpo	Gulf of Guinea, Nigeria	Total	Newbuild	2009	Total
Al Zaafarana	Warda	Gulf of Suez,	Aker Solutions	Conversion	1994	Gemsa Petroleum

FPSO		Egypt				Co
Anasuria FPSO	Teal, Teal South, Guillemot A	North Sea, UK	Shell	Newbuild	1996	
Anoa Natuna	Anoa Field, Natuna Sea	Indonesia	STAR Energy		1990	STAR Energy,KN, Natuna Sea BV
Aoka Mizu	Ettrick	North Sea, UK	Nexen		2009	Bluewater Energy Services
Arco Ardjuna FSO	Ardjuna Oil Field	West Java Sea, Indonesia	Pertamina Hulu Energy		1973	Pertamina
Armada Perkasa	Okoro Setu	Nigeria	Afren/AMNI	Conversion	2009	Bumi Armada Berhad
Åsgard A	Åsgard	North Sea, Norway	Statoil	Newbuild	1999	
Azurite FDPSO	Azurite	Atlantic, Republic of the Congo	Murphy Oil	Conversion	2009	Prosafe Production
Baobab Ivoirien MV10 FPSO	Baobab Field	Côte d'Ivoire	CNR International S.A.R.L.	Conversion	2005	MODEC Inc.
Belanak	Belanak Field	South Natuna Sea, Indonesia	ConocoPhillips	Newbuild	2004	KBR / J. Ray McDermott
Berge Helene(OIM Adarsh Shukla)	Chinguetti	North Atlantic Ocean, Mauretania	Woodside Petroleum	Conversion	2006	
Bleo Holm	Ross, Blake, Parry	North Sea, UK	Talisman Energy	Conversion	1999	Bluewater Energy Services
Bohai Ming Zhu FPSO	Penglai19-3, China	Bohai, China	ConocoPhillips		2003	CNOOC
Bonga FPSO	Bonga	Gulf of Guinea, Nigeria	Shell	Newbuild	2005	Samsung Heavy Industries
Brasil FPSO	Roncador	Campos Basin, Brazil	Petrobras	Conversion	2002	SBM Offshore
Bunga Kertas FPSO	North Lukut & Penara	South China Sea, Peninsula Malaysia	Petronas Carigali	Conversion	2004	DPS/FPSO Ventures
Capixaba FPSO	Golfinho	Espírito Santo Basin, Brazil	Petrobras	Conversion	2006	SBM Offshore
Captain FPSO	Captain	North Sea, UK	Chevron	Newbuild	1996	
Cidade de Niteroi	Jabuti, Brazil	Santos Basin, Brazil	MODEC (for Petrobras)	Conversion	2009	MODEC Inc.
Cidade do Rio de Janeiro MV14 FPSO	Espadarte Sul Field	Campos Basin, Brazil	Petrobras	Conversion	2007	MODEC Inc.
Cidade de Vitoria FPSO	Golfinho II	Espírito Santo Basin, Brazil	Petrobras	Conversion	2007	Saipem

Cossack Pioneer	Cossack, Wanaea	Indian Ocean, Australia	Woodside Petroleum	Conversion	1995	
Cuulong MV9 FPSO	Su Tu Den Field	Vietnam	Cuulong Joint Operating Company (CLJOC)	Newbuild	2003	MODEC Inc.
Dalia FPSO	Dalia	South Atlantic Ocean, Angola	Total	Newbuild	2006	
Dhirubhai 1	MA-D6	Bay of Bengal, India	Reliance Industries Limited	Conversion	2008	AFP
Erha	OPL 209	Gulf of Benin, Nigeria	ExxonMobil	Newbuild	2006	
Espadarte FPSO	Espadarte	Campos Basin, Brazil	Petrobras	Conversion	2000	SBM Offshore
Espirito Santo BC-10 FPSO	Espirito Santo (BC10)	Campos Basin, Brazil	Shell Americas	Conversion	2009	SBM Offshore MISC Bhd
Espoir Ivorien	Espoir	Gulf of Guinea, Côte d'Ivoire	CNR	Conversion	2002	Prosafe
Falcon FPSO	Currently none	Johor River, Malaysia	ExxonMobil	Conversion		SBM Offshore
Farwah	Al-Jurf	Mediterranean, Libya	Total		2003	
Four Vanguard	Woollybutt	Indian Ocean, Australia	ENI	Conversion	2003	Premuda
Gimboa FPSO	Gimboa	South Atlantic Ocean, Angola	Sonangol	Conversion	2009	Saipem
Girassol FPSO	Girassol	South Atlantic Ocean, Angola	Total	Newbuild	2001	
Glas Dowr	Sable	Indian Ocean, South Africa	PetroSA	Newbuild	2003	Bluewater Energy Services
Global Producer III	Dumbarton	North Sea, UK	Maersk	Newbuild	2006	Maersk
Greater Plutonio FPSO	Block 18 Greater Plutonio	South Atlantic Ocean, Angola	BP	Newbuild	2007	BP
Griffin Venture FPSO	Griffin, Chinook, Scindian	Indian Ocean, Australia	BHP Billiton	Newbuild	1994	
Gryphon FPSO	Gryphon	North Sea, UK	Maersk		1993	
Hæwene Brim FPSO	Pierce	North Sea, UK	Shell	Newbuild	1999	Bluewater Energy Services
Jasmine Venture MV7 FPSO	Jasmine Field	Thailand	PEARL Energy Pte Ltd.	Conversion	2004	MODEC Inc.
Jotun A	Jotun	North Sea, Norway	ExxonMobil	Newbuild	1999	Bluewater Energy Services
Kakap Natuna	Kakap KH field	Indonesia	ConocoPhillips(Kakap) Ltd.	Conversion	1986	MODEC Inc.

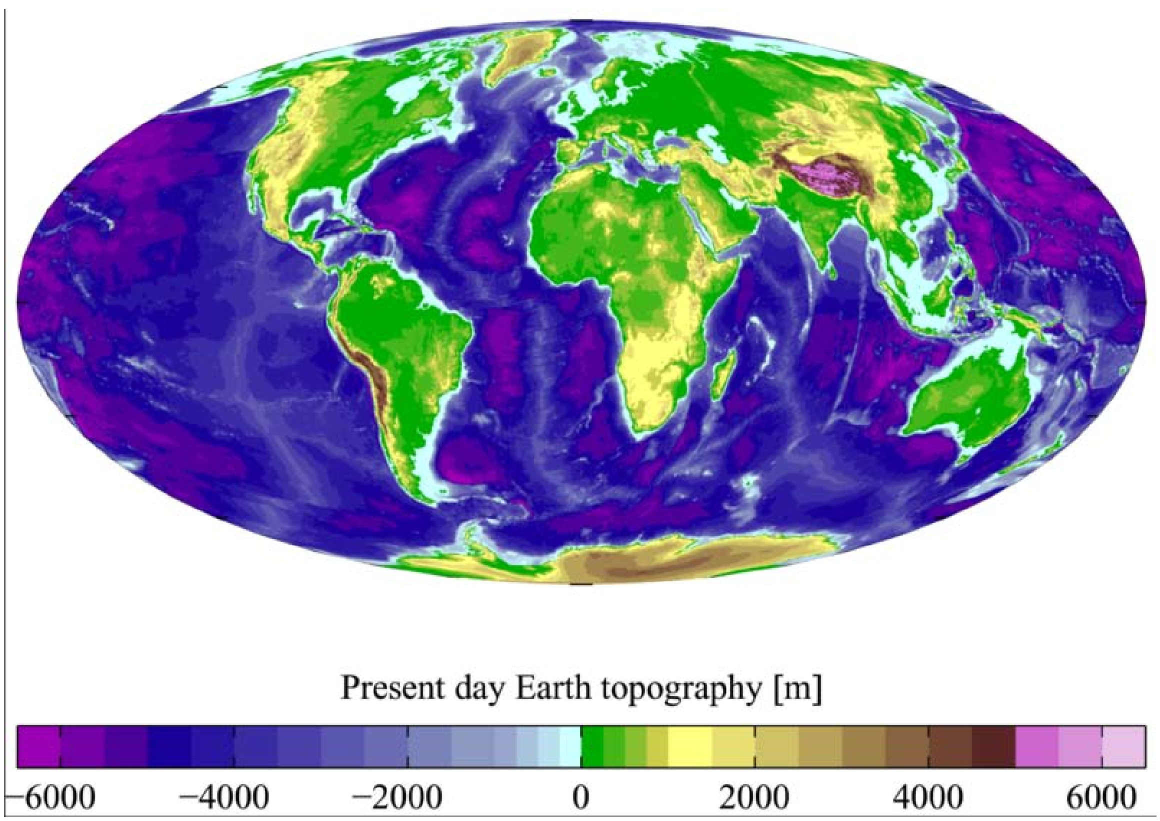
FPSO						
Kikeh	Kikeh	Sabah, Malaysia	Murphy Oil	Conversion	2007	SBM Offshore MISC Bhd
Kizomba A	Hungo, Chocalho	South Atlantic Ocean, Angola	ExxonMobil	Newbuild	2004	SBM Offshore
Kizomba B	Kissanje, Dikanza	South Atlantic Ocean, Angola	ExxonMobil	Newbuild	2005	SBM Offshore
Kuito FPSO	Kuito	Cabinda, Angola	Chevron	Conversion	1999	SBM Offshore
"Kwame Nkrumah" FPSO	Jubilee Fields	Gulf of Guinea, Ghana	Tullow Oil & Others	Conversion	2010	MODEC Inc
MacCulloch FPSO	MacCulloch	North Sea, UK	ConocoPhillips	Conversion	1997	Maersk
Maersk Curlew	Curlew	North Sea, UK	Shell	Conversion	2002	
Marlim Sul FPSO	Marlim Sul	Campos Basin, Brazil	Petrobras	Conversion	2004	SBM Offshore
MODEC Venture 11 FPSO	Mutineer-Exeter Field	Australia	Santos Ltd.	Conversion	2005	MODEC Inc.
Mondo FPSO	Luanda, Angola	Block 15, Angola	ExxonMobil	Conversion	2008	SBM Offshore
Munin	Lufeng, Xijiang	South China Sea, China	CNOOC	Newbuild	1997	Bluewater Energy Services
MV8 Langsa Venture FPSO	Langsa field	Malacca Strait, Indonesia	MEDCO MOECO Langsa Ltd.	Conversion	2001	MODEC Inc.
Mystras FPSO	Okono, Okpoho	Gulf of Guinea, Nigeria	Agip	Conversion	2004	Saipem
Nganhurra FPSO	Enfield	Exmouth Sub-basin, Australia	Woodside Petroleum	Newbuild	2006	
Maersk Ngujima-Yin FPSO	Vincent	Exmouth Sub-basin, Australia	Woodside Petroleum	Conversion	2008	Maersk
Norne FPSO	Norne	North Sea, Norway	Statoil	Newbuild	1997	
Northern Endeavour	Laminaria, Corallina	Timor Sea, Indonesia	Woodside Petroleum	Newbuild		
Perintis	MASA field	South China Sea, Peninsular Malaysia	Petronas Carigali	Conversion	1999	Aker Kvaerner/M3Nergy;
Petrojarl Banff	Banff	North Sea, UK	CNR	Newbuild	1999	Teekay Petrojarl;
Petrojarl Foinaven	Foinaven	North Atlantic, UK	BP	Conversion	1997	Teekay Petrojarl
Petrojarl I	Glitne oilfield	North Sea, Norway	Statoil	Newbuild	2001	Teekay Petrojarl
Petrojarl	Varg	North Sea,	Talisman Energy	Newbuild	1999	Teekay Petrojarl

Varg		Norway				
Pertroleo Nautipa FPSO	Etame	South Atlantic Ocean, Gabon	Vaalco Energy	Conversion	2002	Fred Olsen Production, Prosafe
Polvo FPSO	Polvo	South Atlantic Ocean, Brazil	Devon Energy	Conversion	2007	Prosafe
Rang Dong 1	Rang Dong	South China Sea, Vietnam	JVPC, Nippon Oil	Conversion	1998	Mitsubishi Heavy Industries
Raroa II	Maari	Tasman Sea, New Zealand	OMV	Conversion	2008	
Ruby Princess FPSO	Ruby	South China Sea, Vietnam	Petrovietnam	Conversion	1998	Prosafe
Ruby II FPSO	Ruby	South China Sea, Vietnam	Petronas Carigali Vietnam Ltd	Conversion	2010	MISC Bhd
Sanha LPG FPSO	Angola		Chevron	Newbuild	2005	Chevron
Saxi-Batuque FPSO	Luanda, Angola	Block 15, Angola	ExxonMobil	Conversion	2008	SBM Offshore
Schiehallion FPSO	Schiehallion	North Atlantic, UK	BP	Newbuild	1998	Harland & Wolff
Sea Eagle FPSO	EA	Gulf of Guinea, Nigeria	Shell	Newbuild	2003	
SeaRose FPSO	White Rose	Grand Banks of Newfoundland, Canada	Husky Energy	Newbuild	2005	
Seillean FPSO	Cachalote	Esprito Santo Basin, Brazil	Petrobras but built for BP	Newbuild	1986	Noble Corporation
Serpentina FPSO	Zafiro	Gulf of Guinea, Equatorial Guinea	Exxonmobil	Conversion	2003	SBM Offshore
Skarv FPSO	Skarv and Idun	North Sea, Norway	BP	Newbuild	2011	BP
Song Doc MV19 FPSO	Song Doc Field	Vietnam	Truong Son Joint Operating Company (TSJOC)	Conversion	2008	MODEC Inc.
Stybarrow MV16 FPSO	Stybarrow Field	Exmouth Sub-basin, Australia	BHP Billiton Petroleum	Newbuild	2007	MODEC Inc.
Terra Nova	Terra Nova	Grand Banks of Newfoundland, Canada	Suncor	Newbuild	2002	
Triton	Bittern, Guillemot West, Guillemot Northwest	North Sea, UK	Amerada Hess	Newbuild	2000	
Uisge Gorm FPSO	Fife, Fergus, Flora, Angus	North Sea, UK	Amerada Hess	Conversion	1995	Bluewater Energy Services
Umuroa FPSO	Tui	Tasman Sea, New Zealand	Australian Worldwide Exploration	Conversion	2007	APS/Prosafe Production

Xikomba FPSO	Xikomba	Block 15, Angola	ExxonMobil	Conversion	2003	SBM Offshore
Yunus FSO	BDR3	Mediterranean	Syriah & N.T.J. Group	Conversion	1998	Syriah & NTJ Group
Yúum K'ak'náab FPSO	Ku-Maloob-Zaap field	Gulf of Mexico	PEMEX	Newbuild	1998	BW Offshore AS, Norway

Chapter 4

Physical Oceanography

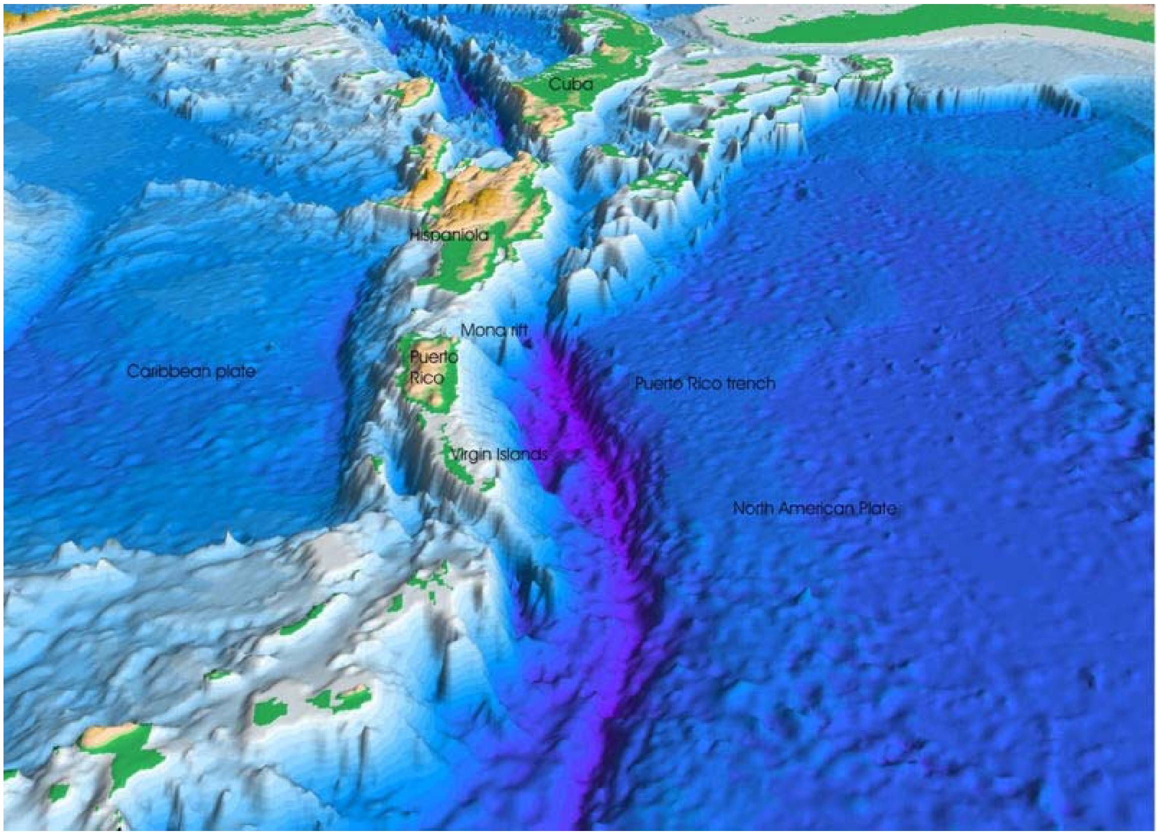


World ocean bathymetry.

Physical oceanography is the study of physical conditions and physical processes within the ocean, especially the motions and physical properties of ocean waters.

Physical oceanography is one of several sub-domains into which oceanography is divided. Others include biological, chemical and geological oceanographies.

The physical setting



Perspective view of the sea floor of the Atlantic Ocean and the Caribbean Sea. The purple sea floor at the center of the view is the Puerto Rico Trench.

The pioneering oceanographer Matthew Maury said in 1855 *"Our planet is invested with two great oceans; one visible, the other invisible; one underfoot, the other overhead; one entirely envelopes it, the other covers about two thirds of its surface."* The fundamental role of the oceans in shaping Earth is acknowledged by ecologists, geologists, meteorologists, climatologists, geographers and others interested in the physical world. An Earth without oceans would truly be unrecognizable.

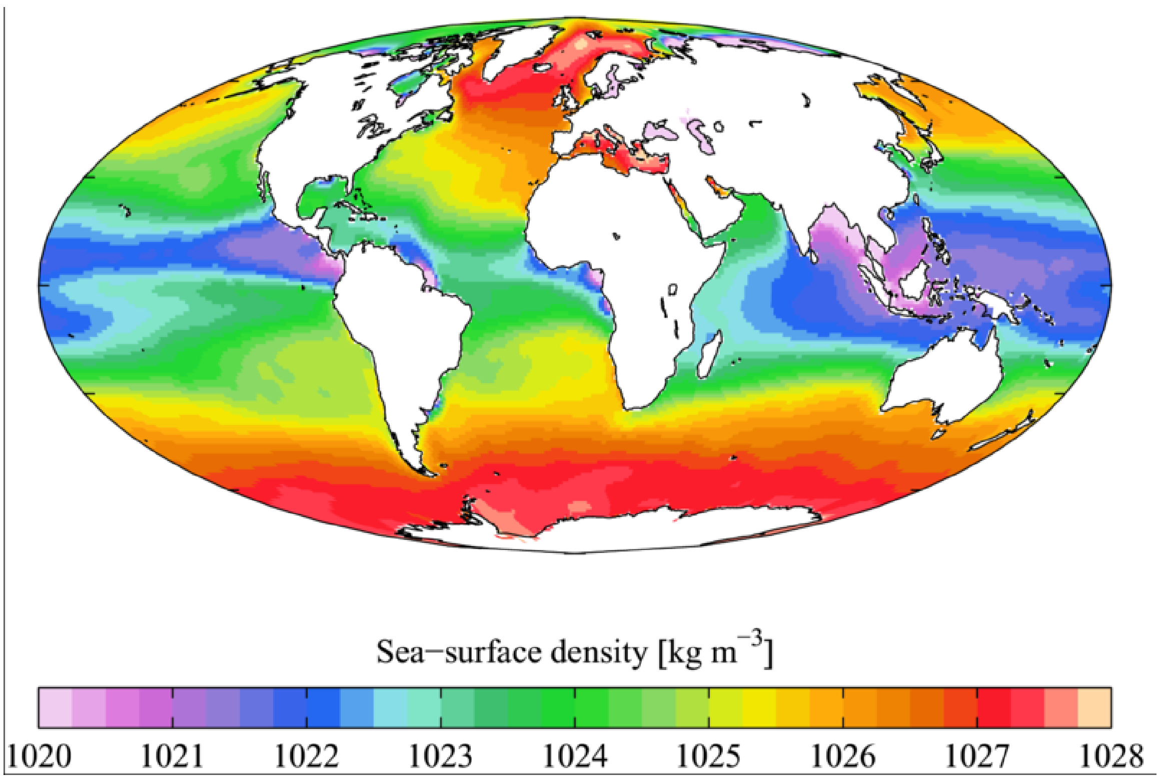
Roughly 97% of the planet's water is in its oceans, and the oceans are the source of the vast majority of water vapor that condenses in the atmosphere and falls as rain or snow on the continents. The tremendous heat capacity of the oceans moderates the planet's climate, and its absorption of various gases affects the composition of the atmosphere. The ocean's influence extends even to the composition of volcanic rocks through seafloor metamorphism, as well as to that of volcanic gases and magmas created at subduction zones.

The oceans are far deeper than the continents are tall; examination of the Earth's hypsographic curve shows that the average elevation of Earth's landmasses is only 840 metres (2,760 ft), while the ocean's average depth is 3,800 metres (12,500 ft). Though this apparent discrepancy is great, for both land and sea, the respective extremes such as mountains and trenches are rare.

Area, volume plus mean and maximum depths of oceans (excluding adjacent seas)

Body	**Area** (10^6km²)	**Volume** (10^6km³)	**Mean depth** (m)	**Maximum** (m)
Pacific Ocean	165.2	707.6	4282	-10911
Atlantic Ocean	82.4	323.6	3926	-8605
Indian Ocean	73.4	291.0	3963	-8047
Southern Ocean	20.3			-7235
Arctic Ocean	14.1		1038	
Caribbean Sea	2.8			-7686

Temperature, salinity and density



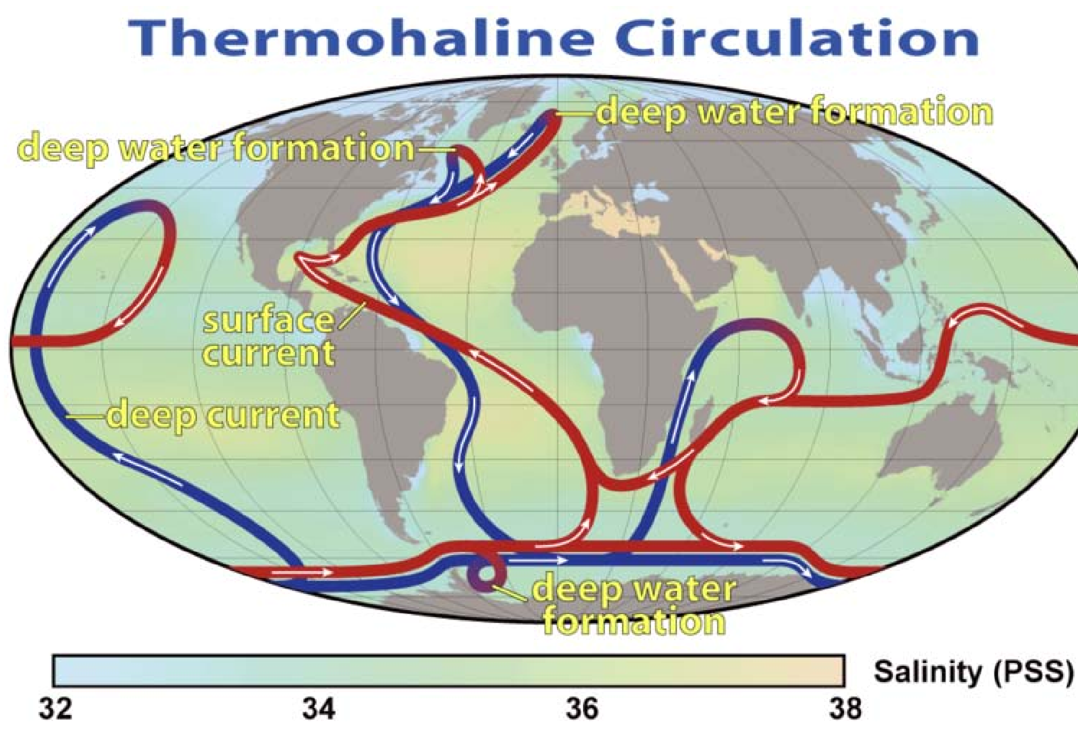
WOA surface density.

Because the vast majority of the world ocean's volume is deep water, the mean temperature of seawater is low; roughly 75% of the ocean's volume has a temperature from 0° – 5°C (Pinet 1996). The same percentage falls in a salinity range between 34–35 ppt (3.4–3.5%) (Pinet 1996). There is still quite a bit of variation, however. Surface temperatures can range from below freezing near the poles to 35°C in restricted tropical seas, while salinity can vary from 10 to 41 ppt (1.0–4.1%).

The vertical structure of the temperature can be divided into three basic layers, a surface mixed layer, where gradients are low, a thermocline where gradients are high, and a poorly stratified abyss.

In terms of temperature, the ocean's layers are highly latitude-dependent; the thermocline is pronounced in the tropics, but nonexistent in polar waters (Marshak 2001). The halocline usually lies near the surface, where evaporation raises salinity in the tropics, or meltwater dilutes it in polar regions. These variations of salinity and temperature with depth change the density of the seawater, creating the pycnocline.

Circulation



Density-driven thermohaline circulation

The ultimate energy source for the ocean circulation (and for the atmospheric circulation) is the sun. The amount of sunlight absorbed at the surface varies strongly with latitude, being greater at the equator than at the poles, and this engenders fluid motion in both the atmosphere and ocean that acts to redistribute heat from the equator towards the poles, thereby reducing the temperature gradients that would exist in the absence of fluid motion. Perhaps three quarters of this heat is carried in the atmosphere; the rest is carried in the ocean.

The atmosphere is heated from below, which leads to convection, the largest expression of which is the Hadley circulation. By contrast the ocean is heated from above, which tends to suppress convection. Instead ocean deep water is formed in polar regions where cold salty waters sink in fairly restricted areas. This is the beginning of the thermohaline circulation.

Oceanic currents are largely driven by the surface wind stress; hence the large-scale atmospheric circulation is important to understanding the ocean circulation. The Hadley circulation leads to Easterly winds in the tropics and Westerlies in mid-latitudes, which creates an anticyclonic wind stress curl over the subtropical ocean. This leads to slow equatorward flow throughout most of a subtropical ocean basin (the Sverdrup balance). The return flow occurs in an intense, narrow, poleward western boundary current. Like the atmosphere, the ocean is far wider than it is deep, and hence horizontal motion is in general much faster than vertical motion. In the southern hemisphere there is a continuous belt of ocean, and hence the mid-latitude westerlies force the strong Antarctic Circumpolar Current. In the northern hemisphere the land masses prevent this and the ocean circulation is broken into smaller gyres in the Atlantic and Pacific basins.

Coriolis effect

The Coriolis effect results in a deflection of fluid flows (to the right in the Northern Hemisphere and left in the Southern Hemisphere). Because the distance around the Earth decreases as one moves away from the equator, and because the Earth rotates in a counter clockwise direction as seen from the north pole, air and water masses are deflected to the east as they move from the equator to the poles, and to the west as they move from the poles to the equator. This has profound effects on the flow of the oceans. In particular it means the flow goes *around* high and low pressure systems, permitting them to persist for long periods of time. As a result, tiny variations in pressure can produce measurable currents. A slope of one part in one million in sea surface height, for example, will result in a current of 1 cm/s at mid-latitudes. The fact that the Coriolis effect is largest at the poles and weak at the equator results in sharp, relatively steady western boundary currents which are absent on eastern boundaries.

The Coriolis effect is also responsible for coastal upwelling as wind-driven currents tend to forced to the right of the winds in the Northern Hemisphere and to the left of the winds in the Southern Hemisphere. When winds blow either equatorward along an eastern ocean boundary or poleward along a western ocean boundary, water is driven away from the coasts (the so called Ekman transport), and denser water rises from below to replace it.

Ekman transport

Ekman Transport results in the net transport of surface water 90 degrees to the right of the wind in the Northern Hemisphere, and 90 degrees to the left of the wind in the Southern Hemisphere. As the wind blows across the surface of the ocean, it "grabs" onto a thin layer of the surface water. In turn, that thin sheet of water transfers motion energy to the thin layer of water under it, and so on. However, because of the Coriolis Effect, the direction of travel of the layers of water slowly move farther and farther to the right as they get deeper in the Northern Hemisphere, and to the left in the Southern Hemisphere. In most cases, the very bottom layer of water affected by the wind is at a depth of 100 m – 150 m and is traveling about 180 degrees, completely opposite of the direction that the wind is blowing. Overall, the net transport of water would be 90 degrees from the original direction of the wind.

Langmuir circulation

Langmuir circulation results in the occurrence of thin, visible stripes, called windrows on the surface of the ocean parallel to the direction that the wind is blowing. If the wind is blowing with more than 3 m s^{-1}, it can create parallel windrows alternating upwelling and downwelling about 5–300 m apart. These windrows are created by adjacent ovular water cells (extending to about 6 m (20 ft) deep) alternating rotating clockwise and counterclockwise. In the convergence zones debris, foam and seaweed accumulates, while at the divergencezones plankton are caught and carried to the surface. If there are many plankton in the divergencezone fish are often attracted to feed on them.

Ocean–atmosphere interface

Hurricane Isabel east of the Bahamas on 15 September 2003

At the ocean-atmosphere interface, the ocean and atmosphere exchange fluxes of heat, moisture and momentum.

Heat

The important heat terms at the surface are the sensible heat flux, the latent heat flux, the incoming solar radiation and the balance of long-wave (infrared) radiation. In general, the tropical oceans will tend to show a net gain of heat, and the polar oceans a net loss, the result of a net transfer of energy polewards in the oceans.

The oceans' large heat capacity moderates the climate of areas adjacent to the oceans, leading to a maritime climate at such locations. This can be a result of heat storage in summer and release in winter; or of transport of heat from warmer locations: a particularly notable example of this is Western Europe, which is heated at least in part by the north atlantic drift.

Momentum

Surface winds tend to be of order meters per second; ocean currents of order centimeters per second. Hence from the point of view of the atmosphere, the ocean can be considered effectively stationary; from the point of view of the ocean, the atmosphere imposes a significant wind stress on its surface, and this forces large-scale currents in the ocean.

Through the wind stress, the wind generates ocean surface waves; the longer waves have a phase velocity tending towards the wind speed. Momentum of the surface winds is transferred into the energy flux by the ocean surface waves. The increased roughness of the ocean surface, by the presence of the waves, changes the wind near the surface.

Moisture

The ocean can gain moisture from rainfall, or lose it through evaporation. Evaporative loss leaves the ocean saltier; the Mediterranean and Persian Gulf for example have strong evaporative loss; the resulting plume of dense salty water may be traced through the Straits of Gibraltar into the Atlantic Ocean. At one time, it was believed that evaporation/precipitation was a major driver of ocean currents; it is now known to be only a very minor factor.

Planetary waves

Kelvin Waves

A Kelvin wave is any progressive wave that is channeled between two boundaries or opposing forces (usually between the Coriolis force and a coastline or the equator). There are two types, coastal and equatorial. Kelvin waves are gravity driven and non-dispersive, meaning that the phase speed of the wave at any one frequency will equal the group speed of the wave energy for all frequencies. This means that Kelvin waves can retain their shape and direction over long periods of time. They are usually created by a sudden shift in the wind, such as the change of the trade winds at the beginning of the El Niño-Southern Oscillation.

Coastal Kelvin waves follow shorelines and will always propagate in a counterclockwise direction in the Northern hemisphere (with the shoreline to the right of the direction of travel) and clockwise in the Southern hemisphere.

Equatorial Kelvin waves propagate to the east in the Northern hemisphere and to the west in the Southern hemisphere, using the equator as a guide.

Kelvin waves are known to have very high speeds, typically around 2–3 meters per second. They have wavelengths of thousands of kilometers and amplitudes in the tens of meters.

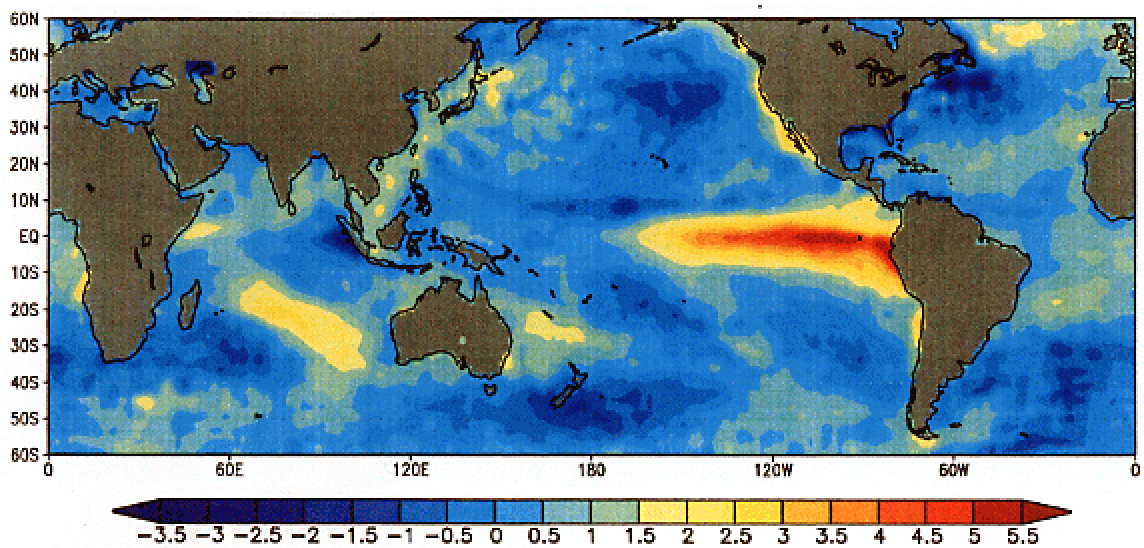
Rossby Waves

Rossby waves, or planetary waves are huge, slow waves generated in the troposphere by temperature differences between the ocean and the continents. Their major restoring force is the change in Coriolis force with latitude. Their wave amplitudes are usually in the tens of meters and very large wavelengths. They are usually found at low or mid latitudes

There are two types of Rossby waves, barotropic and baroclinic. Barotropic Rossby waves have the highest speeds and do not vary vertically. Baroclinic Rossby waves are much slower.

The special identifying feature of Rossby waves is that the phase velocity of each individual wave always has a westward component, but the group velocity can be in any direction. Usually the shorter Rossby waves have an eastward group velocity and the longer ones have a westward group velocity.

Climate variability



December 1997 chart of ocean surface temperature anomaly [°C] during the last strong El Niño

The interaction of ocean circulation, which serves as a type of heat pump, and biological effects such as the concentration of carbon dioxide can result in global climate changes on a time scale of decades. Known climate oscillations resulting from these interactions, include the Pacific decadal oscillation, North Atlantic oscillation, and Arctic oscillation. The oceanic process of thermohaline circulation is a significant component of heat redistribution across the globe, and changes in this circulation can have major impacts upon the climate.

Antarctic circumpolar wave

This is a coupled ocean/atmosphere wave that circles the Southern Ocean about every eight years. Since it is a wave-2 phenomenon (there are two peaks and two troughs in a latitude circle) at each fixed point in space a signal with a period of four years is seen. The wave moves eastward in the direction of the Antarctic Circumpolar Current.

Ocean currents

Among the most important ocean currents are the:

- Antarctic Circumpolar Current
- Deep ocean (density-driven)
- Western boundary currents
    - Gulf Stream
    - Kuroshio Current
    - Labrador Current
    - Oyashio Current
    - Agulhas Current
    - Brazil Current
    - East Australia Current
- Eastern Boundary currents
    - California Current
    - Canary Current
    - Peru Current
    - Benguela Current

: Ocean gyre

Antarctic circumpolar

The ocean body surrounding the Antarctic is currently the only continuous body of water where there is a wide latitude band of open water. It interconnects the Atlantic, Pacific and Indian oceans, and provide an uninterrupted stretch for the prevailing westerly winds to significantly increase wave amplitudes. It is generally accepted that these prevailing winds are primarily responsible for the circumpolar current transport. This current is now thought to vary with time, possibly in an oscillatory manner.

Deep ocean

In the Norwegian Sea evaporative cooling is predominant, and the sinking water mass, the North Atlantic Deep Water (NADW), fills the basin and spills southwards through crevasses in the submarine sills that connect Greenland, Iceland and Britain. It then flows along the western boundary of the Atlantic with some part of the flow moving eastward along the equator and then poleward into the ocean basins. The NADW is entrained into the Circumpolar Current, and can be traced into the Indian and Pacific basins. Flow from the Arctic Ocean Basin into the Pacific, however, is blocked by the narrow shallows of the Bering Strait.

Western boundary

An idealised subtropical ocean basin forced by winds circling around a high pressure (anticyclonic) systems such as the Azores-Bermuda high develops a gyre circulation with slow steady flows towards the equator in the interior. As discussed by Henry Stommel, these flows are balanced in the region of the western boundary, where a thin fast polewards flow called a western boundary current develops. Flow in the real ocean is more complex, but the Gulf stream, Agulhas and Kuroshio are examples of such currents. They are narrow (approximately 100 km across) and fast (approximately 1.5 m/s).

Equatorwards western boundary currents occur in tropical and polar locations, e.g. the East Greenland and Labrador currents, in the Atlantic and the Oyashio. They are forced by winds circulation around low pressure (cyclonic)

Gulf stream

The Gulf Stream, together with its northern extension, North Atlantic Current, is a powerful, warm, and swift Atlantic ocean current that originates in the Gulf of Mexico, exits through the Strait of Florida, and follows the eastern coastlines of the United States and Newfoundland to the northeast before crossing the Atlantic Ocean.

Kuroshio

The Kuroshio Current is an ocean current found in the western Pacific Ocean off the east coast of Taiwan and flowing northeastward past Japan, where it merges with the easterly drift of the North Pacific Current. It is analogous to the Gulf Stream in the Atlantic Ocean, transporting warm, tropical water northward towards the polar region.

Heat flux

Heat storage

Heat storage and transfer in the ocean is very uneven.

Sea level change

Tide gauges and satellite altimetry suggest an increase in sea level of 1.5–3 mm/yr over the past 100 years.

The IPCC predicts that by 2100, global warming will lead to a sea level rise of 110 to 880 mm.

Rapid variations

Tides

The **Bay of Fundy** is a bay located on the Atlantic coast of North America, on the northeast end of the Gulf of Maine between the provinces of New Brunswick and Nova Scotia.

The rise and fall of the oceans due to tidal effects is a key influence upon the coastal areas. Ocean tides on the planet Earth are created by the gravitational effects of the Sun and Moon. The tides produced by these two bodies are roughly comparable in magnitude, but the orbital motion of the Moon results in tidal patterns that vary over the course of a month.

The ebb and flow of the tides produce a cyclical current along the coast, and the strength of this current can be quite dramatic along narrow estuaries. Incoming tides can also produce a tidal bore along a river or narrow bay as the water flow against the current results in a wave on the surface.

Tide and Current (Wyban 1992) clearly illustrates the impact of these natural cycles on the lifestyle and livelihood of Native Hawaiians tending coastal fishponds. *Aia ke ola ka hana* meaning . . . *Life is in labor*.

Tidal resonance occurs in the Bay of Fundy since the time it takes for a large wave to travel from the mouth of the bay to the opposite end, then reflect and travel back to the mouth of the bay coincides with the timing between this repeating wave that is also reinforced by the tidal rhythm producing the world's highest tides.

As the surface tide oscillates over topography, such as submerged seamounts or ridges, it generates internal waves at the tidal frequency, which are known as internal tides.

Tsunamis

A series of surface waves can be generated due to large-scale displacement of the ocean water. These can be caused by sub-marine landslides, seafloor deformations due to earthquakes, or the impact of a large meteorite.

The waves can travel with a velocity of up to several hundred km/hour across the ocean surface, but in mid-ocean they are barely detectable with wavelengths spanning hundreds of kilometers.

Tsunamis, originally called tidal waves, were renamed because they are not related to the tides. They are regarded as shallow-water waves, or waves in water with a depth less than 1/20 their wavelength. Tsunamis have very large periods, high speeds, and great wave heights.

The primary impact of these waves is along the coastal shoreline, as large amounts of ocean water are cyclically propelled inland and then drawn out to sea. This can result in significant modifications to the coastline regions where the waves strike with sufficient energy.

The tsunami that occurred in Lituya Bay, Alaska on July 9, 1958 was 520 m (1,710 ft) high and is the biggest tsunami ever measured, almost 90 m (300 ft) taller than the Sears Tower in Chicago and about 110 m (360 ft) taller than the World Trade Center in New York.

Surface waves

The wind generates ocean surface waves, which have a large impact on offshore structures, ships, coastal erosion and sedimentation, as well as harbours. After their generation by the wind, ocean surface waves can travel (as swell) over long distances.

Chapter 5

Bingham Plastic

A **Bingham plastic** is a viscoplastic material that behaves as a rigid body at low stresses but flows as a viscous fluid at high stress. It is named after Eugene C. Bingham who proposed its mathematical form..

It is used as a common mathematical model of mud flow in offshore engineering, and in the handling of slurries. A common example is toothpaste, which will not be extruded until a certain pressure is applied to the tube. It then is pushed out as a solid plug.

Explanation

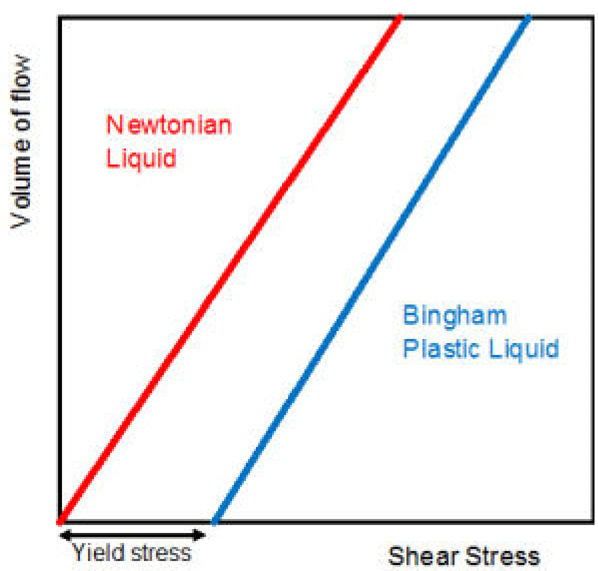


Figure 1. Bingham Plastic flow as described by Bingham

Figure 1 shows a graph of the behaviour of an ordinary viscous (or Newtonian) fluid in red, for example in a pipe. If the pressure at one end of a pipe is increased this produces a stress on the fluid tending to make it move (called the shear stress) and the volumetric flow rate increases proportionally. However for a Bingham Plastic fluid (in blue), stress can be applied but it will not flow until a certain value, the yield stress, is reached. Beyond this point the flow rate increases steadily with increasing shear stress. This is roughly the way in which Bingham presented his observation, in an experimental study of paints.

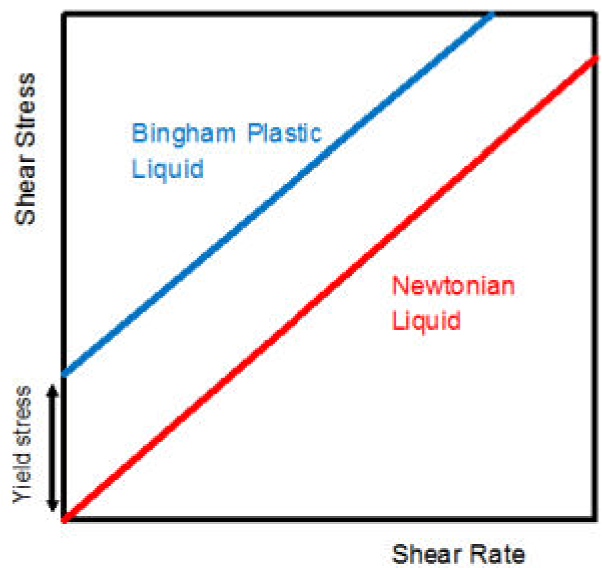


Figure 2. Bingham Plastic flow as described currently

Figure 2 shows the way in which it is normally presented currently. The graph shows shear stress on the vertical axis and shear rate on the horizontal one. (Volumetric flow rate depends on the size of the pipe, shear rate is a measure of how the velocity changes with distance. It is proportional to flow rate, but does not depend on pipe size.) As before, the Newtonian fluid flows and gives a shear rate for any finite value of shear stress. However, the Bingham Plastic again does not exhibit any shear rate (no flow and thus no velocity) until a certain stress is achieved. For the Newtonian fluid the slope of this line is the viscosity, which is the only parameter needed to describe its flow. By contrast the Bingham Plastic requires two parameters, the **yield stress** and the slope of the line, known as the **plastic viscosity**.

The physical reason for this behaviour is that the liquid contains particles (e.g. clay) or large molecules (e.g. polymers) which have some kind of interaction, creating a weak solid structure, formerly known as a **false body**, and a certain amount of stress is required to break this structure. Once the structure has been broken, the particles move with the liquid under viscous forces. If the stress is removed, the particles associate again.

Definition

The material is rigid for shear stress τ, less than a critical value τ_0. Once the critical shear stress (or "yield stress") is exceeded, the material flows in such a way that the shear rate,

$\partial u/\partial y$, is directly proportional to the amount by which the applied shear stress exceeds the yield stress:

$$\frac{\partial u}{\partial y} = \begin{cases} 0 & ,\tau < \tau_0 \\ (\tau - \tau_0)/\mu & ,\tau \geq \tau_0 \end{cases}$$

Friction Factor Formulae

In fluid flow, it is a common problem to calculate the pressure drop in an established piping network. Once the friction factor, *f*, is known, it becomes easier to handle different pipe-flow problems, viz. calculating the pressure drop for evaluating pumping costs or to find the flow-rate in a piping network for a given pressure drop. It is usually extremely difficult to arrive at exact analytical solution to calculate the friction factor associated with flow of non-Newtonian fluids and therefore explicit approximations are used to calculate it. Once the friction factor has been calculated the pressure drop can be easily determined for a given flow by the Darcy–Weisbach equation:

$$f = \frac{2h_f gD}{LV^2}$$

where:

- h_f is the frictional head loss (SI units: m)
- f is the friction factor (SI units: Dimensionless)
- L is the pipe length (SI units: m)
- g is the gravitational acceleration (SI units: m/s²)
- D is the pipe diameter (SI units: m)
- V is the mean fluid velocity (SI units: m/s)

Laminar flow

An exact description of friction loss for Bingham plastics in fully developed laminar pipe flow was first published by Buckingham. His expression, the *Buckingham-Reiner* equation, can be written in a dimensionless form as follows:

$$f_L = \frac{64}{Re}[1 + \frac{He}{6Re} - \frac{64}{3}(\frac{He^4}{{f_L}^3 Re^7})]$$

where:

- f_L is the laminar flow friction factor (SI units: Dimensionless)
- Re is the Reynolds number (SI units: Dimensionless)
- He is the Hedstrom number (SI units: Dimensionless)

The Reynolds number and the Hedstrom number are respectively defined as:

$$\mathrm{Re} = \frac{D\ V}{\nu_\infty}$$, and

$$\mathrm{He} = \frac{D^2 \tau_o}{\rho {\nu_\infty}^2},$$

where:

- ρ is the mass density of fluid (SI units: kg/m^3)
- ν_∞ is the kinematic viscosity of fluid (SI units: m^2/s)

Turbulent flow

Darby and Melson developed an empirical expression that determines the friction factor for turbulent-flow regime of Bingham plastic fluids, and is given by:

$$f_T = \ 10^a\ Re^{-0.193}$$

where:

- f_T is the turbulent flow friction factor (SI units: Dimensionless)
- $a = -1.378[1 + 0.146\ e^{-2.9 \times 10^{-5} Re}]$

Approximations of the **Buckingham-Reiner** *equation*

Although an exact analytical solution of the *Buckingham-Reiner* equation can be obtained because it is a fourth order polynomial equation in *f*, due to complexity of the solution it is rarely employed. Therefore, researchers have tried to develop explicit approximations for the *Buckingham-Reiner* equation.

Swamee-Aggarwal Equation

The *Swamee Aggarwal* equation is used to solve directly for the Darcy–Weisbach friction factor *f* for laminar flow of Bingham plastic fluids. It is an approximation of the implicit *Buckingham-Reiner* equation, but the discrepancy from experimental data is well within the accuracy of the data. The *Swamee-Aggarwal* equation is given by:

$$f_L = \ \frac{64}{Re} + \frac{10.67 + 0.1414(\frac{He}{Re})^{1.143}}{[1 + 0.0149(\frac{He}{Re})^{1.16}]Re}(\frac{He}{Re})$$

Danish-Kumar Solution

Danish *et al.* have provided an explicit procedure to calculate the friction factor *f* by using the Adomian decomposition method. The friction factor containing two terms through this method is given as:

$$f_L = \frac{\left(K_1 + \frac{4K_2}{\left(K_1 + \frac{K_1 K_2}{K_1{}^4 + 3K_2}\right)^3}\right)}{\left(1 + \frac{3K_2}{\left(K_1 + \frac{K_1 K_2}{K_1{}^4 + 3K_2}\right)^4}\right)}$$

where:

$$K_1 = \frac{16}{Re} + \frac{16He}{6Re^2}$$, and

$$K_2 = -\frac{16He^4}{3Re^8}$$

Combined Equation for friction factor for all flow regimes

Darby-Melson Equation

In 1981, Darby and Melson, using the approach of Churchill and of Churchill and Usagi , developed an expression to get a single friction factor equation valid for all flow regimes:

$$f = \left[f_L{}^m + f_T{}^m\right]^{\frac{1}{m}}$$

where:

$$m = 1.7 + \frac{40000}{Re}$$

Both *Swamee-Aggarwal* equation and the *Darby-Melson* equation can be combined to give an explicit equation for determining the friction factor of Bingham plastic fluids in any regime. Relative roughness is not a parameter in any of the equations because the friction factor of Bingham plastic fluids is not sensitive to pipe roughness.

Chapter 6

Oil Platform

A typical offshore Oil/Gas platform.

An **offshore platform**, also referred to as an **oil platform** or **oil rig**, is a large structure with facilities to drill wells and extract and process oil and natural gas and export the products to shore.

Depending on the circumstances, the platform may be fixed to the ocean floor, may consist of an artificial island, or may float.

Remote subsea wells may also be connected to a platform by flow lines and by umbilical connections; these subsea solutions may consist of single wells or of a manifold centre for multiple wells.

History

Offshore platform Gulf of Mexico

Around 1891 the first submerged oil wells were drilled from platforms built on piles in the fresh waters of the Grand Lake St. Marys (a.k.a. Mercer County Reservoir) in Ohio. The wide but shallow reservoir was built from 1837 to 1845 to provide water to the Miami and Erie Canal.

Around 1896 the first submerged oil wells in salt water were drilled in the portion of the Summerland field extending under the Santa Barbara Channel in California. The wells were drilled from piers extending from land out into the channel.

Other notable early submerged drilling activities occurred on the Canadian side of Lake Erie in the 1900s and Caddo Lake in Louisiana in the 1910s. Shortly thereafter, wells were drilled in tidal zones along the Gulf Coast of Texas and Louisiana. The Goose Creek field near Baytown, Texas is one such example. In the 1920s drilling was done from concrete platforms in Lake Maracaibo, Venezuela.

The oldest subsea well recorded in Infield's offshore database is the Bibi Eibat well which came on stream in 1923 in Azerbaijan. Landfill was used to raise shallow portions of the Caspian Sea.

In the early 1930s the Texas Company developed the first mobile steel barges for drilling in the brackish coastal areas of the gulf.

In 1937 Pure Oil Company (now part of Chevron Corporation) and its partner Superior Oil Company (now part of ExxonMobil Corporation) used a fixed platform to develop a field in 14 feet of water, one mile offshore of Calcasieu Parish, Louisiana.

In 1946, Magnolia Petroleum Company (now part of ExxonMobil) erected a drilling platform in 18 ft of water, 18 miles off the coast of St. Mary Parish, Louisiana.

In early 1947 Superior Oil erected a drilling/production platform in 20 ft of water some 18 miles off Vermilion Parish, Louisiana. But it was Kerr-McGee Oil Industries (now Anadarko Petroleum Corporation), as operator for partners Phillips Petroleum (ConocoPhillips) and Stanolind Oil & Gas (BP), that completed its historic Ship Shoal Block 32 well in October 1947, months before Superior actually drilled a discovery from their Vermilion platform farther offshore. In any case, that made Kerr-McGee's well the first oil discovery drilled out of sight of land.

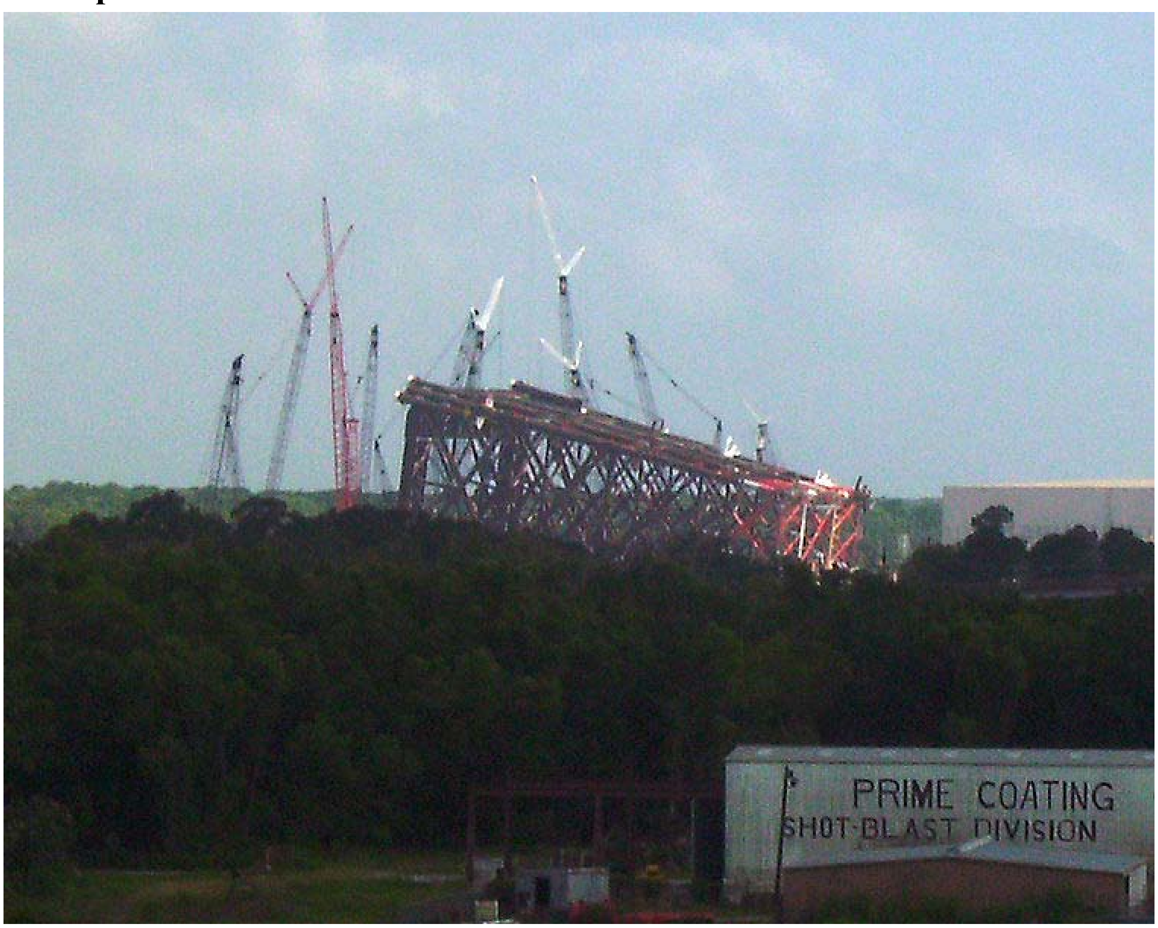
The Thames Sea Forts of World War II are considered the direct predecessors of modern offshore platforms. Having been pre-constructed in a very short time, they were then floated to their location and placed on the shallow bottom of the Thames estuary.

Types

Larger lake- and sea-based offshore platforms and drilling rigs are some of the largest moveable man-made structures in the world. There are several types of oil platforms and rigs:

1, 2) conventional fixed platforms; 3) compliant tower; 4, 5) vertically moored tension leg and mini-tension leg platform; 6) Spar ; 7,8) Semi-submersibles ; 9) Floating production, storage, and offloading facility; 10) sub-sea completion and tie-back to host facility.

Fixed platforms



A fixed platform base under construction on a Louisiana river

These platforms are built on concrete or steel legs, or both, anchored directly onto the seabed, supporting a deck with space for drilling rigs, production facilities and crew quarters. Such platforms are, by virtue of their immobility, designed for very long term use (for instance the Hibernia platform). Various types of structure are used, steel jacket, concrete caisson, floating steel and even floating concrete. Steel jackets are vertical sections made of tubular steel members, and are usually piled into the seabed. Concrete caisson structures, pioneered by the Condeep concept, often have in-built oil storage in tanks below the sea surface and these tanks were often used as a flotation capability, allowing them to be built close to shore (Norwegian fjords and Scottish firths are popular because they are sheltered and deep enough) and then floated to their final position where they are sunk to the seabed. Fixed platforms are economically feasible for installation in water depths up to about 1,700 ft (520 m).

Compliant towers

These platforms consist of slender flexible towers and a pile foundation supporting a conventional deck for drilling and production operations. Compliant towers are designed to sustain significant lateral deflections and forces, and are typically used in water depths ranging from 1,500 to 3,000 feet (460 to 910 m).

Semi-submersible platform

Platform P-51 off the Brazilian coast is a semi-submersible platform

These platforms have hulls (columns and pontoons) of sufficient buoyancy to cause the structure to float, but of weight sufficient to keep the structure upright. Semi-submersible platforms can be moved from place to place; can be ballasted up or down by altering the amount of flooding in buoyancy tanks; they are generally anchored by combinations of chain, wire rope or polyester rope, or both, during drilling or production operations, or both, though they can also be kept in place by the use of dynamic positioning. Semi-submersibles can be used in water depths from 200 to 10,000 feet (60 to 3,000 m).

Jack-up drilling rigs

Jack-up Mobile Drilling Units (or jack-ups), as the name suggests, are rigs that can be jacked up above the sea using legs that can be lowered, much like jacks. These MODU's-Mobile Offshore Drilling Units are typically used in water depths up to 400 feet (120 m), although some designs can go to 550 ft (170 m) depth. They are designed to move from place to place, and then anchor themselves by deploying the legs to the ocean bottom using a rack and pinion gear system on each leg.

Drillships

A drillship is a maritime vessel that has been fitted with drilling apparatus. It is most often used for exploratory drilling of new oil or gas wells in deep water but can also be used for scientific drilling. Early versions were built on a modified tanker hull, but purpose-built designs are used today. Most drillships are outfitted with a dynamic positioning system to maintain position over the well. They can drill in water depths up to 12,000 ft (3,700 m).

Floating production systems

The main types of floating production systems are FPSO (floating production, storage, and offloading system). FPSOs consist of large monohull structures, generally (but not always) shipshaped, equipped with processing facilities. These platforms are moored to a location for extended periods, and do not actually drill for oil or gas. Some variants of these applications, called FSO (floating storage and offloading system) or FSU (floating storage unit), are used exclusively for storage purposes, and host very little process equipment.

Tension-leg platform

TLPs are floating platforms tethered to the seabed in a manner that eliminates most vertical movement of the structure. TLPs are used in water depths up to about 6,000 feet (2,000 m). The "conventional" TLP is a 4-column design which looks similar to a semisubmersible. Proprietary versions include the Seastar and MOSES mini TLPs; they are relatively low cost, used in water depths between 600 and 4,300 feet (180 and 1,300 m). Mini TLPs can also be used as utility, satellite or early production platforms for larger deepwater discoveries.

Spar platforms

Devil's Tower Spar Platform

Spars are moored to the seabed like TLPs, but whereas a TLP has vertical tension tethers, a spar has more conventional mooring lines. Spars have to-date been designed in three configurations: the "conventional" one-piece cylindrical hull, the "truss spar" where the midsection is composed of truss elements connecting the upper buoyant hull (called a hard tank) with the bottom soft tank containing permanent ballast, and the "cell spar" which is built from multiple vertical cylinders. The spar has more inherent stability than a TLP since it has a large counterweight at the bottom and does not depend on the mooring to hold it upright. It also has the ability, by adjusting the mooring line tensions (using chain-jacks attached to the mooring lines), to move horizontally and to position itself over wells at some distance from the main platform location. The first production spar was Kerr-McGee's Neptune, anchored in 1,930 ft (590 m) in the Gulf of Mexico; however, spars (such as Brent Spar) were previously used as FSOs.

Eni's Devil's Tower located in 5,610 ft (1,710 m) of water, in the Gulf of Mexico, was the world's deepest spar until 2010. The world's deepest platform is currently the Perdido spar in the Gulf of Mexico, floating in 2,438 meters of water. It is operated by Royal Dutch Shell and was built at a cost of $3 billion.

The first truss spars were Kerr-McGee's Boomvang and Nansen. The first (and only) cell spar is Kerr-McGee's Red Hawk.

Normally unmanned installations (NUI)

These installations (sometimes called toadstools) are small platforms, consisting of little more than a well bay, helipad and emergency shelter. They are designed to operate remotely under normal conditions, only to be visited occasionally for routine maintenance or well work.

Conductor support systems

These installations, also known as **satellite platforms**, are small unmanned platforms consisting of little more than a well bay and a small process plant. They are designed to operate in conjunction with a static production platform which is connected to the platform by flow lines or by umbilical cable, or both.

Particularly large examples

A 'Statfjord' Gravity base structure under construction in Norway. Almost all of the structure will end up submerged.

The Petronius Platform is a compliant tower in the Gulf of Mexico, which stands 2,000 feet (610 m) above the ocean floor. It is one of the world's tallest structures.

The Hibernia platform is the world's largest (in terms of weight) offshore platform, located on the Jeanne D'Arc basin, in the Atlantic Ocean off the coast of Newfoundland. This *gravity base structure* (GBS), which sits on the ocean floor, is 364 feet (111 m) high and has storage capacity for 1.3 million barrels (210,000 m^3) of crude oil in its 278.8-foot (85.0 m) high caisson. The platform acts as a small concrete island with serrated outer edges designed to withstand the impact of an iceberg. The GBS contains production storage tanks and the remainder of the void space is filled with ballast with the entire structure weighing in at 1.2 million tons.

Maintenance and supply

A typical oil production platform is self-sufficient in energy and water needs, housing electrical generation, water desalinators and all of the equipment necessary to process oil and gas such that it can be either delivered directly onshore by pipeline or to a floating platform or tanker loading facility, or both. Elements in the oil/gas production process include wellhead, production manifold, production separator, glycol process to dry gas, gas compressors, water injection pumps, oil/gas export metering and main oil line pumps.

Larger platforms are assisted by smaller ESVs (emergency support vessels) like the British Iolair that are summoned when something has gone wrong, *e.g.* when a search and rescue operation is required. During normal operations, PSVs (platform supply vessels) keep the platforms provisioned and supplied, and AHTS vessels can also supply them, as well as tow them to location and serve as standby rescue and firefighting vessels.

Crew

Essential personnel

Not all of the following personnel are present on every platform. On smaller platforms, one worker can perform a number of different jobs. The following also are not names officially recognized in the industry:

- OIM (offshore installation manager) who is the ultimate authority during his/her shift and makes the essential decisions regarding the operation of the platform;
- operations team leader (OTL);
- offshore operations engineer (OOE) who is the senior technical authority on the platform;
- PSTL or operations coordinator for managing crew changes;
- dynamic positioning operator, navigation, ship or vessel maneuvering (MODU), station keeping, fire and gas systems operations in the event of incident;
- second mate to meet manning requirements of flag state, operates fast rescue craft, cargo operations, fire team leader;
- third mate to meet manning requirements of flag state, operate fast rescue craft, cargo operations, fire team leader;
- ballast control operator to operate fire and gas systems;
- crane operators to operate the cranes for lifting cargo around the platform and between boats;
- scaffolders to rig up scaffolding for when it is required for workers to work at height;
- coxswains to maintain the lifeboats and manning them if necessary;
- control room operators, especially FPSO or production platforms;

- catering crew, including people tasked with performing essential functions such as cooking, laundry and cleaning the accommodation;
- production techs to run the production plant;
- helicopter pilot(s) living on some platforms that have a helicopter based offshore and transporting workers to other platforms or to shore on crew changes;
- maintenance technicians (instrument, electrical or mechanical).

Incidental personnel

Drill crew will be on board if the installation is performing drilling operations. A drill crew will normally comprise:

- Toolpusher
- Driller
- Roughnecks
- Roustabouts
- Company man
- Mud engineer
- Derrickhand
- Geologist

Well services crew will be on board for well work. The crew will normally comprise:

- Well services supervisor
- Wireline or coiled tubing operators
- Pump operator

Drawbacks

Risks

The nature of their operation — extraction of volatile substances sometimes under extreme pressure in a hostile environment — means risk; accidents and tragedies occur regularly. The U.S. Minerals Management Service reported 69 offshore deaths, 1,349 injuries, and 858 fires and explosions on offshore rigs in the Gulf of Mexico from 2001 to 2010. In July 1988, 167 people died when Occidental Petroleum's Piper Alpha offshore production platform, on the Piper field in the UK sector of the North Sea, exploded after a gas leak. The resulting investigation conducted by Lord Cullen and publicized in the first Cullen Report was highly critical of a number of areas, including, but not limited to, management within the company, the design of the structure, and the Permit to Work System. The report was commissioned in 1988, and was delivered November 1990. The accident greatly accelerated the practice of providing living accommodations on separate platforms, away from those used for extraction.

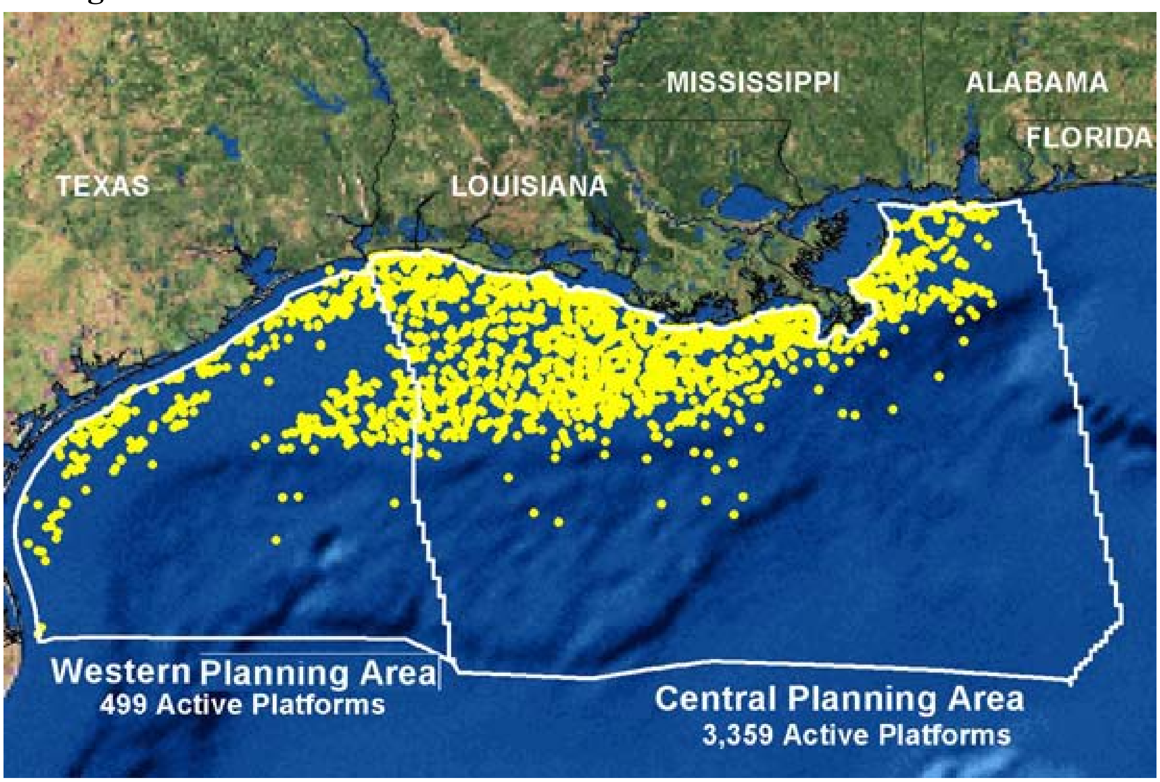
However, this was in itself a hazardous environment. In March 1980, the 'flotel' (floating hotel) platform *Alexander L. Kielland* capsized in a storm in the North Sea with the loss of 123 lives.

In 2001, *Petrobras 36* in Brazil exploded and sank five days later, killing 11 people.

Given the number of grievances and conspiracy theories that involve the oil business, and the importance of gas/oil platforms to the economy, platforms in the United States are believed to be potential terrorist targets. Agencies and military units responsible for maritime counterterrorism in the US (Coast Guard, Navy SEALs, Marine Recon) often train for platform raids.

On April 21, 2010, the *Deepwater Horizon* platform, 52 miles off-shore of Venice, Louisiana, (property of Transocean and leased to BP) exploded, killing 11 people, and sank two days later. The resulting undersea gusher, conservatively estimated to exceed 20 million gallons as of early June, 2010, became the worst oil spill in US history, eclipsing the Exxon Valdez oil spill.

Ecological effects



NOAA map of the 3,858 oil and gas platforms extant in the Gulf of Mexico in 2006

In British waters, the cost of removing all platform rig structures entirely was estimated in 1995 at £1.5 billion, and the cost of removing all structures including pipelines—called a "clean sea" approach—at £3 billion.

In the United States, Marine Biologist Milton Love has proposed that oil platforms off the California coast be retained as artificial reefs, instead of being dismantled (at great cost), because he has found them to be havens for many of the species of fish which are otherwise declining in the region, in the course of 11 years of research. Love is funded mainly by government agencies, but also in small part by the California Artificial Reef Enhancement Program. NOAA has said it is considering this course of action, but wants money to study the effects of the rigs in detail. Divers have been used to assess the fish populations surrounding the platforms. In the Gulf of Mexico, more than 200 platforms have been similarly converted.

Deepest oil platforms

The world's deepest oil platform is the floating Perdido which is a spar platform in the Gulf of Mexico in a water depth of 2,438 metres (7,999 ft).

Non-floating compliant towers and fixed platforms, by water depth:

- Petronius Platform, 531 m (1,742 ft)
- Baldpate Platform, 502 m (1,647 ft)
- Bullwinkle Platform, 413 m (1,355 ft)
- Pompano Platform, 393 m (1,289 ft)
- Benguela-Belize Lobito-Tomboco Platform, 390 m (1,280 ft)
- Tombua Landana Platform, 366 m (1,201 ft)
- Harmony Platform, 366 m (1,201 ft)
- Troll A Platform, 303 m (994 ft)
- Gulfaks C Platform, 217 m (712 ft)

Chapter 7

Offshore Concrete Structure

Offshore concrete structures have been in use successfully for about 30 years. They serve the same purpose as their steel counterparts in the oil and gas production and storage. The first concrete oil platform has been installed in the North Sea in the Ekofisk field in 1973 by Phillips Petroleum. Since then 47 major concrete offshore structures have been built, whereby 21 of the 47 concrete substructures have been designed (concept and detail designs) by Dr. techn. Olav Olsen.

Introduction

Concrete offshore structures are mostly used in the petroleum industry as drilling, extraction or storage units for crude oil or natural gas. Those large structures house machinery and equipment needed to drill and/or extract oil and gas. But concrete structures are not only limited to applications within the oil and gas industry. Several conceptual studies have shown recently, that concrete support structures for offshore wind turbines are very competitive compared to common steel structures, especially for larger water depths.

Depending on the circumstances, platforms may be attached to the ocean floor, consist of an artificial island, or be floating. Generally, offshore concrete structures are classified into fixed and floating structures. Fixed structures are mostly built as concrete gravity based structures (CGS, also termed as caisson type), where the loads bear down directly on the uppermost layers as soil pressure. The caisson provides buoyancy during construction and towing and acts also as a foundation structure in the operation phase. Furthermore, the caisson could be used as storage volume for oil or other liquids.

Floating units will be held in position by anchored wires or chains in a spread mooring pattern. Because of the low stiffness in those systems, the natural frequency is low and the structure can move in all six degrees of freedom. Floating units serve as productions units, storage and offloading units (FSO) or for crude oil or as terminals for liquefied natural gas (LNG). A more recent development is concrete sub-sea structures.

Concrete offshore structures show an excellent performance. They are highly durable, constructed of almost maintenance-free material, suitable for harsh and/or arctic environment (like ice and seismic regions), can carry heavy topsides, often offer storage capacities, are suitable for soft grounds ad are very economical for water depths larger than 150m. Most gravity-type platforms need no additional fixing because of their large foundation dimensions and extremely high weight.

Fixed structures

Since the 1970s, several fixed concrete platform designs have been developed. Most of the designs have in common a base caisson (normally for storage of oil) and shafts penetrating the water surface to carry the topside. In the shafts normally utility systems for offloading, drilling, draw down and ballast are put up.

Concrete offshore platforms of the gravity-base type are almost always constructed in their vertical attitude. This allows the inshore installation of deck girders and equipment and the later transport of the whole structure to the installation site.

The most common concrete designs are:

- Condeep (with one, two, three or four columns)
- ANDOC (with four columns)
- Sea Tank (with two or four columns)
- C G Doris
- Arup Concrete Gravity Substructure (CGS)

Condeep Type

Condeep refers to a make of gravity base structure for oil platforms developed and fabricated by Norwegian Contractors in Norway. A Condeep usually consists of a base of concrete oil storage tanks from which one, three or four concrete shafts rise. The original Condeep always rests on the sea floor, and the shafts rise to about 30m above the sea level. The platform deck itself is not a part of the construction. The Condeep Platforms Brent B (1975) and Brent D (1976) were designed for a water depth of 142m in the Brent oilfield operated by Shell. Their main mass is represented by the storage tank (ca. 100m diameter and 56m high, consisting of 19 cylindrical compartments with 20m diameter). Three of the cells are extended into shafts tapering off at the surface and carrying a steel deck. The tanks serve as storage of crude oil in the operation phase. During the installation these tanks have been used as ballast compartment. Among the largest Condeep type platform are the Troll A platform and the Gullfaks C. Troll A was built within four years and deployed in 1995 to produce gas from the Troll oil field which is operated by Norske Shell. A detailed overview about Condeep platforms is given in a separate article.

Concrete Gravity Base Structures (CGBS) is a further development of the first-generation Condeep drilling/production platforms installed in the North Sea between the late 1970s and mid '90s. The CGBS have no oil storage facilities and the topside installations will be carried out in the field by a float-over mating method. Current or most recent projects are:

- Sakhalin-II platforms (Molikpaq (Piltun-Astokhskoye A; PA-A) platform, Piltun-Astokhskoye B (PA-B) platform and Lunskoye (LUN-A) platform)
- Malampaya
- Wandoo

C G DORIS Type

The first concrete gravity platform in the North Sea was a C G Doris platform, the Ekofisk Tank, in Norwegian waters. The structure has a shape not unlike a marine sea island and is surrounded by a perforated breakwater wall (Jarlan patent). The original proposal of the French group C G DORIS (Compagnie General pour les Developments Operationelles des Richesses Sous-Marines) for a prestressed post-tensioned concrete "island" structure was adopted on cost and operational grounds. DORIS was general contractor responsible for the structural design: the concrete design was prepared and supervised on behalf of DORIS by Europe-Etudes. Further example for the C G DORIS designs are the Frigg platforms, the Ninian Platform and the Schwedeneck platforms. Thedesign typically consists of a large volume caisson based on the sea floor merging into a monolithic structure , which is offering the base for the deck. The single main leg is surrounded by an outer breaker wall perforated with so called Jarlan holes. This wall is intended to break up waves, thus reducing their forces.

McAlpine/Sea Tank

This desigin is quite similar to the Condeep type.

ANDOC Type

To achieve its goal and extract oil within five years after discovering the Brent reservoir Shell divided up the construction of four offshore platforms. Redpath Dorman Long at Methil in Fife, Scotland getting Brent A, the two concrete Condeeps B and D were to be built in Norway by Norwegian Contractors (NC) of Stavanger, and C (also concrete) was to be built by McAlpine at Ardyne Point on the Clyde (which is known as the ANDOC design). The ANDOC design can be considered as the British construction industry's attempt to compete with Norway in this sector. McAlpine constructed three concrete platforms for the North Sea oil industry at Ardyne Point. The ANDOC type is very similar to the Sea Tank design, but the four concrete legs terminate and steel legs take over to support the deck.

Arup Concrete Gravity Substructure (CGS)

The Arup dry-build Concrete Gravity Substructure (CGS) concept was originally developed by Arup in 1989 for Hamilton Brothers' Ravenspurn North. The Arup CGS are designed to be simple to install, and are fully removable. Simplicity and repetition of concrete structural elements, low reinforcement and pre-stress densities as well as the use of normal density concrete lead to economical construction costs. Typical for the Arup CGS is the inclined installation technique. This technique helps to maximise economy and provide a robust offshore emplacement methodology. Further projects have been the Malampaya project in the Philippines and the Wandoo Full Field Development on the North West Shelf of Western Australia.

Floating structures

Since concrete is quite resistant against salt water and keep maintenance costs low, floating concrete structures have become rather attractive to the oil and gas industry within the last two decades. Temporarily floating structures like e.g. the Condeep platforms float during construction and tow-out but will finally be placed on the ground. Permanently floating concrete structures are used in the discovery of oil and gas deposits, for oil and gas production, as storage and offloading units and also for heavy lifting systems.

Common designs for floating concrete structures are the barge or ship design, the platform design (semi-submersible, TLP) as well as the floating terminals e.g. for LNG.

Floating production, storage, and offloading systems (FPSOS) receive crude oil from deep-water wells and store it in their hull tanks until the crude is transferred into tank ships or transport barges. In addition to FPSO's, there have been a number of ship-shaped Floating Storage and Offloading (FSO) systems (vessels with no production processing equipment) used in these same areas to support oil and gas developments. An FSO is typically used as a storage unit in remote locations far from pipelines or other infrastructures.

Semi-Submersible

Semi-submersible marine structures are typically only movable by towing. Semi-submersible platforms have the principal characteristic of remaining in a substantially stable position, presenting small movements when they experience environmental forces such as the wind, waves and currents. Semi-Submersible platforms have pontoons and columns, typically two parallel spaced apart pontoons with buoyant columns upstanding from those pontoons to support a deck. Some of the semi-submersible vessels only have a single caisson, or column, usually denoted as a buoy while others utilize three or more columns extended upwardly from buoyant pontoons. For activities which require a stable offshore platform, the vessel is then ballasted down so that the pontoons are submerged, and only the buoyant columns pierce the water surface - thus giving the vessel a substantial buoyancy with a small water-plane area. The only concrete semi-submersible in existence is Troll B.

Tension Leg Platform (TLP)

A TLP is a buoyant platform, which is held in place by a mooring system. TLP mooring is different to conventional chained or wire mooring systems. The platform is held in place with large steel tendons fastened to the sea floor. Those tendons are held in tension by the buoyancy of the hull. Statoil's Heidrun TLP is the only one with a concrete hull, all other TLPs have steel hulls.

Barge/Ship Design

FPSO or FSO systems are typically barge/ship-shaped and store crude oil in tanks located in the hull of the vessel. Their turret structures are designed to anchor the vessel, allow “weather vaning” of the units to accommodate environmental conditions, permit the constant flow of oil and production fluids from vessel to undersea field, all while being a structure capable of quick disconnect in the event of emergency.

The first barge of prestressed concrete has been designed in the early 1970s as an LPG (liquefied petroleum gas) storage barge in the Ardjuna Field (Indonesia). This barge is built of reinforced and prestressed concrete containing cylindrical tanks each having a cross-section perpendicular to its longitudinal axes that comprises a preferably circular curved portion corresponding to the bottom.

Beryl A Platform, North Sea

A view from the South East of Troll A Platform

A 'Statfjord' Gravity base structure under construction

Major offshore concrete structures

Following table summarizes the major eziating offshore concrete structures.

No.	Year Installed	Operator	Field/Unit	Structure Type	Depth	Location	Design by
1	1973	Phillips	Ekofisk	Tank - DORIS	71 m	North Sea (N)	DORIS
2	1974	Atlantic Richfield	Ardjuna Field	LPG Barge	43 m	Indonesia	Berger/ABAM
3	1975	Mobil	Beryl A	Condeep 3 shafts	118 m	North Sea (UK)	NC/Olav Olsen
4	1975	Shell	Brent B	Condeep 3 shafts	140 m	North Sea (UK)	NC/Olav Olsen
5	1975	Elf	Frigg CDP1	CGS 1 shaft, Jarlan Wall	104 m	North Sea (UK)	DORIS
6	1976	Shell	Brent D	Condeep 3 shafts	140 m	North Sea (UK)	NC/Olav Olsen

7	1976	Elf	Frigg TP1	CGS 2 shafts	104 m	North Sea (UK)	Sea Tank
8	1976	Elf	Frigg MCP-01	CGS 1 shaft, Jarlan Wall	94 m	North Sea (N)	DORIS
9	1977	Shell	Dunlin A	CGS 4 shafts	153 m	North Sea (UK)	ANDOC
10	1977	Elf	Frigg TCP2	Condeep 3 shafts	104 m	North Sea (N)	NC/Olav Olsen
11	1977	Mobil	Statfjord A	Condeep 3 shafts	145 m	North Sea (N)	NC/Olav Olsen
12	1977	Petrobras	Ubarana-Pub 3	CGS caisson	15 m	Brazil	?
13	1978	Petrobras	Ubarana-Pub 2	CGS caisson	15 m	Brazil	?
14	1978	Petrobras	Ubarana-Pag 2	CGS caisson	15 m	Brazil	?
15	1978	Shell	Cormorant A	CGS 4 shafts	149 m	North Sea (UK)	Sea Tank
16	1978	Chevron	Ninian Central	CGS 1 shaft, Jarlan Wall	136 m	North Sea (UK)	DORIS
17	1978	Shell	Brent C	CGS 4 shafts	141 m	North Sea (UK)	Sea Tank
18	1981	Mobil	Statfjord B	Condeep 4 shafts	145 m	North Sea (N)	NC/olav Olsen
19	1981	Amoco Canada	Tarsiut Island	4 hollow caissons	16 m	Beaufort Sea	?
20	1982	Phillips	Maureen ALC	Concrete base artic. LC	92 m	North Sea (UK)	?
21	1983	Texaco	Schwedeneck A*	CGS Monotower	25 m	North Sea (D)	DORIS/IMS
22	1983	Texaco	Schwedeneck B*	CGS Monotower	16 m	North Sea (D)	DORIS/IMS
23	1984	Mobil	Statfjord C	Condeep 4 shafts	145 m	North Sea (N)	NC/Olac Olsen
24	1984	Global Marine	Super CIDS	CGS caisson, Island	16 m	Beaufort Sea	?
25	1986	Statoil	Gullfaks A	Condeep 4 shafts	135 m	North Sea (N)	NC/Olav Olsen
26	1987	Statoil	Gullfaks B	Condeep 3	141 m	North Sea	NC/Olav Olsen

				shafts		(N)	
27	1988	Norsk Hydro]	Oseberg A	Condeep 4 shafts	109 m	North Sea (N)	NC/Olav Olsen
28	1989	Statoil	Gullfaks C	Condeep 4 shafts	216 m	North Sea (N)	NC/olav Olsen
29	1989	Hamilton Bros	N. Ravenspurn	CGS 3 shafts	42 m	North Sea (UK)	Arup
30	1989	Phillips	Ekofisk P.B	CGS Protection Ring	75 m	North Sea (N)	DORIS
31	1996	Elf Congo	N'Kossa	Concrete Barge	170 m	Congo	BOS/Bouygues
32	1993	Shell	NAM F3-FB	CGS 3 shafts	43 m	North Sea (NL)	Hollandske Bet.
33	1992	Saga	Snorre Concrete Foundation Templates (CFT)	3 cells suction anchores	310 m	North Sea (N)	NC/Olav Olsen
34	1993	Statoil	Sleipner A	Condeep 4 shafts	82 m	North Sea (N)	NC/Olav Olsen
35	1993	Shell	Draugen	Condeep Monotower	251 m	North Sea (N)	NC/Olav Olsen
36	1994	Conoco	Heidrun	Condeep	350 m	North Sea (N)	NC/Olav Olsen
37	1996	BP	Harding	CGS	109 m	North Sea (UK)	Taylor Wood Eng.
38	1995	Shell	Troll A	Condeep 4 shafts	303 m	North Sea (N)	NC/Olav Olsen
39	1995	Conoco	Heidrun TLP	Concrete TLP	350 m	North Sea (N)	NC/Olav Olsen
40	1995	Norsk Hydro	Troll B	Semisub	325 m	North Sea (N)	DORIS
41	1996	Esso	West Tuna	CGS 3 shafts	61 m	Australia	Kinhill/DORIS
42	1996	Esso	Bream B	CGS 1 shaft	61 m	Australia	Kinhill/DORIS
43	1996	Ampolex	Wandoo	CGS 4 shafts	54 m	Australia	Arup
44	1997	Mobil	Hibernia	CGS 4 shafts	80 m	Canada	DORIS
45	1999	Amerada Hess	South Arne	CGS 1 shaft	60 m	North Sea (DK)	Taylor Woodrow

46	2000	Shell	Malampaya	CGS 4 shafts	43 m	Philippines	Arup
47	2005	Sakhalin Energy Investment Company Ltd. (SEIC)	Lunskoye A	CGS 4 shafts	48 m	Sakhalin (R)	AK/GMAO
48	2005	Sakhalin Energy Investment Company Ltd. (SEIC)	Sakhalin PA-B	CGS 4 shafts	30 m	Sakhalin (R)	AK/GMAO
49	2008	ExxonMobil	Adriatic LNG	LNG terminal	29 m	Adriatic Sea (I)	AK/GMAO
50	2008	MPU Heavy Lifter (MPU filed for bankruptcy before completion, it was thereafter demolished)	Heavy Lift Vessel	LWA	n/a	na	Olav Olsen

Chapter 8

Offshore Drilling

Offshore drilling typically refers to the discovery and development of oil and gas resources which lie underwater. Most commonly, the term is used to describe oil extraction off the coasts of continents, though the term can also apply to drilling in lakes and inland seas.

Offshore drilling presents environmental challenges, especially in the Arctic or close to the shore. Controversies include the ongoing US offshore drilling debate.

There are many different types of platforms for offshore drilling activities, from shallow-water steel jackets and jackup barges, to floating semisubmersibles and drillships able to operate in very deep waters.

History

Around 1891, the first submerged oil wells were drilled from platforms built on piles in the fresh waters of the Grand Lake St. Marys (a.k.a. Mercer County Reservoir) in Ohio. The wells were developed by small local companies such as Bryson, Riley Oil, German-American, and Banker's Oil.

Around 1896, the first submerged oil wells in salt water were drilled in the portion of the Summerland field extending under the Santa Barbara Channel in California. The wells were drilled from piers extending from land out into the channel.

Other notable early submerged drilling activities occurred on the Canadian side of Lake Erie in the 1900s and Caddo Lake in Louisiana in the 1910s. Shortly thereafter wells were drilled in tidal zones along the Texas and Louisiana gulf coast. The Goose Creek Oil Field near Baytown, Texas is one such example. In the 1920s drilling activities occurred from concrete platforms in Venezuela’s Lake Maracaibo.

One of the oldest subsea wells is the Bibi Eibat well, which came on stream in 1923 in Azerbaijan. The well was located on an artificial island in a shallow portion of the Caspian Sea. In the early 1930s, the Texas Co., later Texaco (now Chevron) developed the first mobile steel barges for drilling in the brackish coastal areas of the Gulf of Mexico.

In 1937, Pure Oil (now Chevron) and its partner Superior Oil (now ExxonMobil) used a fixed platform to develop a field 1 mile offshore of Calcasieu Parish, Louisiana in 14 feet of water.

In 1946, Magnolia Petroleum (now ExxonMobil) drilled at a site 18 miles off the coast, erecting a platform in 18 feet of water off St. Mary Parish, Louisiana.

In early 1947, Superior Oil erected a drilling and production platform in 20 feet of water some 18 miles off Vermilion Parish, La. But it was Kerr-McGee Oil Industries (now Anadarko Petroleum), as operator for partners Phillips Petroleum (ConocoPhillips) and Stanolind Oil & Gas (BP) that completed its historic Ship Shoal Block 32 well in October 1947, months before Superior actually drilled a discovery from their Vermilion platform farther offshore. In any case, that made Kerr-McGee's well the first oil discovery drilled out of sight of land.

When offshore drilling moved into deeper waters of up to 100 feet, fixed platform rigs were built, until demands for drilling equipment was needed in the 100- to 400-foot depth of the Gulf of Mexico, the first jack-up rigs began appearing from specialized offshore drilling contractors such as forerunners of ENSCO International.

The first semi-submersible resulted from an unexpected observation in 1961. Blue Water Drilling Company owned and operated the four-column submersible Blue Water Rig No.1 in the Gulf of Mexico for Shell Oil Company. As the pontoons were not sufficiently buoyant to support the weight of the rig and its consumables, it was towed between locations at a draught mid-way between the top of the pontoons and the underside of the deck. It was noticed that the motions at this draught were very small, and Blue Water Drilling and Shell jointly decided to try operating the rig in the floating mode. The first purpose-built drilling semi-submersible *Ocean Driller* was launched in 1963. Since then, many semi-submersibles have been purpose-designed for the drilling industry mobile offshore fleet.

The first offshore drillship was the *CUSS 1* developed for the Mohole project to drill into the Earth's crust.

As of June, 2010, there were over 620 mobile offshore drilling rigs (Jackups, semisubs, drillships, barges) available for service in the competitive rig fleet.

The world's deepest platform is currently the Perdido in the Gulf of Mexico, floating in 2,438 meters of water. It is operated by Royal Dutch Shell and was built at a cost of $3 billion.

Main offshore fields

Notable offshore fields today are found in the North Sea, the Gulf of Mexico, the Campos and Santos Basins off the coasts of Brazil, Newfoundland and Nova Scotia (Atlantic Canada), several fields off West Africa most notably west of Nigeria and Angola, as well as offshore fields in South East Asia and Sakhalin, Russia. Also major offshore oil fields are located in the Persian Gulf such as Safaniya, Manifa, and Marjan which belong to Saudi Arabia and are developed by Saudi Aramco.

Challenges

Offshore oil and gas production is more challenging than land-based installations due to the remote and harsher environment. Much of the innovation in the offshore petroleum sector concerns overcoming these challenges, including the need to provide very large production facilities. Production and drilling facilities may be very large and a large investment, such as the Troll A platform standing on a depth of 300 meters.

Another type of offshore platform may float with a mooring system to maintain it on location. While a floating system may be lower cost in deeper waters than a fixed platform, the dynamic nature of the platforms introduces many challenges for the drilling and production facilities.

The ocean can add several hundred meters or more to the fluid column. The addition increases the equivalent circulating density and downhole pressures in drilling wells, as well as the energy needed to lift produced fluids for separation on the platform.

The trend today is to conduct more of the production operations subsea, by separating water from oil and re-injecting it rather than pumping it up to a platform, or by flowing to onshore, with no installations visible above the sea. Subsea installations help to exploit resources at progressively deeper waters, locations which have been inaccessible, and overcome challenges posed by sea ice, such as in the Barents Sea.

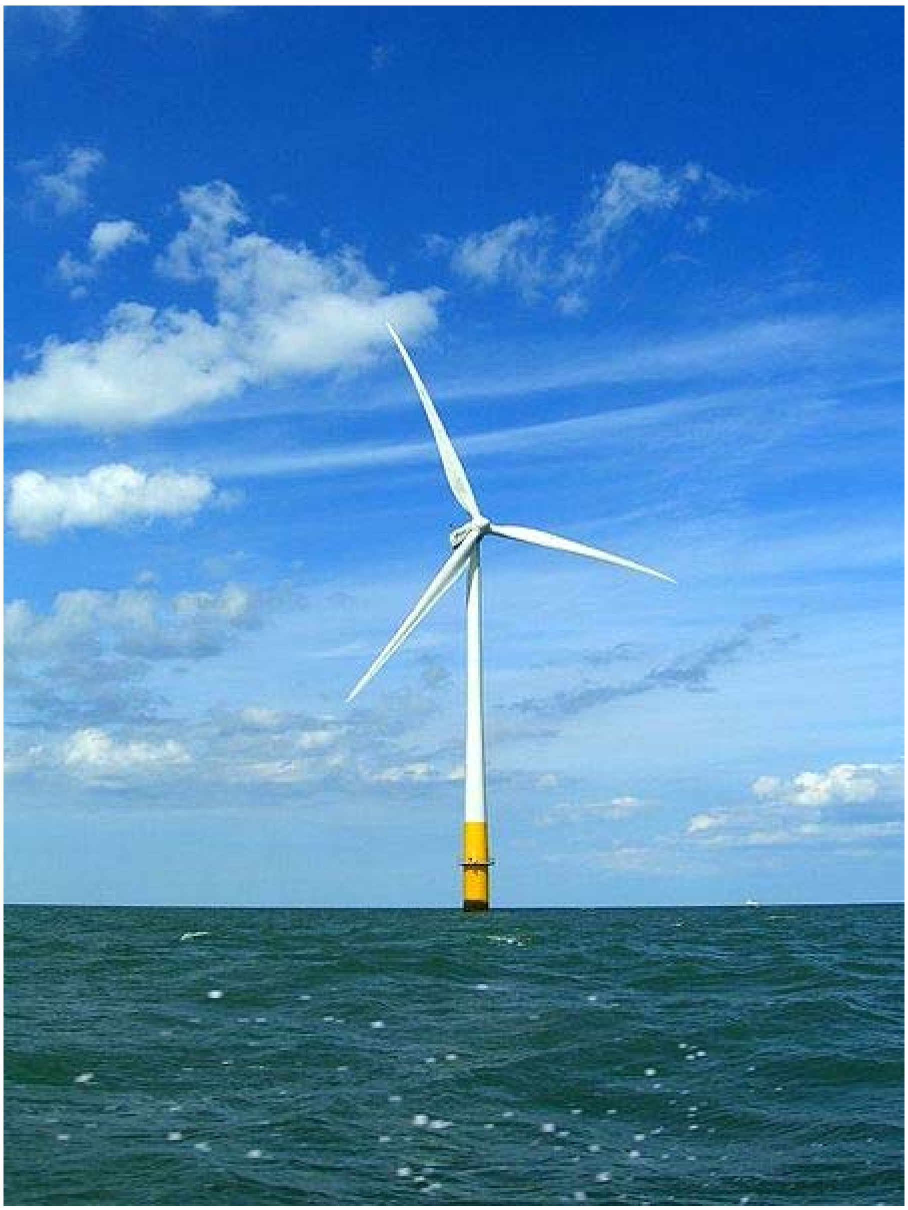
Offshore manned facilities also present logistics and human resources challenges. An offshore oil platform is a small community in itself with cafeteria, sleeping quarters, management, and other support functions. In the North Sea, staff members are transported by helicopter for a two-week shift. They usually receive higher salary than onshore workers do. Supplies and waste are transported by ship, and the supply deliveries need to be carefully planned because storage space on the platform is limited. Today, much effort goes into relocating as many of the personnel as possible onshore, where management and technical experts are in touch with the platform by video conferencing. An onshore job is also more attractive for the aging workforce in the petroleum industry, at least in the western world. These efforts among others are contained in the established term integrated operations. The increased use of subsea facilities helps achieve the objective of keeping more workers onshore. Subsea facilities are also easier to expand, with new separators or different modules for different oil types, and are not limited by the fixed floor space of an above-water installation.

Effects on the environment

Offshore oil production involves environmental risks, most notably oil spills from oil tankers or pipelines transporting oil from the platform to onshore facilities, and from leaks and accidents on the platform. Produced water is also generated, which is excess water from oil or gas production and includes varying amounts of oil, or other chemicals used in, or resulting from, oil production. According to the organization Culture Change, a Gulf of Mexico rig dumps about 90,000 tons of drilling fluid and cuttings over its lifetime, with its wells also contributing with heavy metals.

Chapter 9

Offshore Wind Farms

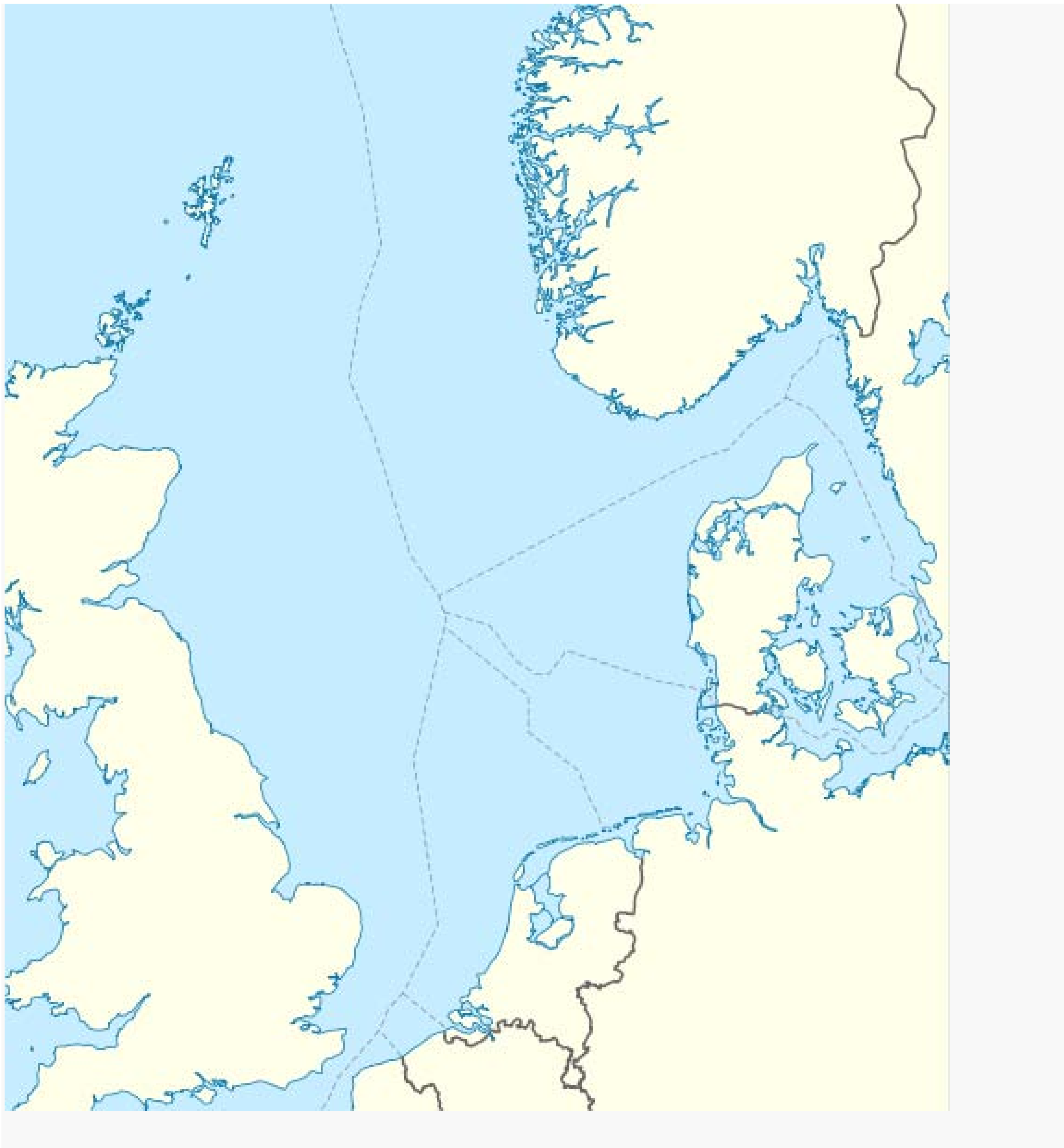


One of the turbines at the Kentish Flats Wind Farm.

This page lists the top 25 **offshore wind farms** that are currently operational, rated by nameplate capacity.
Also listed are the ten largest offshore wind farms which are currently under construction, the ten largest proposed, and offshore wind farms with notability other than size.

As of January 2011, the Thanet Offshore Wind Project in United Kingdom is the largest offshore wind farm in the world at 300 MW, followed by Horns Rev II (209 MW) in Denmark. Greater Gabbard (504 MW) is the largest project under construction. These projects will be dwarfed by subsequent wind farms that are in the pipeline, including Dogger Bank at 9,000 MW, Norfolk Bank (7,200 MW), and Irish Sea (4,200 MW).

The 25 largest operational offshore wind farms



This is a list of the top 25 offshore wind farms that are currently operational, rated by nameplate capacity. In the case of a tied bottom place in the table, the wind farm with the earliest commissioning date is used.

Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned
Thanet	300	United Kingdom	100 × Vestas V90-3MW	2010
Horns Rev II	209	Denmark	91 × Siemens 2.3-93	2009
Rødsand II	207	Denmark	90 × Siemens 2.3-93	2010
Lynn and Inner Dowsing	194	United Kingdom	54 × Siemens 3.6-107	2008
Robin Rigg (Solway Firth)	180	United Kingdom	60 × Vestas V90-3MW	2010
Gunfleet Sands	172	United Kingdom	48 × Siemens 3.6-107	2010
Nysted (Rødsand I)	166	Denmark	72 × Siemens 2.3	2003
Bligh Bank (Belwind)	165	Belgium	55 × Vestas V90-3MW	2010
Horns Rev I	160	Denmark	80 × Vestas V80-2MW	2002
Princess Amalia	120	Netherlands	60 × Vestas V80-2MW	2008
Lillgrund	110	Sweden	48 × Siemens 2.3	2007
Egmond aan Zee	108	Netherlands	36 × Vestas V90-3MW	2006
Donghai Bridge	102	China	34 × Sinovel SL3000/90	2010
Kentish Flats	90	United Kingdom	30 × Vestas V90-3MW	2005
Barrow	90	United Kingdom	30 × Vestas V90-3MW	2006
Burbo Bank	90	United Kingdom	25 × Siemens 3.6-107	2007
Rhyl Flats	90	United Kingdom	25 × Siemens 3.6-107	2009
North Hoyle	60	United Kingdom	30 × Vestas V80-2MW	2003
Scroby Sands	60	United Kingdom	30 × Vestas V80-2MW	2004
Alpha Ventus	60	Germany	6 × REpower 5M, 6 × AREVA Wind M5000-5M	2009
Middelgrunden	40	Denmark	20 × Bonus (Siemens) 2MW	2001

Jiangsu Rudong Wind Farm	32	China	2 x 3 MW, 2 x 2.5 MW, 6 x 2 MW, 6 x 1.5 MW	2010
Kemi Ajos I + II	30	Finland	10 × WinWinD 3MW	2008
Thornton Bank I	30	Belgium	6 × REpower 5 MW	2008
Vänern (Gässlingegrund)	30	Sweden	10 × WinWinD WWD-3-100	2010

Top 10 under construction

This is a list of the 10 largest offshore wind farms currently under construction. However, as of February 2011, there are only eight offshore windfarms that are confirmed by reliable sources as being under construction.

Wind farm	Capacity (MW)	Country	Turbines and model	Completion
Greater Gabbard	504	United Kingdom	140 × Siemens 3.6-107	2012

Bard 1	400	Germany	80 × BARD 5.0	2011
Sheringham Shoal	315	United Kingdom	88 × Siemens 3.6-107	2012
Walney Phase 1	183.6	United Kingdom	51 x Siemens 3.6	2011
Ormonde	150	United Kingdom	30 × REpower 5M	2012
Tricase	90	Italy	38 × 2.4 MW	2012
Baltic 1	48	Germany	21 × Siemens 2.3-93	2011
Weihai I	45	China	30 x 1.5 MW	2011
?	?	?	?	?
?	?	?	?	?

Top 10 Proposed windfarms

The following table lists the ten largest offshore wind farms (by nameplate capacity) that are only at a *proposal* stage, and have achieved at least some of the formal consents required before construction can begin.

Wind Farm	Capacity (MW)	Country	Consents
Dogger Bank	9,000	United Kingdom	Crown Estate Round 3
Norfolk Bank	7,200	United Kingdom	Crown Estate Round 3
Irish Sea	4,200	United Kingdom	Crown Estate Round 3
Hornsea	4,000	United Kingdom	Crown Estate Round 3
Firth of Forth	3,500	United Kingdom	Crown Estate Round 3
Bristol Channel	1,500	United Kingdom	Crown Estate Round 3
Moray Firth	1,300	United Kingdom	Crown Estate Round 3
Triton Knoll	1,200	United Kingdom	Crown Estate Round 2
Codling	1,100	Ireland	99-year Foreshore Lease
London Array	1,000	United Kingdom	Crown Estate Round 3

Other strongly notable offshore wind farms

Wind Farm	Country	Year	Notability
Vindeby	Denmark	1991	First offshore wind farm; 11 × Bonus 450kW
Beatrice	United Kingdom	2007	2 x REpower 5MW prototype turbines, deepest fixed-foundation at 45-metre water depth
Hywind	Norway	2009	First full-scale, deep-water floating turbine: Siemens 2.3 MW turbine in 220 meter-deep water

Chapter 10

Offshore Wind Power

Aerial view of Lillgrund Wind Farm, Sweden

Offshore wind power refers to the construction of wind farms in bodies of water to generate electricity from wind. Better wind speeds are available offshore compared to on land, so offshore wind power's contribution in terms of electricity supplied is higher.

Siemens and Vestas are the leading turbine suppliers for offshore wind power. Dong Energy, Vattenfall and E.on are the leading offshore operators. As of October 2010, 3.16 GW of offshore wind power capacity was operational, mainly in Northern Europe. According to BTM Consult, more than 16 GW of additional capacity will be installed before the end of 2014 and the United Kingdom and Germany will become the two leading markets. Offshore wind power capacity is expected to reach a total of 75 GW worldwide by 2020, with significant contributions from China and the United States.

Definition

Offshore wind power refers to the construction of wind farms in bodies of water to generate electricity from wind. Unlike the term typical usage of the term "offshore" in the marine industry, offshore wind power includes inshore water areas such as lakes, fjords and sheltered coastal areas, utilizing traditional fixed-bottom wind turbine technologies, as well as deep-water areas utilizing floating wind turbines.

History

Europe is the world leader in offshore wind power, with the first offshore wind farm being installed in Denmark in 1991. In 2008, offshore wind power contributed 0.8 GigaWatt (GW) of the total 28 GW of wind power capacity constructed that year. By October 2009, 26 offshore wind farms had been constructed in Europe with an average rated capacity of 76 MW, and as of 2010 the United Kingdom has by far the largest capacity of offshore wind farms with 1.3 GW, more than the rest of the world combined at 1.1 GW The UK is followed by Denmark (854 MW), The Netherlands (249 MW), Belgium (195 MW), Sweden (164 MW), Germany (92 MW), Ireland (25 MW), Finland (26 MW) and Norway with 2.3 MW.

As of October 2010, Danish wind turbine manufacturers Siemens Wind Power and Vestas have installed 91.8% of the world's 3.160 MW offshore wind power capacity. Based on current orders, BTM expects 15GW more between 2010 and 2014.

Technology

In 2009, the average nameplate capacity of an offshore wind turbine in Europe was about 3 MW, and the capacity of future turbines is expected to increase to 5 MW.

Offshore turbines require different types of bases for stability, according to the depth of water. A monopile (single column) base, six meters in diameter, is used in waters up to 30 meters deep. In water 20-80 metres deep, a tripod base, or one with a steel jacket is used. Floating wind turbines are being developed for deeper water.

Turbines are much less accessible when offshore (requiring the use of a service vessel for routine access, and a jackup rig for heavy service such as gearbox replacement), and thus reliability is more important than for an onshore turbine. A maintenance organization performs maintenance and repairs of the components, spending almost all its resources on the turbines. Access to turbines is by helicopter or service access vessel. Some wind farms located far from possible onshore bases have service teams living on site in offshore accommodation units.

The planning and permitting phase can cost more than $10 million, take 5–7 years and have an uncertain outcome. The industry puts pressure on the governments to improve the processes. In Denmark, many of these phases have been deliberately streamlined by authorities in order to minimize hurdles.

Offshore wind farms

Offshore wind turbines near Copenhagen.

As of 2010, there are 39 European offshore wind farms in waters off Belgium, Denmark, Finland, Germany, Ireland, the Netherlands, Norway, Sweden and the United Kingdom, with an operating capacity of 2,396 MW. More than 100 GW (or 100, 000 MW) of offshore projects are proposed or under development in Europe. The European Wind Energy Association has set a target of 40 GW installed by 2020 and 150 GW by 2030.

As of November 2010, the Thanet Offshore Wind Project in United Kingdom is the largest offshore wind farm in the world at 300 MW, followed by Horns Rev II (209 MW) in Denmark.

World's largest offshore wind farms

Wind farm	Capacity (MW)	Country	Turbines and model	Commissioned
Thanet	300	United Kingdom	100 × Vestas V90-3MW	2010
Horns Rev II	209	Denmark	91 × Siemens 2.3-93	2009
Rødsand II	207	Denmark	90 × Siemens 2.3-93	2010
Lynn and Inner Dowsing	194	United Kingdom	54 × Siemens 3.6-107	2008
Robin Rigg (Solway Firth)	180	United Kingdom	60 × Vestas V90-3MW	2010
Gunfleet Sands	172	United	48 × Siemens	2010

		Kingdom	3.6-107	
Nysted (Rødsand I)	166	Denmark	72 × Siemens 2.3	2003

The province of Ontario in Canada is pursuing several proposed locations in the Great Lakes, including Trillium Power Wind 1 approximately 20 km from shore and over 400 MW in size. Other Canadian projects include one on the Pacific west coast.

As of 2010, there are no offshore wind farms in the United States. However, projects are under development in wind-rich areas of the East Coast, Great Lakes, and Pacific coast.

Economics and benefits

Most entities and individuals active in offshore wind power believe that prices of electricity will grow significantly from 2009, as global efforts to reduce carbon emissions come into effect. BTM expects cost per kWh to fall from 2014, and that the resource will always be more than adequate in the three areas Europe, United States and China.

Offshore wind power can help to reduce energy imports, reduce air pollution and greenhouse gases (by displacing fossil-fuel power generation), meet renewable electricity standards, and create jobs and local business opportunities.

Aesthetics

Offshore wind turbines are less obtrusive than turbines on land, as their apparent size and noise is mitigated by distance. A 2006 Survey by the University of Delaware near the proposed Cape Wind development found that residents most frequently based their decisions to support or oppose the wind farm on perceived impacts to marine life, the environment, electricity rates, aesthetics, fishing and boating.