

Deepwater fossil fuel extraction and production technologies – a developing source of ocean noise pollution.

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The era of “easy oil” is rapidly closing and more challenging reservoirs are being developed “offshore” on outer continental shelves using a suite of developing technologies. Deepwater (>1000 ft.– 10,000 ft.) development occurs under ambient pressures of 30 to 300 atmospheres (400 to 4000 psi.) and wellhead differential pressures of up to 20,000 psi. Active processing equipment is mounted on the sea floor to diminish the risks and costs of the multiple pipe runs that would be required for above sea level processing. The equipment includes separators, multi-phase and multi stage pumps, injectors, and metering equipment. Given the potential for extreme pressure differentials and the multi-phase nature of the product (liquids, gas, and solids) it is likely that some of these processes generate substantial noise. This paper is a review of the deepwater extraction and production technologies and an overview of the physical conditions found in global deepwater fossil fuel extraction and production.

Overview:

Incidental noise pollution from human enterprise has been increasing in the ocean since the mechanization of ocean transportation. As a consequence of the globalization of trade, shipping noise source has increased exponentially so that ambient noise in the ocean is in certain places ten times louder than it was just 50 years ago. (Ross, D.1974, 1976, 1993, McDonald et.al. 2006). Additionally global scale noises from seismic airgun surveys are adding to the ambient noise (Nieukirk et.al. 2004).

While there is some uncertainty about the impacts of the increased ambient noise levels on marine life, it stands to reason that marine habitat for animals that depend of acoustic communication is being adversely compromised.(Clarke et.al. 2009). The impacts may include masking of biologically significant signals such as vocalizations of conspecifics, navigation cues provided by geological or hydrodynamic features in the natural marine soundscape, and the sounds of predators and prey.

Heretofore the main concern for the increase in ambient ocean noise levels has been focused on global shipping and seismic exploration, and some regulations and guidelines have been crafted to mitigate for the potential impacts of these noises (McCarthy 2004).

The mitigations around seismic airgun exploration have been the primary focus of fossil fuel industry mitigation (Bain et.al. 2009).

But as the “easy oil” is becoming scarce, more challenging sources of oil are sought. This includes sources on the outer continental shelf of all continents, and increasingly in deeper waters. This expansion is into water depths that can not be served by stationary, bottom mounted platforms. And due to the extreme water pressures at operating depths

they can not easily be serviced by living operators in hard-hat diving gear or human occupied submersible vehicles.

The entire chain of technologies in these deepwater settings from exploration to production involves new and developing technologies in increasingly challenging environments. Each of these technologies involves the expenditure of energy in large and novel ways, in an environment that is under extreme pressures working with a complex product that depending on the depth can be under extreme pressures as well.

This paper will provide an overview of the exploration to production chain in the context of potential noise generated by each process.

Fossil fuel exploration to production sequence

Fossil fuel is the product of once living matter decomposing in geological formations that due to pressure, heat, and physical structure of the earth store the hydrocarbons of the decomposed matter in geological deposits. These deposits are initially identified by way of likely geological features.

Once a likely deposit area is identified the first stage of exploration begins by exciting the substrate with seismic scale stimulus. This can be done through seismic vibroseis, common in terrestrial surveys, or through seismic airgun surveys most common in ocean settings.

When deposits are found and characterized, exploratory wells are sunk to determine the production potential of the deposit and the quality of the product. In deepwater settings exploratory wells are drilled from large stabilized floating platforms.

At the beginning of the exploration, caissons are built to mount a blowout preventer (BOP) – a safety feature used in exploratory settings. Once a deposit is determined to be suitably productive the BOP will be replaced by a flow control system to prepare the well for production.

Fossil fuel deposits are not just oil; rather they contain many other substances in various concentrations depending on the nature of the deposit. It is not uncommon for liquids (oil and water), solids (sand, coal, shale), and gas (methane, ethane, butane, CO₂, nitrogen, etc) to all be part of the product extracted out of the deposit. So the product coming out of the well is called “multiphase” containing gas, liquids and solids.

This multiphase product emerges from the wellhead typically under pressure. The flow is mediated by a “choke” valve and distributed to a manifold.

Each of these materials needs to be separated and dealt with. Waste water is often injected back into the well, sand and solids are separated and dumped, and gasses are either burned off, injected back into the well, or extracted and utilized – depending on the

proximity to gas processing facilities and the environmental laws of the governing jurisdiction.

In shallow water operations separation was done on platforms above water, but increasingly these processes are occurring on the seafloor with seafloor mounted separation and processing equipment.

Control and monitoring of this equipment is accomplished through instrument packages mounted on the various pieces of equipment, and by way both tethered (remotely operated) and autonomous underwater vehicles (ROV's and AUV's respectively). Communication to these instruments and vehicles takes place by way of wires as well as acoustic modems.

Noise sources

Each of the stages of exploration and production includes some form of noise. Some of the noise – such as the signals and noise from seismic airgun operations has been well characterized. Other noises such as the noise contribution of multi-node acoustic communication nets have not been characterized or evaluated yet.

The following discussion will look at the potential noise sources from deepwater offshore fossil fuel exploration through production.

Seismic exploration

Marine seismic exploration utilizes a number of techniques. Passive techniques include satellite Infra-red scanning (for shallow waters and shallow deposits), electromagnetic field characterization, gravity gradiometry, and passive listening to the distortions of geo-seismic noise on sub-sea deposits. Active techniques include seismic airgun surveys, vibroseis, and other low frequency acoustic sources.

As this paper concerns the impacts of introduced noise we will briefly review the active acoustic techniques. The fundamental principal being that an acoustic source is used to stimulate the environment. The time domain distortions caused by the energy interacting with the environment reveals details about the physical characteristics of the environment.

Airguns

Seismic airgun surveys are the most common form of profiling fossil fuel deposits. This is done in the exploration phase, but also during the production phase to monitor the dynamics of a deposit during extraction.

Airguns are devices that create a controlled acoustical impulse by way of “exploding” a volume of air into the water column, and consequently into the seafloor. Deepwater surveys most commonly employ an array of airguns that are sequentially timed to focus

the energy down through constructive interference. The reflected signal is returned to hydrophone “streamers” towed behind the survey vessel. The time domain distortions of this impulse are received and processed to reveal density characteristics of the seafloor substrate.

Airguns are towed in transects across an area of interest to yield three dimensional maps of the geology beneath the sea floor. The airguns and streamers are drawn behind large survey vessels at 6 – 10 knots and generate impulses in excess of 250 dB re; 1μPa every 10 to 15 seconds for the duration of the survey – up to 20 hours per day, often weeks, but sometimes months on end. While the intent is to focus the signal downward, the signals can often be heard thousands of kilometers from the origin. Surveys executed in deeper water exacerbate the lateral transmission of the noise. The deployment depth of this system is limited by the water pressure that the airgun needs to overcome, so the arrays are towed near the surface.

Currently there are between 40 and 50 seismic airgun surveys taking place worldwide at any given time.

One of the environmental liabilities with the airgun array is that due to hydrostatic pressure at depth this method can not be effectively deployed near the seafloor:

$$p = \rho gh$$

where p is the pressure, ρ is the fluid density (water = 1000 kg/m³ at 5° C) and h is the height $z-z_0$ of the liquid column between the test volume and the zero reference point of the pressure.

As a consequence airgun arrays are most efficient at or near the surface. As there is an attenuation at the seafloor as a product of distance, significant signal losses occur before the target is stimulated:

$$SPL_2 = SPL_1 * 20\log(d_1/d_2) + K$$

Where A = attenuation, d_1 = 1 meter and d_2 is the seafloor depth. K is the attenuation factor: -8 for hemispherical propagation due to the ocean surface boundary.

The second liability with this model is that due to the ratio between the useful signal hitting the target (the seafloor) and the wasted signal propagating throughout the ocean environment.

One solution for this is to locate the stimulus signal closer to the target, and where possible locate the receivers near or on the seafloor. Placing the receivers on the seafloor is possible in a stationary installation but not possible in a towed survey.

Deepwater towing

The transit speed of deepwater towed equipment is constrained by hydrodynamic friction on the equipment and the control and towing cables to only 2-3 knots. At higher speeds the friction overcomes the mass of the system and the equipment rises to the surface. By comparison, airgun arrays may be towed at 10 knots, allowing for three times the survey area for equal time expense.

The following systems are designed to bring the signal closer to the target, and to spread out the acoustical stimulus over time to decrease the peak noise levels while maintaining the required stimulus energy.

Seismic exploration – vibroseis

Seismic vibroseis has been used in terrestrial seismic surveys for decades and is one of the most common methods of profiling the earth. It is a relatively new technology in marine surveys and is still in development. The principal involves exciting the water column, and thus the sea bottom over with a vibratory signal instead of an impulse with the objective of distributing the required seismic excitation energy over time to decrease the impulse level. In theory this type of signal would have less impact on biologically sensitive areas. (Okeanos 2009).

Vibroseis systems are either electromechanical or hydraulic and are towed at depths of 100m bringing the excitation signal closer to the seafloor, although the depth is constrained by resistive losses in cabling and hoses and not very effective at depths of 1000m, thus vibroseis has not been deployed in deepwater applications.

Typical systems produce a vibratory signal between 5-100Hz with a typical duty cycle of 6-10 seconds at between 200-230dB at 1m re: 1 μ Pa. Because it is a driven system the excitation signal can be swept, coded, or random to deliver various characteristics.

Static systems can be suspended in place above the seafloor to provide a monitor signal, or towed in unison or in arrays. Due to the required depth, towing speeds are limited to 2-3 knots.

Vibroseis are not typically placed directly on the seafloor as a static excitation source because they can “dig in” to sandy or muddy sea bottoms and become difficult to extract.

Low Frequency Acoustic Sources

A recent device produced by Bjørge Naxys called LACS (Low-frequency Acoustic Source) was originally designed for hydro-acoustic mine sweeping applications. This is a fuel-combustion driven device can be towed at depth without the hydrodynamic signal loss associated with air driven systems due to water pressures.

As the signal is electrically generated the output can be purpose-programmed and timed to work in arrays is required. Single unit output levels of 218 dB at 1m re: 1 μ Pa are possible. Two or more devices can be towed in an array and synchronized to provide a time-coded signal and increased output levels.

Deep-Towed Acoustics/Geophysics System (DTAGS)

The Naval Research Laboratory's deep-towed acoustics/geophysics system (DTAGS) is an example of a seismic source technology capable of generating 220 Hz – 1 kHz swept frequency sound waves at levels 200 dB re 1 μ Pa @ 1 m, and at full ocean depths. (Wood et.al. 2004). The source is composed of a series of five concentric rings each composed of pie-shaped piezo-ceramic material. The natural resonance of the ceramic transducers provides the high frequencies and the size and shape of the barrel-shaped resonator cavity boosts the low frequencies. This combination yields a broadband (over two octaves) signal with a relatively flat spectrum. The solid-state nature of the construction is insensitive to changes in depth; yielding nearly identical signals from the sea surface to full ocean depth (6000 m). The source can be energized with almost any kind of waveform, and produce almost any sound level below 200 dB, allowing significant flexibility to tune the source amplitude, frequency, and waveform for specific needs.

Given the relatively low amplitude of the signal this system is more adapted to upper levels of the sea bottom and not suitable for deep fossil fuel deposits, although theoretically these could be configured in an array and synchronized to increase the signal strength.

Low Impact Seismic Array (LISA)

“The concept of the low impact seismic array (LISA) was based on the use of inexpensive but powerful and rugged electromagnetic projectors to replace airgun arrays. The prospective benefit was that since the signal could be well controlled, both in frequency content and in the direction in which the sound propagated, the possibility existed of undertaking seismic surveys in environmentally sensitive areas with little or no collateral environmental impact. The LISA project embodied the idea of using a large array of small but powerful electromagnetic projectors to replace airgun arrays. Initial measurements were made on a small (n=4) array of existing electromagnetic transducers designed by Subacoustech. It was found that a Source Level of about 142 dB re 1 μ Pa per volt @ 1 meter was achieved, at a peak frequency of 25 Hz. The operating frequency could be reduced to less than 10 Hz with reasonable modifications, allowing use of an array for seismic exploration. The results indicate that it would be possible to achieve an array Source Level of about 223 dB re 1 μ Pa @ 1 meter, which is adequate for seismic surveying.” (This entry was quoted directly from Okeanos 2009)

Exploratory drilling platforms

Once fossil fuel reservoir are located the product and characteristics of the deposit needs to be characterized. A drilling site is prepared or “completed” by installing a wellhead “tree” and blow out preventer (BOP) on the sea floor. This is then used to seal the wellhead and guide the drilling bits and pipe into the earth.

The drill bits and pipe are fed from the ocean surface from a stabilized drilling platform. In shallow water settings up to 100 meters “jack-up rigs” can be deployed as temporary drilling platforms. Deeper than 100 meters requires a floating, or “semi-submersible” platform such as the Transocean “Deepwater Horizon.”

Noise from jack-up platforms would include vibration and mechanical noise from deck operations transmitted into the sea by way of the legs. Deck noise would include drive motors, power generation equipment, drill pipe clatter, moving of equipment and supplies on the deck, and landing noise from service vehicles such as helicopters and boats.

Semi-submersible platforms can have a deck area the size of a soccer field with displacements in excess of 30,000 tons. In order to push miles of pipe into a well with accuracy they are dynamically stabilized using six to eight “thrusters” that can keep the drilling operation stable within 1 meter on the x, y, and z axes.

The thrusters that stabilize the platform are large propellers powered by diesel-electric drives and depending on the sea conditions during operation can generate significant noise from turbulence and blade cavitation.

Noise from propeller cavitation:

$$I = \frac{BsDP U_t}{r^2} f(K_t K_{ti})$$

(Ross D. 1976)

Where:

I = the total acoustic intensity

B = the number of blades

s = the blade chord

D = is drag force

P = pressure

U_t = tip speed

r = distance from the source

f = frequency

K_t = tip cavitation parameter (geometry dependant)

K_{ti} = inception value of cavitation parameter

This model suggests that these 2-3m diameter thruster propellers can be quite loud due to cavitation alone. Noise from marine turbulence would be dependant on sea state such as swell size, peak to peak period, and surface conditions.

Drilling noise

The actual drilling noise is not substantial because any noise generated by drill bit will be attenuated by the surrounding earth formation. Even when the pipes “bang the hole” due to eccentricities in drilling actions, these noises when monitored by geophones or

seismometers will generate at most a Richter scale value of 1 or less. (By way of comparison, a 40,000 lb. cargo truck passing by might generate a Richter scale 4 “quake” – in a logarithmic scale 1,000 greater energy than a Richter value of 1.)

Underwater telemetry

Increasingly though equipment used in seafloor operations are fitted with telemetric equipment communicating through multi-nodal networks for dynamic positioning references, equipment identification, equipment condition monitoring, and AUV/ROV communication.

These acoustical modems operate in mid frequency (1- 10 kHz) and high frequency (10-50 kHz) ranges, at typical source levels of 180dB re: 1 μ Pa with an operating range of 5-10 km. Signals from various sources need to be identified by way of some codec scheme. These are most often digitally modulated analog signals using “Frequency Hop Spread Spectrum” (FHSS) using a center carrier for data and a “hop” sequence to identify the communication node. “Frequency Shift Key” (FSK) is used for simple transmission of serial data, and “Modulated Frequency Shift Key” (MFSK) is used for data transmission in multi-nodal networks.

Noises in these frequency ranges, and with these characteristics and amplitudes have been correlated with signals that aggravate beaked whales, dolphins,(Southall et.al. 2007) and porpoises, (Kastelein et.al. 2008a,b) and may also have negative impacts on some forage fish such as herring or shad.(Mann et.al. 2001)

Production:

Once a well becomes productive the exploratory drilling apparatus’ are removed and production piping and processing equipment are deployed. While this processing has historically occurred on “Floating Production and Storage Operations” (FPSO’s), increasingly as fields get out in deeper water, production processing is being located on the sea floor – called “subsea processing.”

Wellhead pressures can be quite high – ½ psi per foot (11.3 kPa/m) depth in water and an additional 1 psi per foot (22.6 kPa/m) depth in rock. By way of example, a well in 5000ft. (1500m) of water with a deposit at 13,000 ft (4000m) below the seafloor will be pressurized at approximately 15,500 psi (16.5 MPa).

Some wells are also “over pressure” due to pressurization from heat and gas release.

Wells with these depth profiles are increasingly common, such as the BP Macondo – Deepwater Horizon operation.

From the borehole the first pressure control contact point for the product is the “choke” – a valve that mediates the flow of product into the distribution tree. Given the excessive pressures and hostile conditions these chokes are made of tungsten carbide “tool steel.”

Even so they wear out and need periodic replacement. It is likely that the multiphase product flowing through the choke and distribution tree will produce loud broad-band noise.

From the distribution tree the product is piped to separators to separate the valuable product from brine, sand, and solids. Depending on the composition of the mix these separators are gravity, centrifugal, or product density driven. In most cases separators form an expansion point in the product flow, decreasing the net pressure of the product relative to flow, although ideally pressures are kept high enough to push the product up to the surface.

As the pressure of the product decreases through processing equipment, the flow noise will also decrease.

In the cases where the pressure is not adequate to overcome the column weight, multistage pumps are deployed (driven by electrical motors). Additional pumps are used to inject the brine and other waste products back into the deposit. Each one of these pumps may not generate significant noise in and of itself, but as operations expand across the seafloor cumulative noises from all of these pumps will increase the noise floor of the marine habitat.

Once the valued product is separated from the “waste” products, it is piped to centralized storage and distribution operations. These “tiebacks” can be 20 km from the wellhead and processing field and can be floating platforms (FPSO’s) or in some cases located on shore. Floating platforms will be tended by lighters, tankers, maintenance craft, and crew transport vessels and helicopters, making these operations an area of high noise concentrations.

Heretofore no impact studies have been conducted to determine the effects that these new noise fields have on the short or long term viability of marine life, but there is a high probability that the impacts are not negligible.

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