RPSEA 09121-3100-01 Project Status

AICHE Forum

Nov.3, 2011

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Agenda – AICHE monthly dinner meeting

19:20	**Welcome & Introductions**	**Stan Cone**
	Safety Topic	
	RPSEA Study Overview	**Tim Daigle**
	Regulatory Issues	
	Marine Life & Seabed Findings	
	State of the Art Review **Topside and Subsea**	
	Address New Subsea Concepts	
	What Next	
	End	

Safety Topic
Current Trends in Offshore Safety

- Survey results of a survey sent to Offshore Safety Professionals.
- IQPC Offshore Safety Summit 2011
- 28 February – 01 March, 2011
- Aberdeen, UK
- http://www.offshoresafetysummit.com

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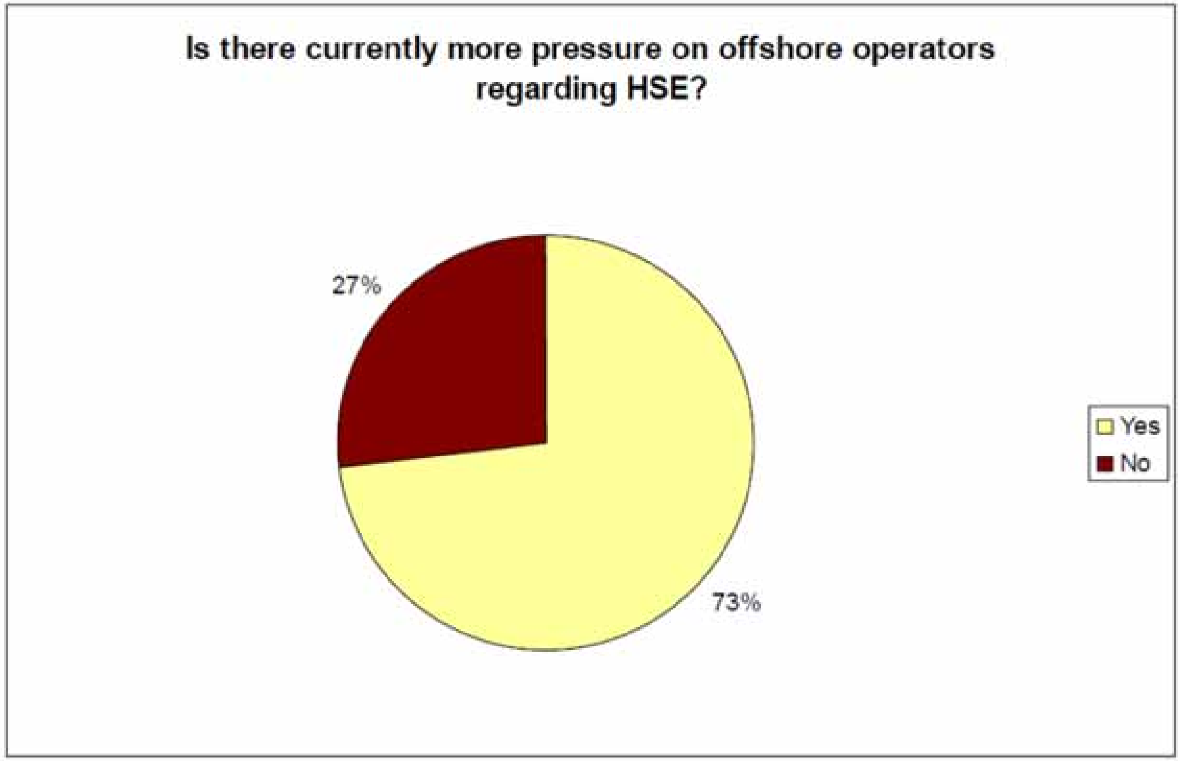
Is there currently more pressure on offshore operators regarding HSE?



Additional Survey Comments

- There is now more pressure on Offshore operators to improve Awareness of personnel to adopt the personal responsibility for their actions
- There are regulatory pressures i.e. KP4 People pressures i.e. shortage of quality HSE resources Fiscal pressures as UKCS moves to a new financial model based on asset life extension
- HSE have certainly made there presence known (and quite rightly so) especially on older platforms

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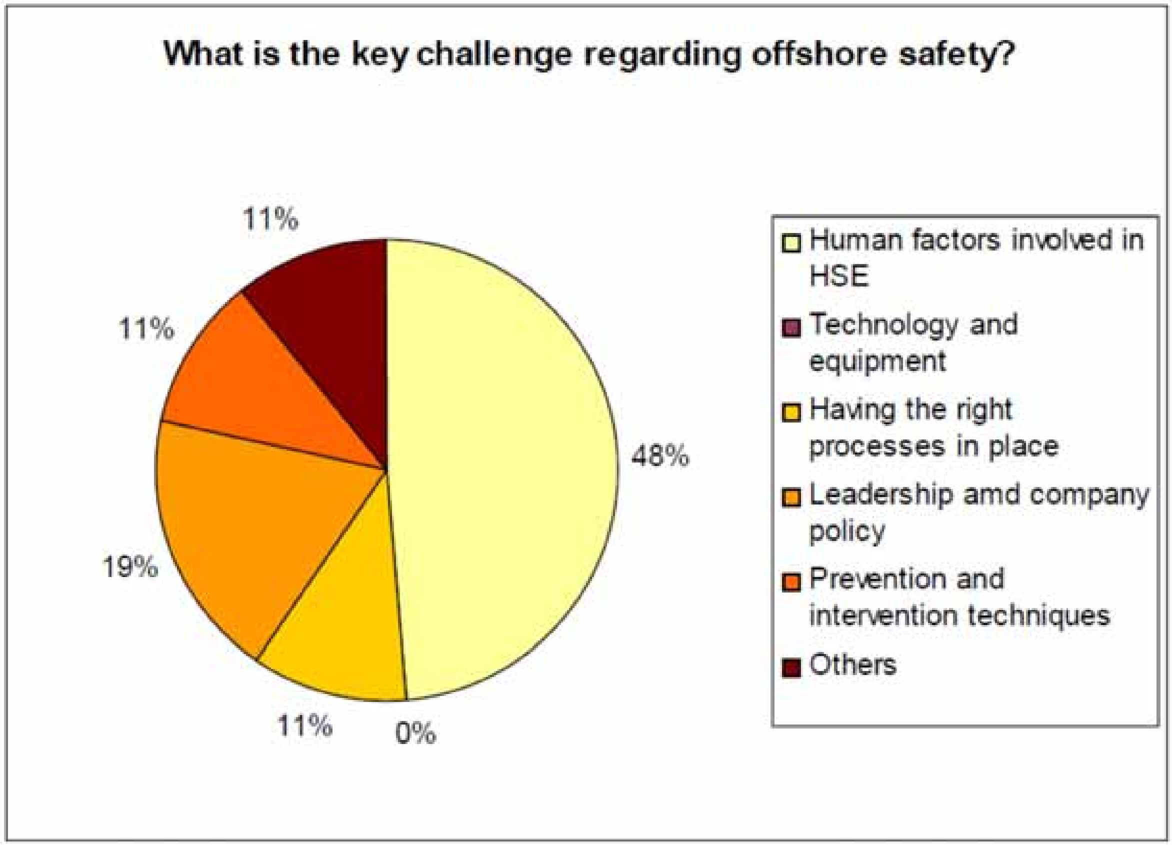
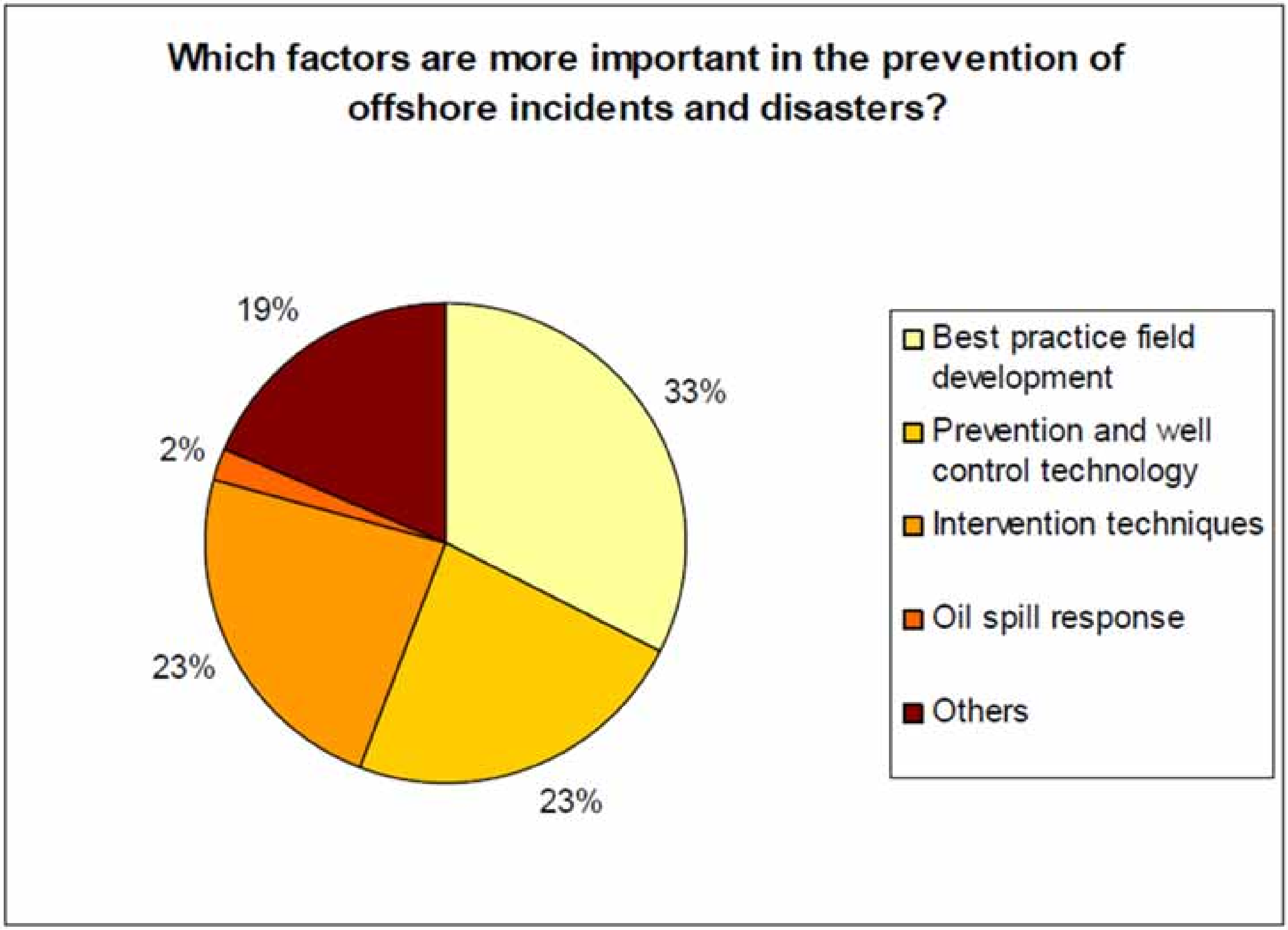
What is the key challenge regarding offshore safety?



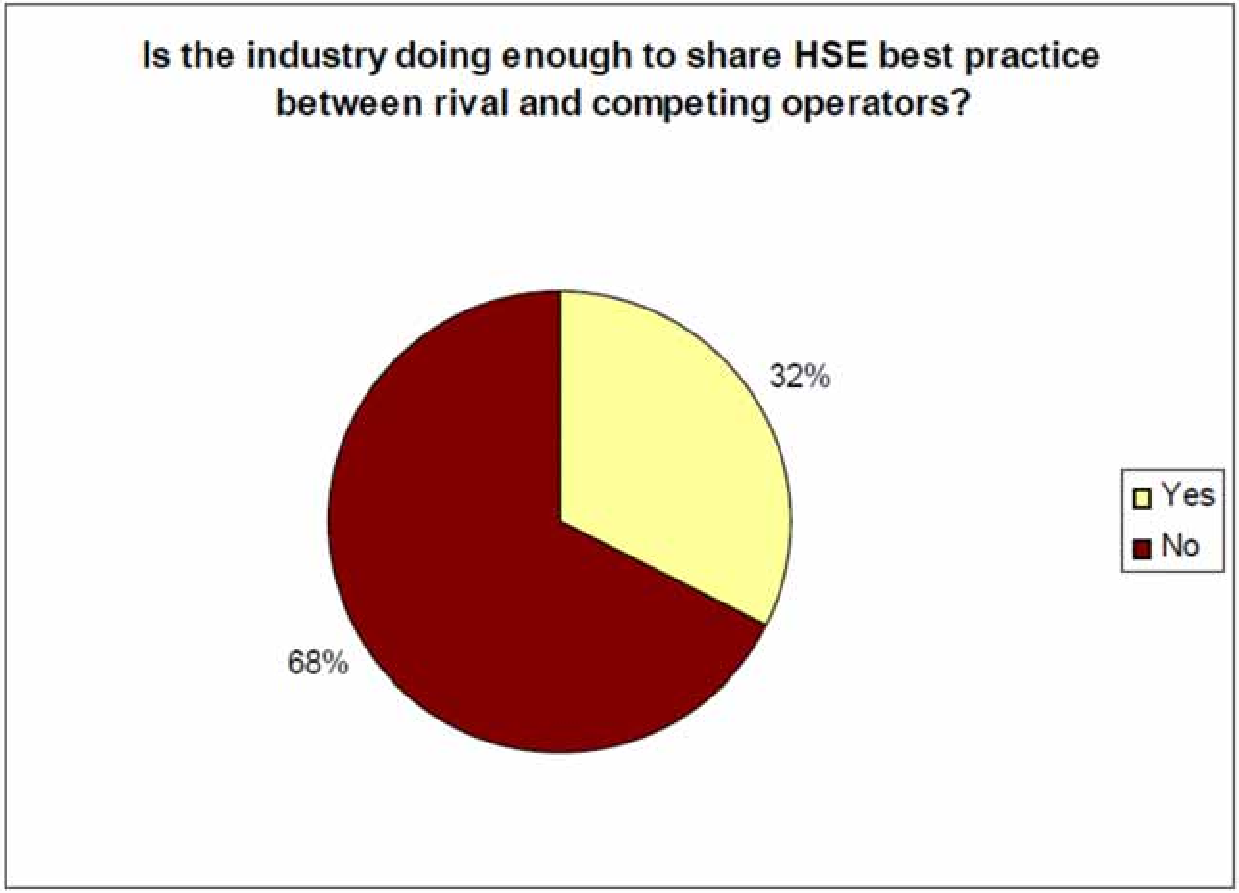
Additional Survey Comments

- Cost is an over rider
- Asset Life Extension
- Managing ageing assets
- One has to create a higher level of awareness on Q-HSE matters, in order to reduce human failure

Which factors are more important in the prevention of offshore incidents and disasters?



Is the industry doing enough to share HSE best practice between rival and competing operators?



Additional Survey Comments

- Everybody is worried to share mistakes and learning points. Perceived as advantage
- Standardization across fields is necessary due to migratory service personnel. Insufficient focus at Contract level
- More meetings to be held to share from others

RPSEA DW3100-01 Project Objectives – Study Overview

- Study for Discharge of Produced Water and/or Solids at the Seabed
- Study Regulations in the Industry with an emphasis on key Deepwater locations, i.e. GOM, North Sea, Brazil, West Africa
- Study Marine Life @ Seabed depths of 5,000 – 8,000 ft
- Study Produced Water Techniques by Performing a State of the Art Market Sweep
- Use research results to derive a new Subsea Produced Water Treatment Process
- Submit Final Report

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US Regulations (Gulf of Mexico)

- Philosophy of Whole Effluent Toxicity Testing
- Limits set at 29mg/L monthly average, 40 mg/L daily maximum
- Sampling Minimum Once per Month
- Toxicity Testing Quarterly (high volume) or Annually
- No free oil discharged - Visual sheen method on the surface of the receiving water. Monitoring done daily
- Observed sheens must be recorded on NPDES permit
- No discharge of sand

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US Regulations (Gulf of Mexico)

- **Toxicity test required, per EPA Lab Method**
  - ***7-day avg minimum for the test effluent to be diluted and placed in 8 different test replicas, each containing at least 5 organisms of mysid shrimp***
- **½ must remain alive for the 7 day test**
- **A No Observable Effect Concentration (NOEC) => specified critical dilution concentration**
- **Dilution rates set on discharge pipe diameter and water depth from the seafloor**

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Offshore Regulatory Issues

- **Worldwide (WW) Review Completed**
- **Reviewed Regulatory Issues for Key Offshore Regions**
  - ***GOM, North Sea, West Africa, Brazil***
- **Final emphasis made on US Regulatory Requirements**
- **Oil in water content primary target for WW regulations, but toxicity is a major factor and focus, West – whole effluent , East – components contributing to effluent.**

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Regulatory Impact on Seabed Discharge

- **No Discharge of Sand**
  - *Sand must be collected for retrieval to shore, or send to platform*
  - *Radioactivity monitoring may be required*
- **Monitoring and Reporting Challenges**
  - *Oil and Grease Monitoring*
  - *Toxicity*
- **Toxicity**
  - *Dilution allowed by, adding seawater, using diffuser, or using multiple ports*
  - *Specific software to use if diffuser is used to increase dilution*
  - *Are the critical dilution tables or software applicable to deepwater seabed (potentially very little current)?*
- **Visual Sheen**
  - *Observation required for seabed discharge?*
  - *Observation method and frequency issues*
  - *Water sampling requirement after observing sheen may cause difficulty*
- **Total dissolved solids**
  - *No regulation other than through toxicity*

Marine Life and Seabed Effects

•Marine life is sensitive to changes in temperature and salinity.

•Decreases in Salinity effect some marine life by causing them to swell and explode.

•Increases in Salinity effect some marine life by causing them to shrivel up or implode.

•Thus the importance of dilution and diffusion.

A swimming shrimp at over 9000 feet water depth in the Gulf of Mexico

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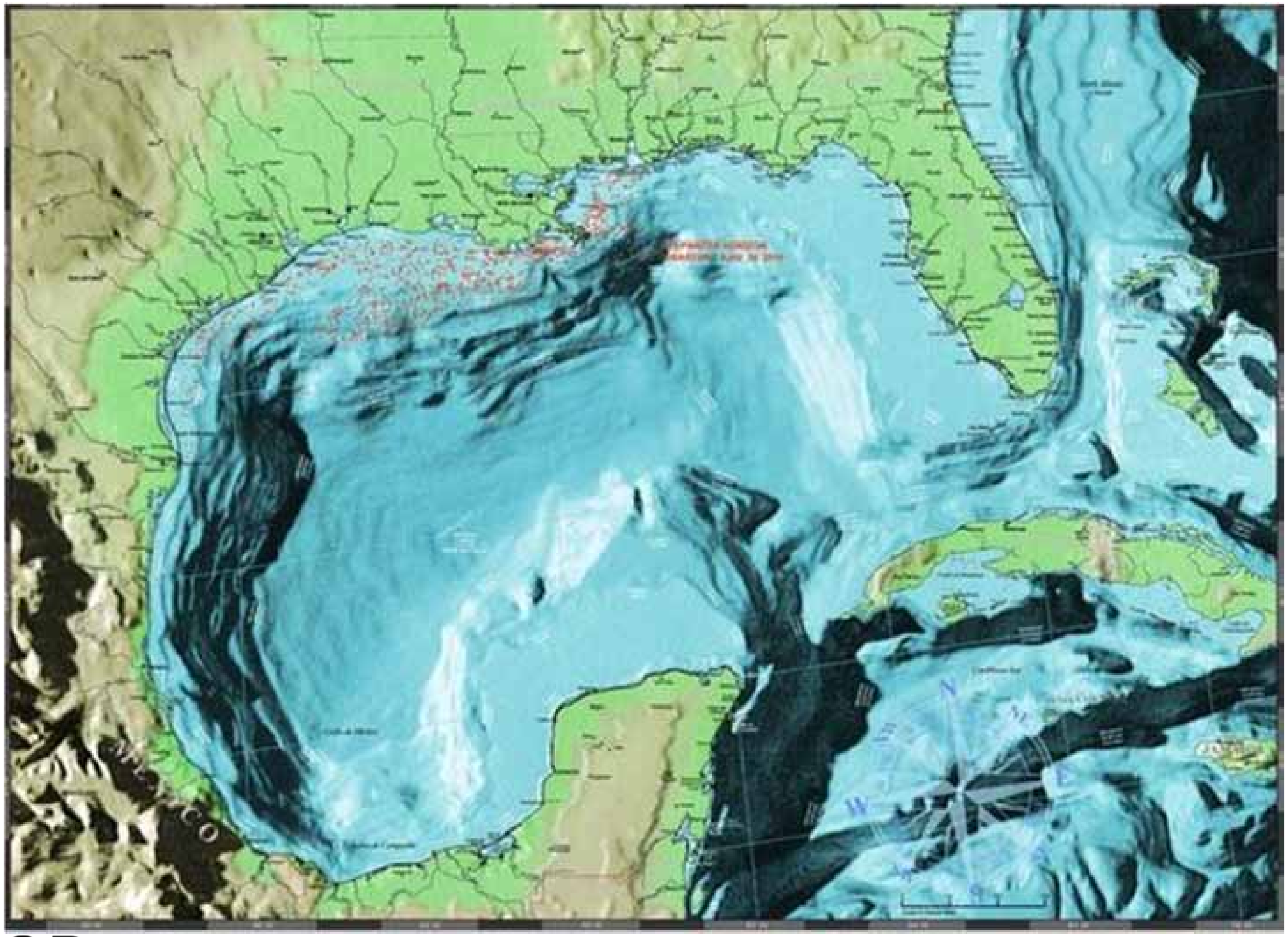
Gulf of Mexico - Seafloor



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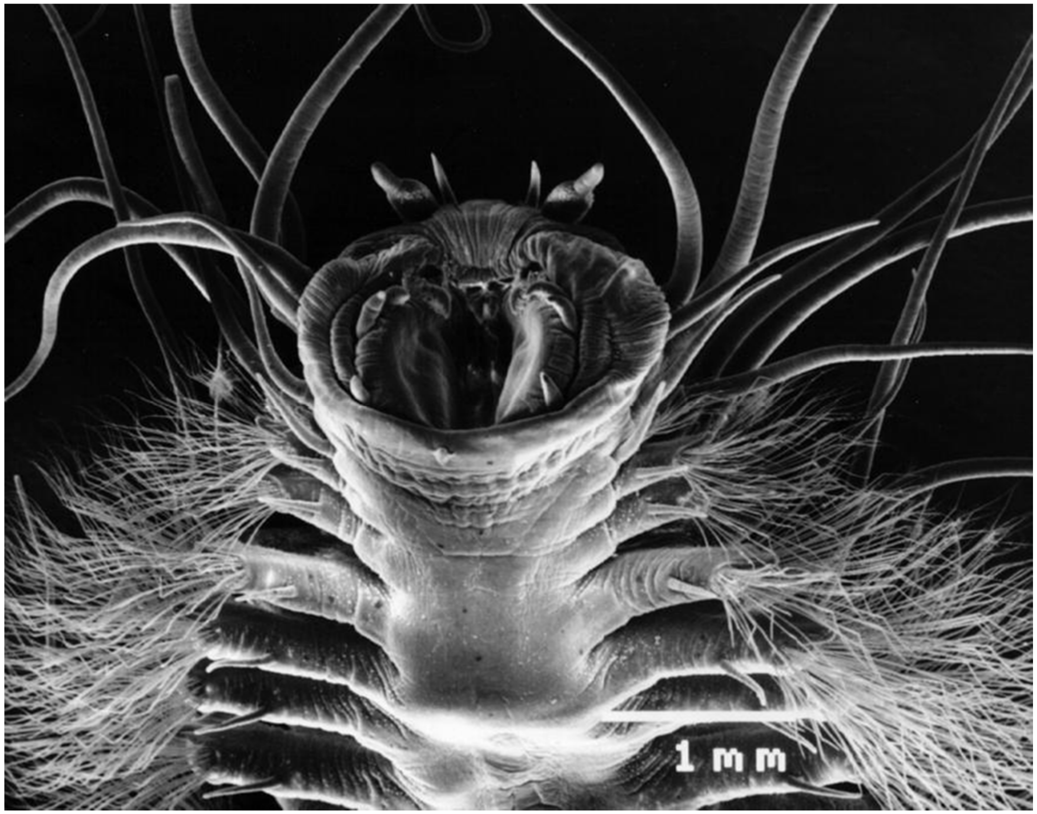
Marine Life and Seabed Effects

- **July 1997 — Scientists found new species of centipede-like worms living on and within mounds of methane ice on the floor of the GOM, ~ 150 miles S of N.O.**
- **Dense colonies, 1-2" long, flat, pinkish worms burrow into mushroom-shaped mound of methane seeping up from the sea floor**



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Marine Life and Seabed Effects

- DW GOM has a very muddy seabed, variance of marine life; Studies show GOM is robust
- UDW toxicity effects not well understood.
- More to learn, but the marine science industry needs to work closely with oil industry.

Thaumastasoma species 521 (Crustacea; Isopoda; Nannoniscidae), a typical species of the lower continental slope.

Photo: George D. F. Wilson

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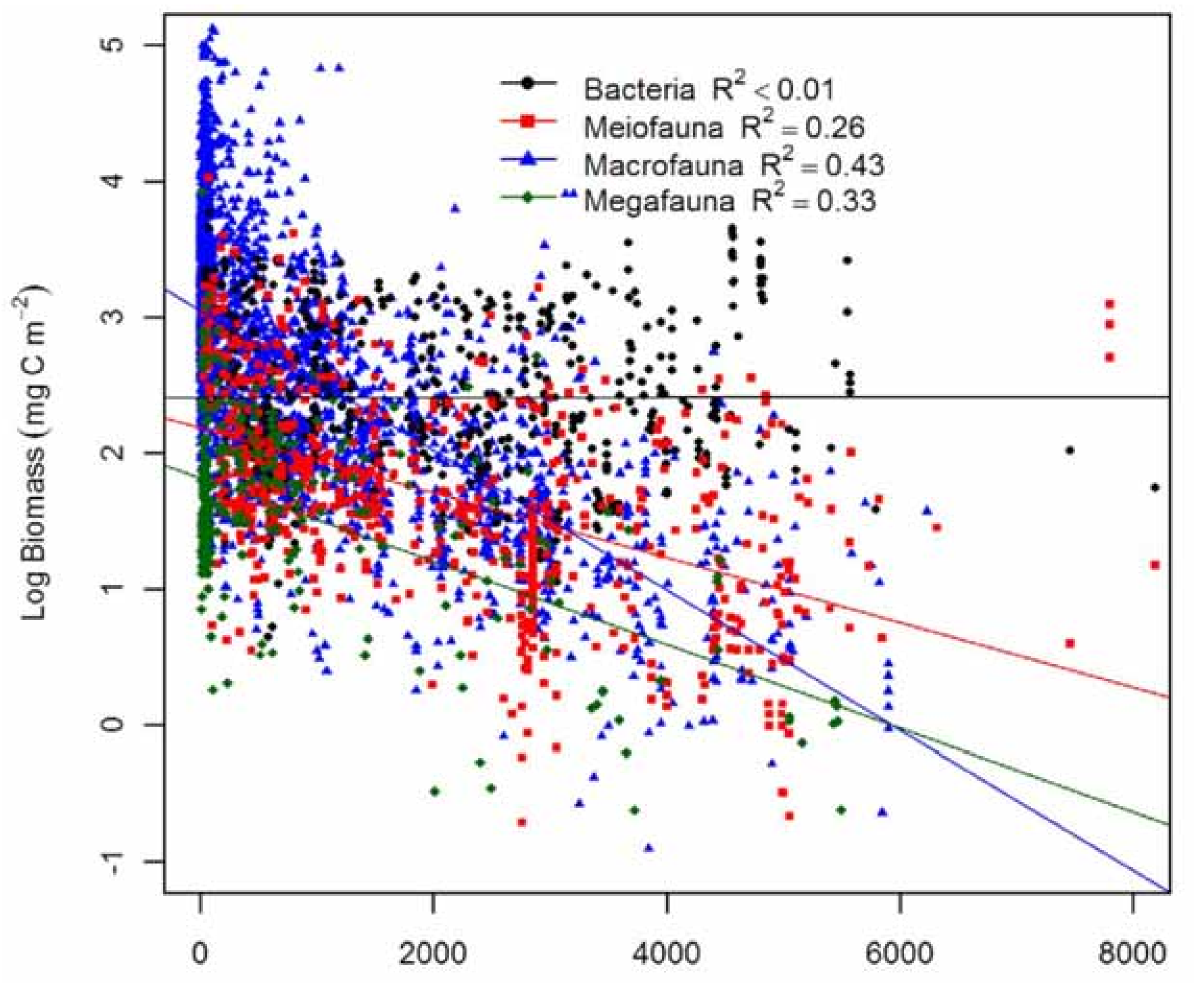
Marine Life and Seabed Effects

- **Bacteria is a key component**
- **All throughout the world's oceans in all depths biomass varies.**
- **Except the quantity of bacteria – It's constant!**



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State of Art Review Areas

- **Topsides Water Treatment**
  - *Primary technologies*
  - *Special technologies*
- **Subsea Separation**
  - *Both gas-liquid and oil-water separation systems*
  - *Installed systems*
  - *Planned systems*
  - *Technologies under development*
  - *Sand handling in subsea separation systems*
- **Oil-in-Water Monitoring**
  - *Topsides*
  - *Subsea technologies under development*

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Oil & Grease Removal Processes

- **Separator**
  - *Gravity oil-water separator tank*
  - *A variant uses corrugated plates for collecting oil*
  - *Removes particulates over 150 microns; Free oil 15 – 100 ppm*
- **Filtration**
  - *Sand or wallnut shell granular media at least 4 feet deep*
  - *Requires influent oil to be < 100 ppm*
- **Hydrocyclone**
  - *Low space requirement*
  - *Can reach below 10 ppm free oil; removes particulates over 5 microns*
  - *May not be able to meet NPDES permit oil and grease limitations*
- **Induced Gas Flotation**
  - *Oil removal of greater than 93% demonstrated with chemical additions*
- **Membrane Filtration**
  - *Can consistently remove oil and grease to < 14 ppm*

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Other Technologies

- **Weighted/Ballasted Flocculation**
- **Adsorptive Filtration**
- **Evaporation/Condensation**
- **Electro-Flocculation**
  - *Similar to gas flotation system but with electrolysis to gas (hydrogen and some oxygen) bubbles*
- **Adsorptive Bubble (Foam Fractionation)**
  - *Bubble column*
  - *Water injected at mid height*
  - *Gas bubble from bottom*
  - *Contaminants are adsorbed onto rising bubbles*
  - *Surfactant chemicals usually added*

Recent Technologies

- **Separation by Filtration**
  - *Flow directions: down-flow, up-flow, bi-flow*
  - *Single, Dual, or Multi-media beds*
- **Liquid-Liquid Extraction**
  - *Injecting condensate to extract dissolved hydrocarbons*
- **Enhanced Separation by Coalescence**
  - *Installed upstream of hydrocyclones*
  - *Fiber media pipe lining, chemical injection (coagulation/flocculation), mechanical agitation*
- **Adsorption**
  - *Activated carbon filters with regeneration by wet air oxidation; generally requiring upstream system such as chemical treatment or filtration to remove solids etc*
  - *Oil-adsorbing media canisters based on resins, polymers, and clay*
- **Ion Exchange to Remove Pollutant Ions**
  - *Heavy Metals, Radioactive Constituents, Arsenic, Other*

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Subsea Separation Installations

- **Statoil Troll C (2001) – Horizontal Oil-Water Separation. Water Depth 1116 ft**
  - *Supplied by ABB, now GE*
- **Petrobras Marimba (2001) – Gas-Liquid Separation with Caisson. WD 1296 ft**
  - *VASPS field test, supplied by Cameron*
  - *Stopped operation is 2008*
- **Statoil Tordis (2007) – Horizontal Gas-Oil-Water Separation. WD 689 ft.**
  - *Supplied by FMC Technologies*
- **Shell Perdido (2009) – Gas-Liquid Separation with Caisson. WD 7054 ft.**
  - *Supplied by FMC Technologies*
- **Shell BC-10 (2010) – Gas-Liquid Separation with Caisson. WD 7999 ft.**
  - *Supplied by FMC Technologies*
- **Total Pazflor (2011) – Vertical Gas-Liquid Separation. WD 2625 ft.**
  - *Supplied by FMC Technologies*
- **Petrobras Marlim (2011) – Inline Separation. WD 2881 ft.**
  - *To be supplied by FMC*
- **Petrobras Congro, Malhado & Corvina (2012) – VASPS with horizontal ESP**
  - *To be supplied by FMC*
- **Petrobras Canapu (Start Up Year TBD) – Twister. WD 5579 ft.**
  - *To be supplied by Twister BV. In-line supersonic separation*

Subsea Separation – Statoil Troll 1116ft

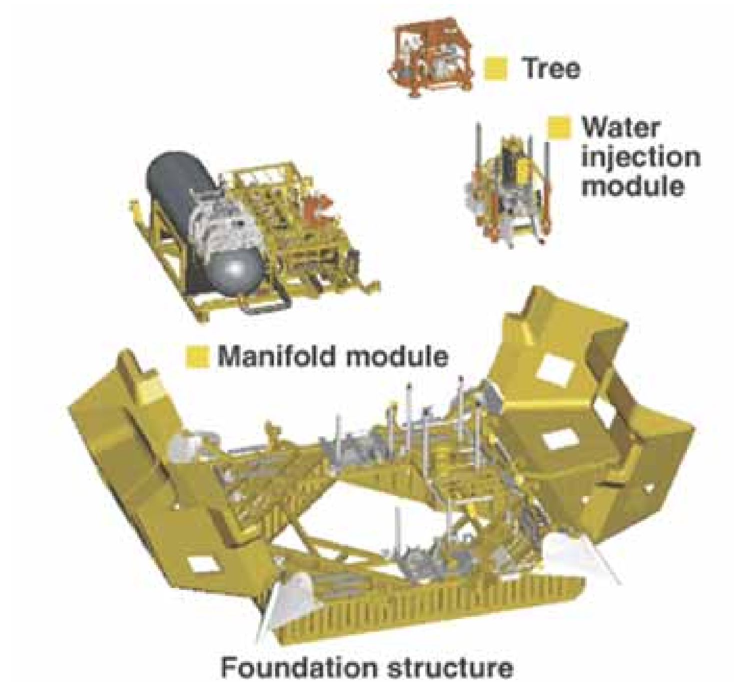
- **Horizontal separator; water for re-injection**
- **Measured Oil-in-Water is 15 to 600 ppm**
  - *Sample with 15 ppm was at 100% design flowrate*

Design parameters for the Troll C subsea separation station

Total liquid capacity:	10,000 cu m/day (~ 63,000 b/d)
Water capacity:	6,000 cu m/day (~ 38,000 b/d)
Oil capacity:	4,000 cu m/day (~ 25,000 b/d
Gas capacity:	800,000 cu m/day (~28 MMcf/d)
Max water cut:	90%

Key performance requirements for the Troll C subsea separation station

Max oil in water (re-injection product):	1,000 ppm
Max water in oil (produced to host):	10%



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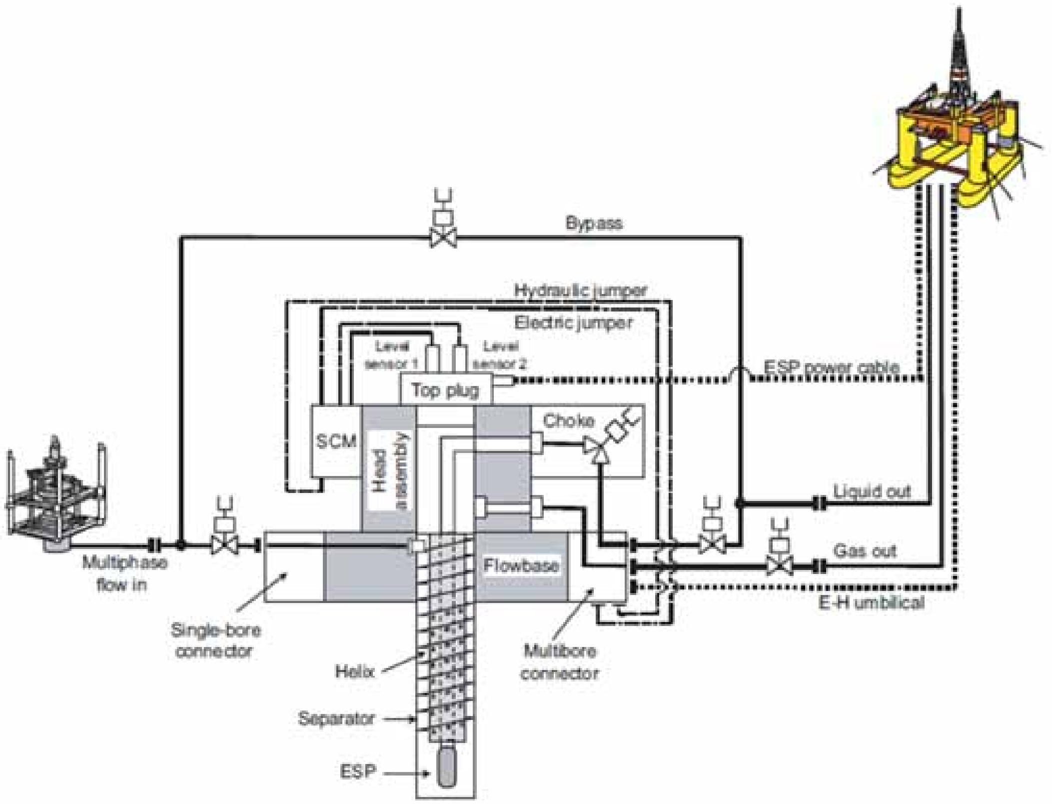
Petrobras Marimba 1296 ft

- Gas-Liquid Separation
- Oil and Water Not Separated



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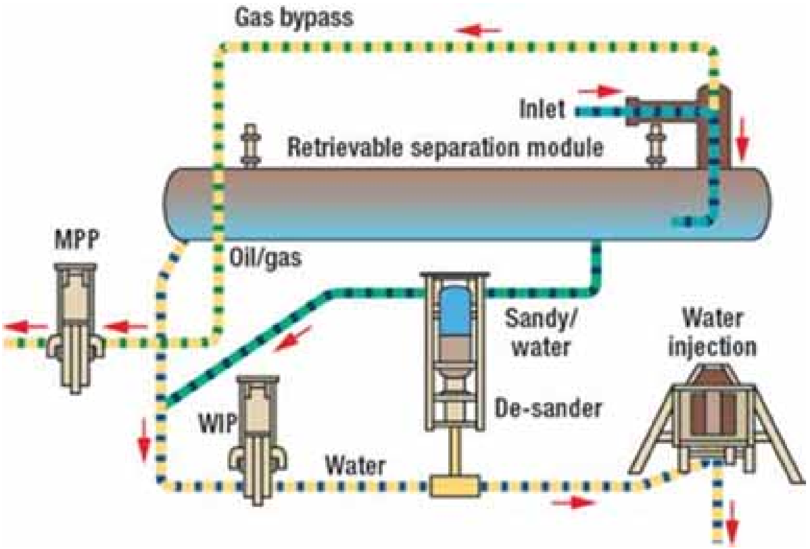
Subsea Separation – Statoil Tordis 689 ft

- **Horizontal separator; water for re-injection**
- **Design Spec**
  - *1000 ppm oil-in-water; observed performance of 500 ppm*
- **17 m Long, diameter 2.1 m; liquid retention time 3 minutes**
- **Capacity 100 KBWPD, 50 KBOPD**
- **Sand was disposed with water to injection well, then surface facility**
- **Lessons learned**
  - *Sand jetting was required more often than designed.*



Statoil Tordis – Sand Management

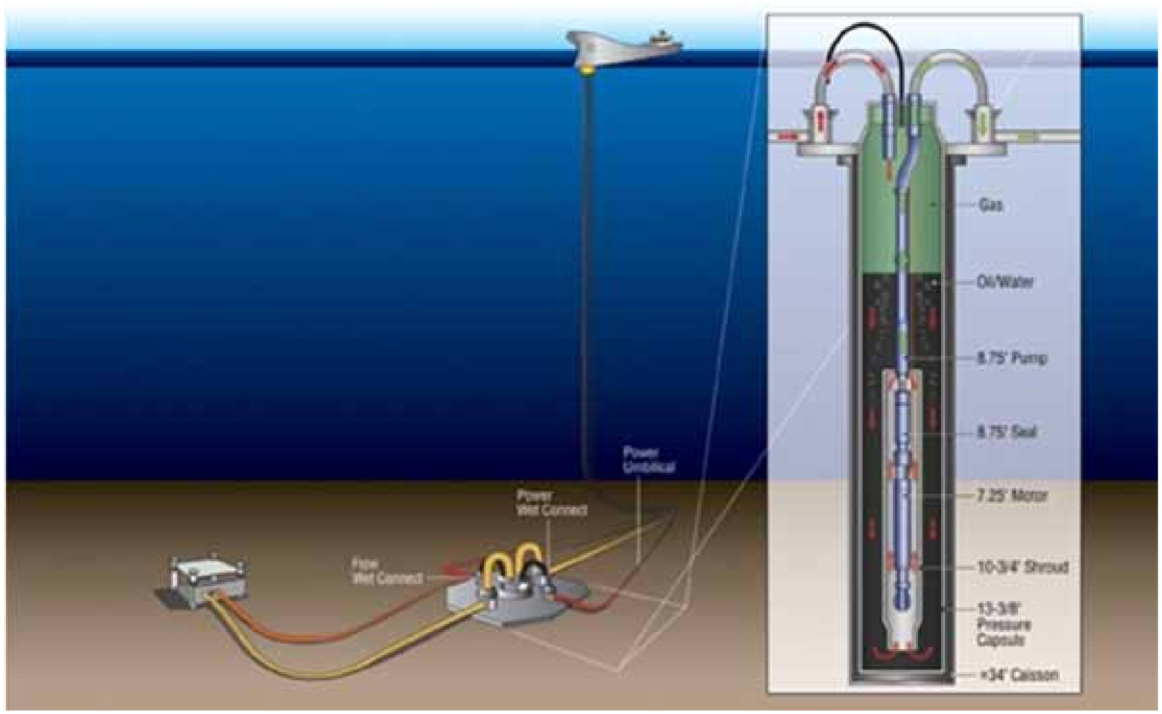
- **A CDS Sand Jetting system as the primary sand removal**
- **A cyclonic sand removal system as a back-up**
- **The removed sand is transported to a desander and sand accumulator vessel in batches.**
- **The accumulated sand is pressurized and transported to the discharge side of the water injection pump.**
- **All the separated sand is injected with the water.**

FMC Tordis Subsea Separation System, Courtesy of FMC

Shell BC-10 and Perdido

7k – 8k ft

- **Gas-Liquid Separation Only**
- **Oil and Water Not Separated**
- **Sand Is Sent to Platform with Flow. Large Debris Is Collected in Caisson Bottom and Removed when ESP is Serviced**



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Total Pazflor 2625 ft

- Vertical Gas-Liquid Separation
- Purpose is to reduce gas volume fraction to enable multiple pump use
- Vessel design including curved lower section to prevent sand accumulation
- A sand handling system including sand flushing is installed as a back-up solution to remove snd build-up

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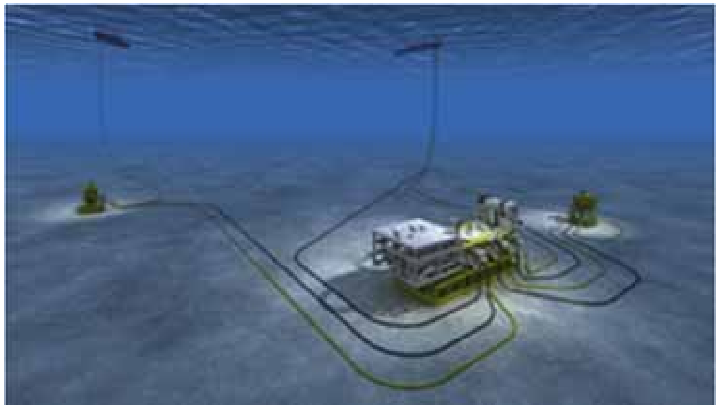
Petrobras Marlim 2881 ft

- **The water is separated from the well-stream and re-injected back into the reservoir for pressure maintenance**
- **Subsea Separation System**
  - *PipeSeparator concept for the separation of the water from the well stream*
  - *Water treatment system using InLine HydroCyclones.*
  - *Sand handling system*
    - An InLine DeSander at the inlet of the separation system
    - A dual redundant Sand Jetting System in the outlet section of the PipeSeparator,
    - An InLine DeSander for removal of the particles in the water stream from the separator to protect the re-injection well and reservoir.
    - The separated sand is routed with the oil up to the topside facility.



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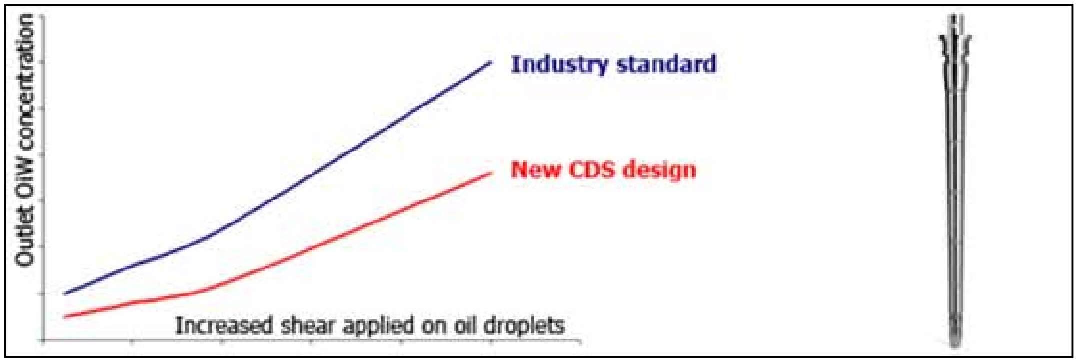
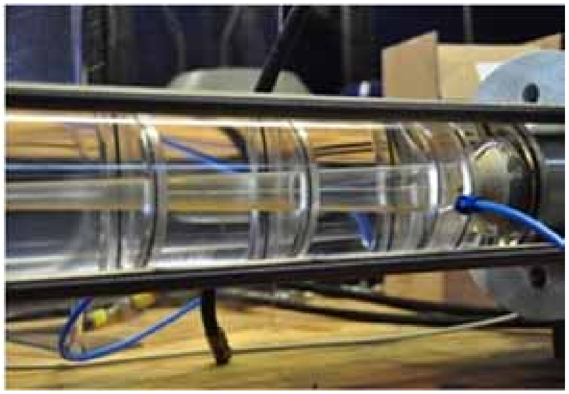
Petrobras Marlim – Subsea Separation System Components





Inline HydroCyclone

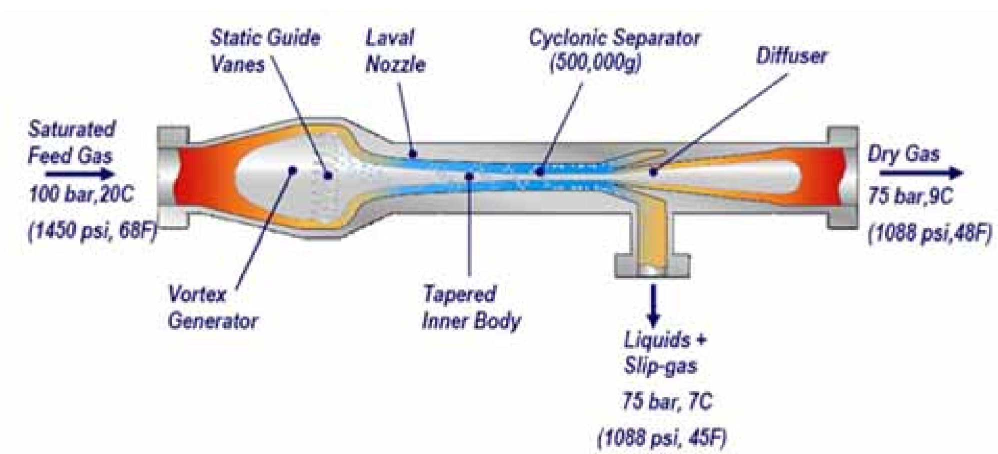
Inline Desander

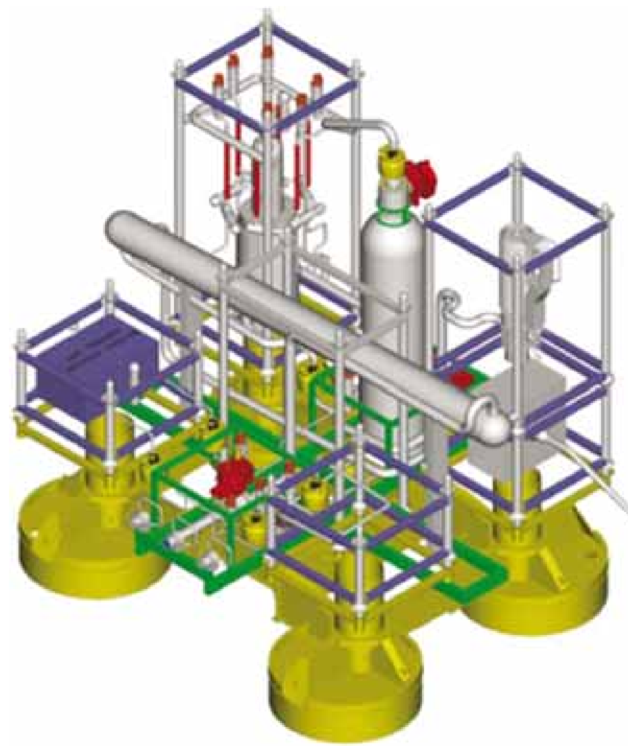
Petrobras Congro, Malhado & Corvina

- **VASPS with Horizontal ESP**
- **According FMC's pressure release, the control system incorporates an innovative subsea robotics technology, designed by Schilling Robotics, to operate the manifold and separation station valves.**

Petrobras Canapu

- **Twister BV. In-line supersonic**
- **Process steps in a compact, tubular device**
  - *Expansion*
  - *Cyclonic gas/liquid separation*
  - *Re-compression*
- **Dehydrate gas and removes heavy hydrocarbon components**
- **Technology is not applicable to oil-wate separation**





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Subsea Technology Under Development

- Aker Solutions DeepBooster with Subsea Separation
- Cameron Compact Separator
- Cameron Compact Separator with ESP
- FMC InLine ElectroCoalescer
- FMC InLine DeWaterer
- GE Separator with Electrostatic Coalescers
- Saipem COSSP (2-Phase Gas/Liquid Separation & Boosting System Concept)
- Saipem Subsea 3-Phase Separation Module

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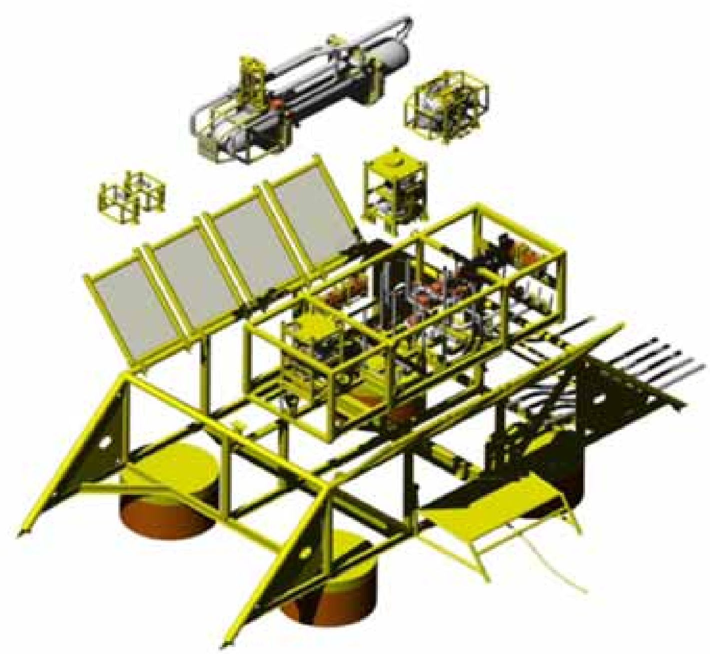
Aker Solutions DeepBooster with Separation System Flexsep

- **Compact degassing and scrubbing as a first separation stage**
- **Compact Electrostatic Coalescer, CEC**
  - *Technology is qualified and has several topside applications*
- **Compact separator due to the CEC**
- **Cyclonic Separation, Multistage cyclonic separation**
  - *Reduces oil content in water down to 40-100 ppm.*
- **Liquidbooster: Multistage centrifugal pump concept**



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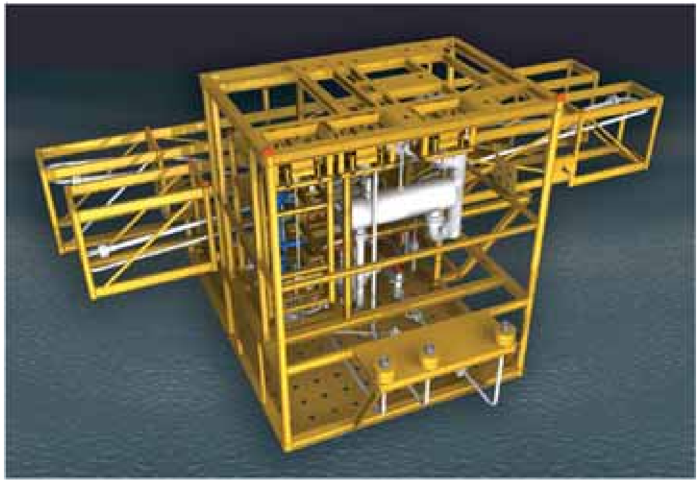
Cameron Compact Subsea Separators

- Without ESP
- With ESP
- Using Electrostatic Method?



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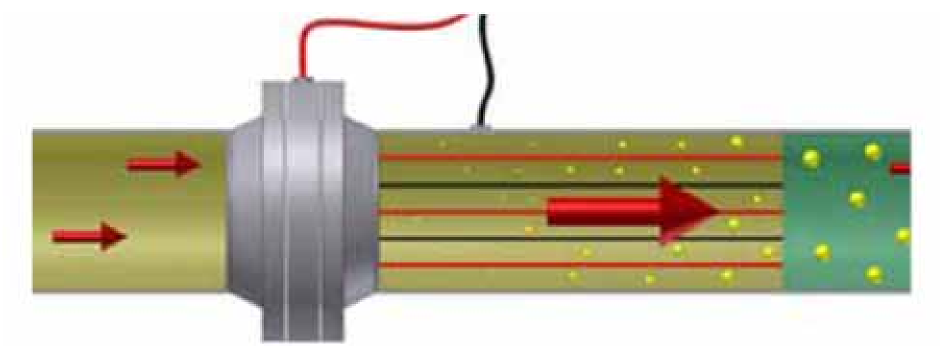
FMC InLine ElectroCoalescer

- Uses electric fields to promote water-in-oil droplet growth and emulsion breakdown to facilitate effective oil-water separation
- Designed to be fitted into pipe spool upstream of the separator
- High voltage power system



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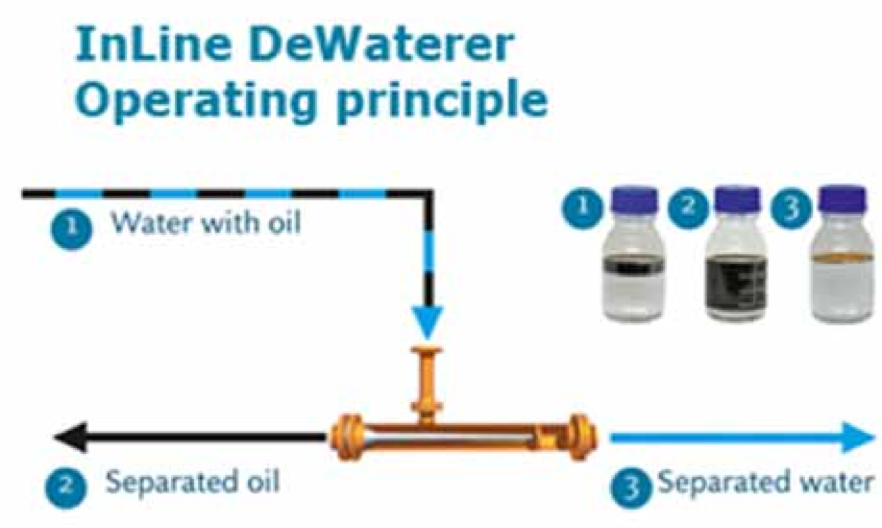
FMC InLine DeWaterer

- Axial flow cyclone design
- Specially designed swirl element - low energy loss and shear.
- An oil core is formed by the oil droplets
- The separated oil is removed through a reject (overflow) opening
- The clean water leaves the cyclone through a water outlet (underflow)



Criteria	Results
Oil in Water at inlet	1 - 50 %
Oil in Water after separation	200 - 2000 ppmv
Gas Volume Fraction at inlet	0 - 50 %
Total Flow rate at inlet	10 - 40 m^3/h
Water removal efficiency	< 95 %
Pressure Drop reject (from inlet to oil outlet)	0.3 - 2.5 Bar
Pressure Drop underflow (from inlet to water outlet)	0.1 - 2.0 Bar

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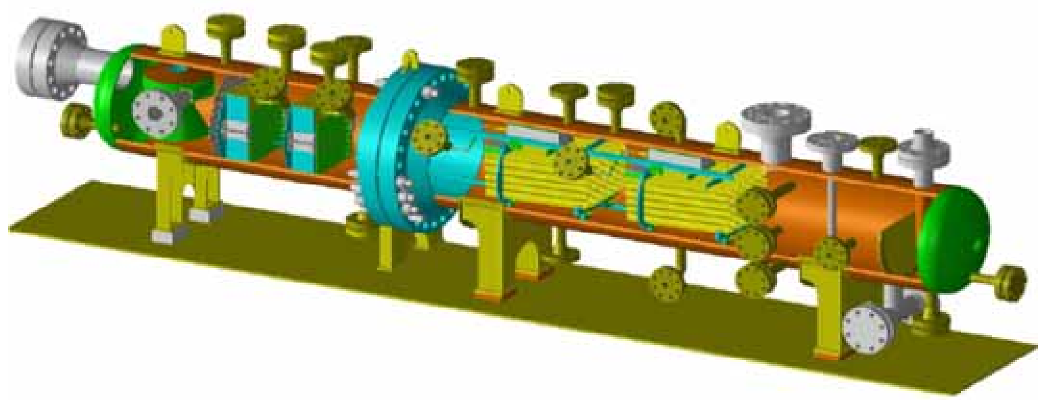
GE Nu-Proc Test Separator With Electrostatic Coalescers

- **GE**
- **DEMO 2000 – 2004**
- **Made to fit Norsk Hydro's test loop**
- **Length: 5200 mm**
- **Diameter: 630 mm**
- **Capacity: 6000 BL/day (as test loop)**
- **Max Pressure: 100 Bar (as test loop)**
- **Max Temp: 120 C (as test loop)**
- **Dual VIECS, Dual LOWACCS**



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Saipem Subsea Separators

- COSSP (2-Phase Gas/Liquid Separation & Boosting System)
- 3-Phase Separation Module

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Sand Handling - Hydrocyclones

Inline Cyclonic Separation Equipment - Clockwise: Liquid-Liquid Separation, Phase Splitter, De-Sander, Deliquidizer, (Courtesy of OTC 20080 paper, 2009)

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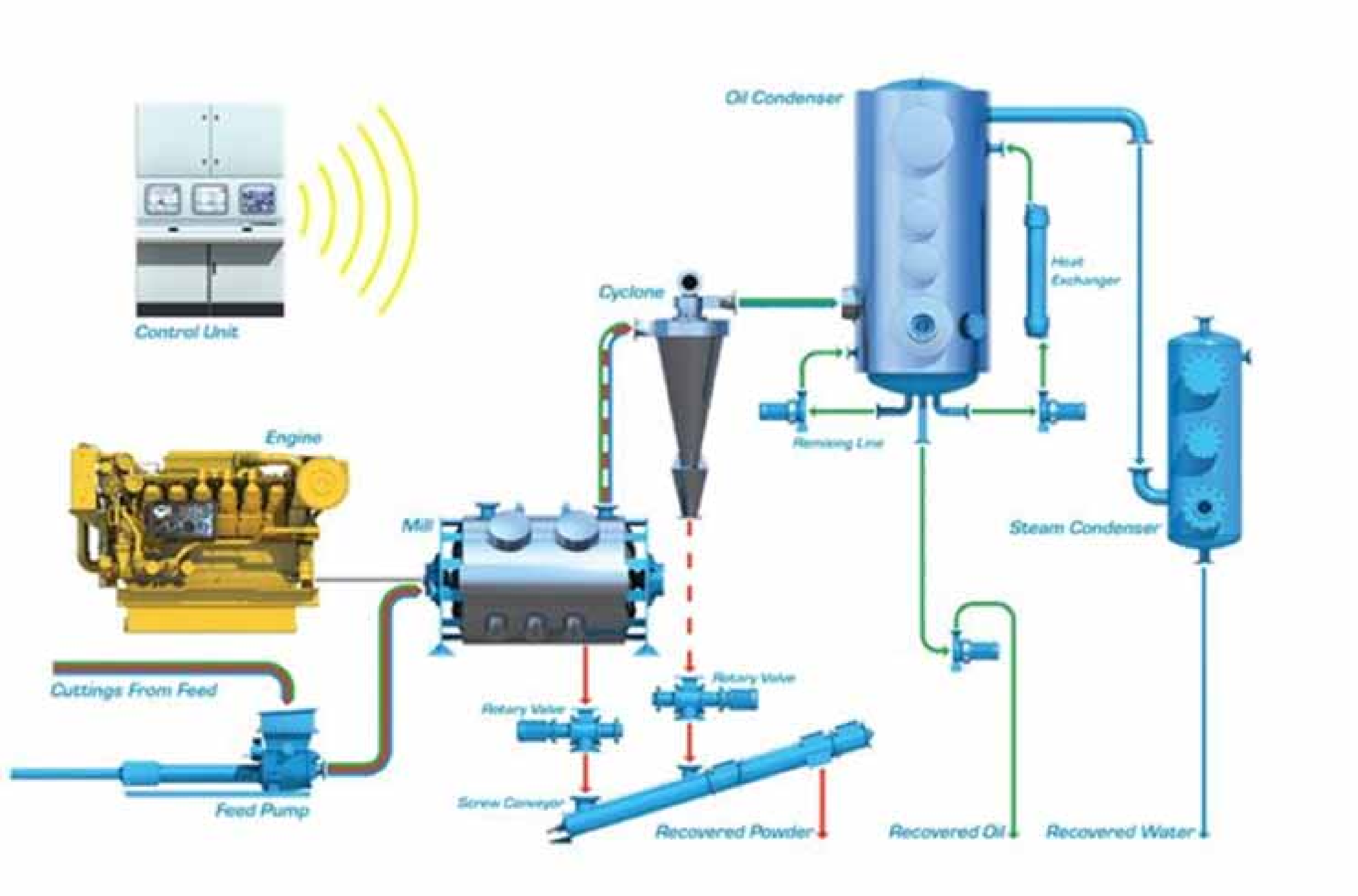
Sand Handling – Hammer Mill



Process Flow of TWMA Hammer Mill (Courtesy of TWMA Ltd Website)

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Sand Handling – Hammer Mill

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Main Findings from State of Art Review

- **Topsides Water Treatment Generally Requires Tertiary System**
  - *CPI separator/Hydrocyclones/Skimmer*
  - *Induced Gas Flotation*
  - *Filtration is sometimes required to achieve low oil and grease concentrations*
  - *Membrane filtration is sometimes required to remove dissolved organics*
- **Subsea Separation Technologies Have Focused on**
  - *Two-phase gas liquid separation*
  - *Water separation for injection use*
    - Much higher oil in water content than discharge limitations
    - De-sanders and/or filters to remove suspended solids to sizes small enough for injection
- **Compact Subsea Oil/Water Separators and Desanders for Deepwater**
  - *Have been developed and to be installed in the near future*
  - *Under development*
- **Currently Subsea Oil/Water Separation Systems Do Not Meet Discharge Limitations on Oil and Grease Concentrations**

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Main Findings from State of Art Review

- Monitoring and sensing will need to be sufficient to allow for proper control.
- System will need to include capacity for equilibration and up set overflow.
- Use of Desanders and Hydrocyclones will be important to add in concepts.
- Control System Module will be included.
- Architecture for Discharge Diffusion should be considered.
- Options should consider minimal use of moving parts.
- Process flow should consider dual trains for double 100% capacity.

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Major Technology Gaps

- **Current Subsea Technology Can Not Meet Oil and Grease Limitation for Discharge**
  - *Installed systems*
  - *Planned systems*
  - *Technology under development*
- **Subsea equipment design to withstand collapse pressure**
  - *Large volume vessels required in current water treatment technology*
- **Potentially have to pump water for discharge**
  - *High volume*
  - *Large pressure differential*
  - *High power requirement*
  - *Pump technology is mature since only water is discharged*
- **Accurate Monitoring of Discharged Water**
  - *Oil and Grease*
  - *Sampling for measurements in laboratory of oil and grease, toxicity etc*
- **Handling of Start-Up and Upset Conditions**
  - *Storage Issues*

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Conceptual Design will address the following:

- Monitoring and sensing will need to be sufficient to allow for proper control.
- System will need to include capacity for equilibration and up set overflow.
- Use of Desanders and Hydrocyclones will be important to add in concepts.
- Control System Module will be included.
- Architecture for Discharge Diffusion should be considered.
- Standardization should be considered in equipment design.
- Options need to consider minimal use of moving parts.
- Process flow should consider dual trains for double 100% capacity.
- Hysys Modeling to be done on process stream

Hot Topics & Challenges to Consider

- Final lowest limits reached by hydrocyclones and filtration
- RO not successful in oil industry due to oil clogging filters
- Discharge of sand prohibited in most areas
- Need for high reliability
- Control and Measurement Key Requirements
- Verification to Regulators

Work to be Done

- Initiate conceptual design for Subsea Produced Water Treatment and Solids Handling System capable of Seabed Discharge
- Review concept with Working Committee
- Finalize Subsea concept
- Issue Final Report

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09121-3100-01 Discharge of Produced Water and/or Solids at the Seabed

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