Ocean Energy Safety Research Roadmap for the 21st Century

A Forum for Dialogue

October 7-8, 2014, Texas A&M University

Summary of Events, Lectures, Panels, and Discussions

Ocean Energy Safety Institute
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Disclaimer:
These proceedings provide a transcript of the presentations and discussion that happened during the two-day event on October 7 and 8, 2014. The views and opinions expressed in these proceedings are those of the presenters, moderators, and attendees and do not necessarily reflect the position of the Ocean Energy Safety Institute.
Executive summary

On October 7-8, 2014, the Ocean Energy Safety Institute (OESI) convened top academic and research experts from various companies, universities and organizations throughout the world for an unprecedented think-tank workshop to address the development of an “Ocean Energy Safety Research Roadmap for the 21st Century” that was held in Texas A&M University, College Station, TX. The morning of the first day was dedicated to the presentation of current and future research initiatives by some of the key players: National Academy of Science (NAS), American Petroleum Institute (API), Center for Offshore Safety (COS), DeepStar, and Research Partnership to Secure Energy for America (RPSEA). These talks were preceded by an overview of the Ocean Energy Safety Research portfolio presented by the Mary Kay O'Connor Process Safety Center (MKOPSC). The afternoon of the first day welcomed presentations on more specific research topics related to Ocean Energy Safety like nano-technologies, system reliability, subsea well modeling, real-time monitoring, and smart cementing. Presenters coming from other industries also provided valuable insights on atmospheric modeling of climate extremes and military simulations. During the breaks, a poster session was organized were students from Texas A&M University and the University of Houston could interact and discuss their research with academic and industrial experts.

In addition to the presentations, OESI distributed to the attendees a first draft report which intends to provide a compilation of research initiatives in Ocean Energy Safety and to serve as a background for discussion. An in-depth evaluation of the research results and a precise evaluation and prioritization of future research needs is beyond the scope of this document, but the report is defined as a summary of the main research topics in the different areas of Ocean Energy Safety: oil spill, platform, subsea, environmental conditions, and safety management systems, together with the main funding agencies and a general assessment of research gaps whenever possible and/or identified.

During the second day, the attendees were divided in three sessions discussing drilling safety, well containment, and spill response. The results of the breakout discussions, consisting on identified research topics identified together with some comments on the draft report, were reported during a general session and commented. With over 80 attendees, the Research Workshop was successful at bringing together industry, academia, and the government in an environment of dialogue and cooperation.
Forum Day 1

Welcoming remarks – Jim Pettigrew

Jim Pettigrew began by welcoming everyone to the third OESI event and thanking those who attended the previous forums. He first provided a brief historical explanation of the Memorial Student Center (MSC) that was hosting the workshop and overviewed his first five months as OESI Director of Operations: learning and questioning his perspective every day, continuing his network building, and receiving great interest from many stakeholders. Jim Pettigrew presented a brief safety moment about the fires of Peshtigo and Chicago that both happened on October 8, 1871 and provided some safety tips about preparation of homes for fires. Then, he listed some of the major offshore incidents, and stated that we must continue to learn all we can from past opportunities, to continue enabling safe and environmentally responsible operations offshore. Finally, Jim Pettigrew reviewed the agenda for the forum and introduced Dr. Sam Mannan.

Opening Remarks – Dr. Sam Mannan

Dr. Mannan welcomed everyone and expressed his pleasure to have all distinguished delegates for the forum at College Station, wishing that this research forum will provide better answers for the reason and focus for OESI, and will re-emphasize the OESI mission which is to create forums for dialogue and continuing education programs, frame opportunities and add them to academic curriculum, and address research issues. From the research point of view, OESI will be a vehicle where students who will work for the industry tomorrow can be mentored.

Dr. Mannan explained that research is important both for academia, but also to address industry needs. Ocean Energy Safety related research is already performed in many institutions, and the objective of OESI is not to take the research monopole. Many agencies like COS, API, NAS, DeepStar, RPSEA together with some of universities and companies will present their perspective on their research.

Dr. Mannan introduced the draft report compiling the state-of-the-art of research in Ocean Energy Safety, hoping to see similar initiative published on a yearly basis that will help tying
together the Ocean Energy Safety research. Comments, inputs, suggestions and criticisms are welcome as this report is the first effort in this direction. The document should be used as background for compassionate discussions and talks about what may have been presented, not presented, recommendations, and listing of gaps. These discussions will be used by Research Advisory Committee to make decisions, prioritize areas and devise methodology to address future research in Ocean Energy Safety. During the discussions, the audience should think about how research is to be done based on different criteria: 1. monitor, 2. companies sponsoring to carry out research, 3. contracts to be developed with other universities and national labs. This mechanism can accomplish a lot if the right expertise and the right people are involved.

Dr. Mannan concluded by saying that he is hopeful and excited about this activity, welcomed everyone and is looking forward to passionate and inspiring discussions.

Session I
Moderator:
David Moore – AcuTech

Speakers:

Dr. Delphine Laboureur (MKOPSC): Portfolio Summary of Ocean Energy Safety Research Efforts
Dr. Laboureur presented the summary of research efforts, with the objective to provide an overview of the Ocean Energy Safety Research. She reemphasized the point that Dr. Mannan already announced that provided research portfolio is a draft document and expressed her expectations from attendees to provide as many comments and remarks as needed to improve the report. The report investigated safety in oil and gas exploration, production, and decommissioning, looking at deepwater and Arctic conditions, but did not investigated safety of helicopters, vessels, and renewable ocean energy. The research initiatives have been divided in five major areas: Oil spill, Subsea, Platform, Environment and Risk Management. Oil spill research investigates oil spill prevention, response and influence of Arctic conditions. Subsea research is looking at drilling, piping, cementing, mooring, instrumentation, and underwater facilities. Platform research investigates structural and maritime integrity, design, and decommissioning. Environment research investigates effects of deepwater, Arctic, or climate variability, and is looking at environmental impacts, hydrates, and well abandonment. Finally, risk research is looking at indicators, risk assessment, risk management, and human factors. In addition to these topics, Dr. Laboureur presented some of the key players and funding agencies, and introduced the speakers of the day, introducing where their talk is fitting in the portfolio summary.

Charlotte Schroeder (RPSEA): Current and Planned Topics of Ocean Energy Safety Research
Charlotte Schroeder presented an overview of the programs and type of projects funded under RPSEA, and shared their vision for the future. RPSEA is a nonprofit and private organization under contract with the National Energy Technology Laboratory (NETL) related to the Energy Policy Act of 2005. RPSEA is composed of different members from all
areas: universities, industry, and regulatory bodies, and received funding for a 10 years R&D program (37.5 M$/year). RPSEA is working primarily on three areas of research: unconventional resources, ultra-deepwater, and small producers, with the focus primarily on emerging technologies to give the United States of America success in terms of increased production.

The speaker then briefly discussed how RPSEA manages the research projects. One of the major strengths of RPSEA is the Ultra-Deepwater Advisory Committee system. The Program Advisory Committee decides on the research projects that should be conducted by RPSEA, while the Technical Advisory Committees (6) are much closer to the research projects and divided by technical areas. They identify current technical gaps and define specific R&D efforts needed to address the gaps.

The objectives of the Ultra-Deepwater Projects are to find cost effective technologies, identify research resources, understand risk, and try to assess and mitigate risk. Some of the RPSEA programs include:

- Section 999 Program (Since 2007)
- Battelle Memorial Institute JIP: Biological impacts due to air-gun
- Bastion Technologies JIP: Pyro-accumulator
- Bastion Technologies JIP: Intervention Separator

Charlotte Schroeder also analyzed the differences between the RPSEA TAC (Technical Advisory Committee) Structure and the OESI R&D Structure. RPSEA has different TACs for different research topics: drilling, completions and in-well interventions; environmental, safety, regulatory and metocean; floating facilities, risers and systems engineering; flow assurance; geosciences and reservoir engineering; and subsea systems.

OESI is developing a similar model as RPSEA. It’s important that industry contributing so graciously for public-private partnership and research project on the RMP standard should provide funds for OESI.
Charlie Williams (COS): OESC Review and Risk/Safety Management Systems Research

Overview

Charlie Williams talked about the Ocean Energy Safety Advisory Committee (OESC) recommendations on OESI and emphasized that OESI is going to be an independent institute that would facilitate research and development, training, and implementation of operational improvements in the areas of: offshore drilling safety, environmental protection, blowout containment and oil spill response. He stated the previous approaches to find gaps related to safety and control of hazards in the industry; but more efforts need to be made. According to him, it is important to avoid spending billion dollars a year on technology and research without having classified the hazards or barriers the respective research is addressing.

Charlie Williams highlighted the works of OESC’s Arctic Subcommittee, Containment subcommittee, Spill Response subcommittee and Spill Prevention subcommittee. The Arctic subcommittee did not focus much on technology but rather on standards and regulations. The primary study encompassed standards for Arctic spill prevention, development of Arctic-specific work practices, technologies and operating procedures and spill containment. The Containment subcommittee worked on several topics including instrumentation and data to diagnose mechanical condition of well after loss of control, assessing and mitigating risks posed by underground blowouts, secondary capabilities, and systems for back-up blowout preventer (BOP) operation. Some of the technical works focused on post Deepwater Horizon, where control was one of the main significant problems identified. Charlie Williams made a recommendation to thoroughly diagnose the secondary capabilities and systems for a backup BOP (e.g. acoustic activation, Remotely Operated Vehicles (ROV) intervention) and analysing systems to regain control of a BOP. The Spill response subcommittee was focused on the development of a process to evaluate selected oil spill response equipment and tactics under realistic conditions. The effectiveness of mechanical recovery tools was discussed and Charlie Williams urged industry to develop more realistic measures for skimming systems and oil removal equipment. For that objective, the Ohmsett facility in New Jersey is currently the only one that provides an opportunity to conduct research on oil, on the water. Charlie Williams mentioned R&D needs to focus on in-situ burning, dispersants, cold weather and ice response, and remote sensing technologies. Finally, the Spill Prevention subcommittee studied automation of well safety systems and identified robust instrumentation, data stream analysis, alarms and automatic control systems, well flow detection algorithms, and enhanced kick detection sensors and technologies that are all critical components for well safety.

Automation does not eliminate human interaction but is needed for decision support. The OESC recommended establishing a JIP to address work needed regarding automated well safety systems: look at what is available, what needs to be done, what are the gaps, are there other places to get this technology. Participants in the JIP should include expertise from these organizations: BSEE, U.S. Coast Guard (USCG), U.S. Geological Survey (USGS),
Department of Energy (DOE), and National Oceanic and Atmospheric Administration (NOAA), industry companies from operators, equipment manufacturers, service companies, drilling contractors, academia and national laboratories.

Charlie Williams emphasized technology development and research needs on early kick detection, shearing technology, acoustic activation, and continuous monitoring of well-bore integrity, and distinguished the **process enablers**: measuring Safety and Environmental Management Systems (SEMS) effectiveness, sharing data information for continuous learning and improvement, enhancing Management Of Change (MOC), recognizing hazards in complex/interrelated activities, moving from training to continuously applied skills and knowledge, coaching, mentoring, and interacting from the **technical enablers**: automation and data systems delivering decision support, sensors and well-control models delivering decision support, real-time data systems delivering enhanced Management of Change (MOC) and teamwork, enhanced barriers, better experienced simulators and exercises, and alarm fatigue.

When asked about critical functions of BOP, Charlie Williams urged others to think about secondary activation and the capacity of ROV activation, and he further stated that having such forum a could lead to solutions.

**Q&A**

Some comments were made by the audience on the draft report, which were:

**In the Ocean Energy Research Portfolio, the Oil Spill research is divided into prevention and response. However, the industry usually categorizes oil spill into prevention, intervention (capping, drilling fluid), containment, and response. For an improved organization of Oil Spill research efforts, intervention and containment should be placed between prevention and response.**

**Which are the key players with regard to the research document? Why the absence of OTRC and other labs from the research portfolio?** By no means is this draft report an exhaustive list. The report just handed out is only a preliminary draft (work in progress). What OESI is looking for with this draft is to create a model. Is this what people want to see from OESI? Is this an initiative that OESI should continue to perform?

**What are the boundaries selected for the research portfolio? Why is OESI not considering vessels? What about transportation?** What OESI wants with these boundaries of study is to stay close to the drilling as much as possible. However, as OESI moves further, more topics will be incorporated. If the OESI stakeholders decide on it, ultimately OESI will cover helicopters, and other operational and transportation issues.

**A lot of the focus has gone into R&D. There are also opportunities in prevention and mitigation.** Efficiency and safety are closely linked, so a decision needs to be made regarding priorities. Work should be properly organized and OESI provides an opportunity. Categorization will be useful and thinking about how best to segregate industry needs is
helpful. Bow-tie analysis can be the architecture to best provide a prioritization and categorization of needs.

Other questions and comments to the other speakers of the session included:

**What is the current state of RPSEA? Any update on future RPSEA projects?** RPSEA is not gone and will continue to manage technical aspects of projects that help the industry for two more years. A lot of manpower has migrated already; however, RPSEA is also active via JIPs. Several of them were mentioned in the presentation. RPSEA is actually admitting new participants to these projects right now. The RPSEA public-private partnership model with its advisory structure is a good one and it should be taken into consideration in the future.

**There is always an issue with funding in JIPs. Who is going to take the lead in these initiatives? What have you seen so far in feedback? Is there industry consensus?** Post-Macondo industry has come together, and is committed to make these changes happen, there is great commitment and results from industry collaboration are always good. Furthermore, the industry was present when all of these recommendations were put together. It is important that when a JIP is developed, everybody has skin in the game, and a federal oversight on the projects is needed.

**The recent drilling magazine had a cover story on human factors. Is the OESI thinking about simulations? How about human-technology (HT) interfaces? How about human factors in the face of scenario simulation? What do we think in that perspective? What does OESI think about that line of work?** Simulators are useful for real scenario training. Everybody is committed on the acquisition of real life experience via simulators. It is an example of how technology drives human response. Apart from being used as a tool to acquire real life experience in emergency scenarios, simulators can also be used to improve the technology. However, while it is a great asset to develop expensive simulators, it is also important to think about what is more appropriate; simulators are not the end solution. Since human factors are a very important issue, OESI is going to have a human factor forum to address what needs to be done. The forum is currently in preparation and further information will be provided in the following months. This forum will address questions like what needs to be changed in the technology to improve the interaction with humans or how to use automation and how to train people.

Dr. Mannan ended the Q&A session by asking the audience for suggestions about the submitted report, as it is important to improve it as much as possible in order to create a model for future versions of the Ocean Energy Research Summary.

**Session II**

**Moderators:**
David Moore – AcuTech
Speakers:

**Holly Hopkins (API): American Petroleum Institute Post-Macondo Research Efforts and Programs**

Holly Hopkins presented the API offshore energy research program. The discussion revolved around four main topics: API input on OESI, Joint Industry Task Forces (JITF) Post-Macondo Research, API standards-related research, and operations in the Arctic environment. For the first part, the API letter (dated November 2010) to the Department of Interior (DOI) was discussed, along with the guidelines set by API for OESI at the time. For the second part, the four post-Macondo JITFs were outlined along with their objectives. These JITFs are: operating procedures, operating equipment, oil spill preparedness and response, and subsea well control and containment. Several examples of the subsea well control and containment JITF recommendations were provided. For the third part, API and non-API standards-related research initiatives were reviewed. From the API side, the following research initiatives were discussed: subsea dispersants injection program, in-situ burning, mechanical recovery, oil sensing and tracking, and shore line protection and clean-up. From other non-API agencies the following research initiatives were presented: thread compounds for casing, tubing, and line pipe; performance impact of material toughness on large steel forged components in mooring systems; and drilling structures’ load and resistance factor design studies. Finally, a list of Arctic related research topics and initiatives from other groups was presented. The discussion following the presentation also mentioned the BSEE Arctic Research initiatives that included: real time ice monitoring, ice scouring, and safety factors for crew quarters design, and elastomeric materials for cold weather environments.

**Dr. Kim Waddell (NAS): Research to Advance Oil System Safety, Human Health, and the Environment in the Gulf of Mexico**

Dr. Kim Waddell started with a brief overview of the National Academy of Sciences, which was established in 1863, and which is not a government agency. The Gulf Research Program is a 30-year, $500 million program funded by the Deepwater Horizon criminal plea agreements. The Program mission is to enhance oil safety and the protection of human health and the environment in the Gulf of Mexico (GoM) and other U.S. outer continental shelf areas, and to improve understanding of the region’s interconnecting human, environmental, and energy systems, and fostering application of these insights to benefit the Gulf communities, ecosystems, and the Nation.

The program has activities in three areas: Research and development, Education and training, and Environmental monitoring. This program began last year and includes people from various agencies and industry who bring expertise to this council. One of the major program goals is to foster innovative improvements to safety technologies, safety culture, and environmental protection systems associated with offshore oil and gas development.

The objectives for the next five years were released September 2014, and are to first partner with industry, government, and academia to identify key opportunities to enhance
the safety of offshore energy. The second objective is to explore decision support systems for safe and environmentally sustainable offshore oil and gas development, disaster response, and remediation. The third objective is to provide research opportunities that improve the understanding of how social, economic, and environmental factors influence community vulnerability, recovery, and resilience. The final objective is to support research, long-term observations/monitoring, and information development to advance the understanding of environmental conditions, ecosystem services, and community health and well-being in the GoM.

The 30-year duration of the program is a great opportunity to perform long term studies think strategically and use the funding effectively. The potential program themes in oil system safety are organized in three main areas: workforce education and safety training, decision science and communication, and technology and engineering to enhance process safety.

In the following months, NAS will announce exploratory grants, which are small “seed grants” to explore and catalyze innovative ideas, approaches, methodologies, and/or collaborations. In 2014, the announcement will focus on approaches for effective education and training of workers in the offshore oil and gas industry, and linking ecosystem services related to and influenced by, oil and gas production to human health and wellbeing. The 2015 announcement will focus on scenario planning and decision support for oil-spill response, connecting environmental and health data for trans-disciplinary research, monitoring, and syntheses, and building resilience in human and environmental systems.

Finally, the NAS believes in building capacities in the Gulf to help prepare a future generation of professionals to work at the intersections of oil system safety, environmental resources, and human health and to think holistically about the region’s challenges. Three initial activities are proposed: early-career research fellowships, science policy fellowships, and the Christine Mirzayan Science and Technology Policy Graduate Fellowship program.

**Dr. Greg Kusinski (DeepStar): Emerging Technology to Enable Safe and Environmentally Responsible Ocean Energy Operations**

Global energy demand is expected to have a 45% increase from 2012 to 2035, and approximately 40% of the recent discoveries are in the deepwater basins. Therefore, the main challenges are to provide affordable energy, energy security, reliable resources, and the energy development that addresses the environmental expectation. The DeepStar consortium is working to improve safety, proper design, and proper qualifications to bring all the technologies that would improve the recovery of these resources. DeepStar has over 20 years’ experience in research in a continuing effort of developing technology. Currently, 12 major companies are participating to the phase XII of the DeepStar program, in addition to a larger group of contributors composed of manufacturing, engineering, and consulting companies as well as universities and research centers.

The mission of DeepStar is to improve profitability, execution, operability, reliability, flexibility and safety of deepwater production systems. DeepStar investigates and frames
the use of effective technologies, develops new enabling deepwater technologies, enhances existing technologies, gains acceptance of certain deepwater technologies by regulators and industry, and in a similar approach as OESI, provides forums and a process for discussion, guidance and feedback.

The funding projects of DeepStar Phase XI and XII are divided into five categories: understanding design conditions; engineering and design; technology selection and qualification; inspection, monitoring, surveillance and repair; and decommissioning - covering all aspects of the deep-water technology puzzle. One project example for “understanding design conditions” is the model development for probabilistic prediction of eddies to better design installations and conduct offshore operations. Examples of “engineering design” projects are riser fatigue and design, flexible risers, and standardizing approaches for 20K psi designs. Examples of “technology selection and qualification” are high pressure flexible flow lines, or the ability for industry to deploy lazy wave steel risers. Examples of “monitoring and surveillance” projects are standard development for Automated Unmanned Vehicles (AUV), and the development of a roadmap for subsea integrity and inspection technology.

While OESI is about safety, DeepStar is about technology development that involves safety management systems, design conditions, and understanding the engineering design limits and opportunities from the perspective of demanding supply.

Q&A

To DeepStar: Is DeepStar going to develop standards? Not exactly, DeepStar is trying to identify the best practices and offer some guidelines. It could later result in a standard but it is too soon right now. DeepStar recognizes approaches that lead to safe operations.

To DeepStar: With respect to technology revamping, how do you approach research questions? What is the overall approach? DeepStar primarily consults experts who can understand their companies’ resource based technological needs. Annual meetings are held in which broad common areas are identified. For each area, engaging committees is a good idea to develop roadmaps for specific perspectives. The objective is always to lead to safer and more economical operations, and progressively close the gaps. DeepStar also hires facilitators and funds fundamental works (like flow assurance: phase diagrams). Another example of a research approach would be engaging with Stress Engineering Services to facilitate work related to subsea integrity. The approach should be performance and function driven with advanced capabilities. DeepStar targets developing resources for the near future and the main strength of DeepStar is to truly define the gaps and what we don’t know that could allow for better decision making with a pragmatic approach, and analysing cost of gaining that knowledge vs. the benefit that this knowledge would bring. In summary, DeepStar studies technology allowing better and safer operations that prove business value. Being accountable allows having a purpose that brings value. DeepStar history proves that being accountable is very powerful and keeps an organization focused.
**To DeepStar:** Values need to be shown on spending the money on projects, how to assure that? Accountability should be associated with each project. Taking pride in being able to maintain a very high degree of work will ensure the quality and effectiveness of research.

**OESI happened because of the vision of BSEE with the support of other industries ideas, and it is therefore important for OESI to be in agreement with other organizations. What should be the OESI's operational space? What role should other organizations play? How can OESI work best with others?**

**Kim Wadell - NAS:** NAS has lot of expertise, but there is a need to dig deeper. OESI can have access to the technology side, while NAS has the experts and ideas and can offer potential expertise to work with OESI in the area of process safety, education, and training human dimension, interaction with environment, and policy. It is important to create a mechanism to develop actionable items, and maintain the communication to clarify the needs.

**Holly Hopkins - API:** OESI can identify the existing gaps, make sure that there is ample, ongoing analysis of all the research, and can leverage all existing bodies and entities that are performing research.

**Dr. Kusinsky - DeepStar:** From a DeepStar perspective, the preparation of an annual report which OESI has already undertaken, is a very valuable piece of information. From an industry perspective, OESI can help to develop further visibility to DOE-funded work. Government stakeholders would like to understand industry developments, and industry would like to understand advancement that is developed through federal government funding. Frequent dialogue is valuable and OESI can arrange that. Academia wants more research, but industry wants research that has a perceived value to them. OESI should stay focused on safety research and should not become involved in the BAST decision process. DeepStar is interested in continuing collaboration, to ensure that the dialogue is in place which is 100% consistent with the DeepStar mission: to continuously engage different stakeholders.

**Other Responses:** Many recommendations have been issued after the Macondo incident. But it is necessary to mark out the key learning and look at research studies and mechanical solutions. OESI can help with these tasks, which may help to identify and try to anticipate the next incident before it occurs. Its focus should be on learning and thinking about the future. A nice product from OESI would be having an overview on recommendations. Regarding academic research, academics do not do research for the money they receive, but instead they use research as a vehicle to mentor and educate the students for the future. In doing that, they have to abide by certain rules, prove their work and also need to be accountable. In addition, academia has the mission to explore what we don't realize that we don't know, explore and investigate if a solution or a theory is worth further investigation and then perform the research.
Session III

Moderator:
David Moore – AcuTech

Speakers:

Dr. Debjyoti Banerjee (Texas A&M University): Nano-Devices for Enhanced Thermal Energy Storage

Dr. Banerjee discussed his current research focuses which are “nano-fins” for thermal management, nanofluids, micro/nano-thermocouples (thin film thermocouples or “tft”), carbon nanotubes (cnt), molecular dynamics simulation, and boiling chaos. He talked about the schematics of subsea operations: high pressure high temperature, gas emissions and detecting combustible vapors and highlighted the use of nanofluids for cooling and drilling operations. Not only are thermal conductivity and heat transfer enhanced when nanofluids are used, but the specific heat capacity also increases. Current research is ongoing to understand from where this enhancement is coming and future application will include heat storage or thermal cycling to prevent hydrate formation. Dr Banerjee discussed the use of nanocalorimeters to detect combustibles, gasoline vapors, or chemical agents. Instrumentation of subsea operations was discussed, in that nanoparticles are still not used in instrumentation of platforms. Nanoparticle additives are also used in compact heat exchangers; adding nanoparticles to hot oil enhances the heat transfer as they precipitate the heat exchanger surface and form nanofins, which could be an impeding mechanism to prevent corrosion. Finally, Dr Banerjee summarized his work as below:

- “NanoFin Effect” cause heat transfer enhancement on nanostructures during boiling: which have enhanced liquid-solid interactions
- Nanoparticles precipitate to form nanofins which control the heat transfer
- Molecular Dynamic simulations show that chemical properties affect heat transfer on nanofins
- Partial precipitation causes enhancement of heat flux where excessive precipitation causes degradation
- Spray cooling enhances local heat flux
- Decomposing AC was simulated in an industrial chevron heat-exchanger

Dr. J. Eric Bickel (University of Texas): Quantifying System Reliability for HIPPS and SCSSV Subsystems

Dr. Bickel started his talk by stating that the risk of an incident is cumulative. Decision making is difficult due to uncertainties and risk. And from the probability pattern of an incident or hydrocarbon discharge it can be concluded that focusing on spill prevention may lower the probability that there will be any event, but not the probability of having any significant event. So, focusing solely on prevention could misallocate resources, and therefore, the focus also needs to be on mitigation.
Dr. Bickel also discussed the energy research project collaboration between the University of Texas at Austin and BP, with the objectives of quantifying reliability of offshore systems and developing a reliability assessment process. This process will quantify the system-level reliability of differing system concepts, identify the most important drivers of system reliability and risk, provide a common baseline upon which differing concepts can be compared, and facilitate faster and better decision making regarding candidate concepts. The use of a Markov chain to represent the risk of a system was discussed and an example calculation of the availability for a subsea High Integrity Pressure Protection System (HIPPS) was provided.

Dr. Bickel concluded that the general benefits of this reliability assessment process are that the process can recognize and capture inherent uncertainties, determine the most important drivers of reliability across all metrics, and identify what drives the difference between competing concepts or systems. He stated that there is a possibility to develop new technology that can provide early insights on parameters that affect system reliability with little available data.

Jeff Sattler and Michael Crosby (Lloyds Register Energy): An Ideal Rig-One Vision and Informing the BOP Pull Decision with the LR BOP Risk Model

Jeff Sattler and Michael Crosby described an ideal rig vision based on the BOP Risk model developed by Lloyds Register after the Macondo incident to specifically eliminate problems associated with the decision process on whether to continue or to suspend drilling operations. Problems with the current, human decision methodology include: inconsistent decision making, biased decisions that are not backed up by science and sound engineering principles, and slow decision making that put personnel, environment and assets at risk for long time periods. The BOP Risk model is customizable for a specific BOP stack being used in a specific country’s waters, and can be tailored to the host nation’s rules and regulations and the company’s operational procedures. For each model a complete Failure Mode and Effect Analysis (FMEA) of the stack has been performed with a group of Subject of Matter Experts (SME). Fault trees and P&IDs are also incorporated in the program.

After demonstrating the risk model, the speakers shared their ideal rig vision that would include a common data platform that could provide information about what studies are applicable, sort and prioritize them, and make them available to the people that make the decisions. Three visions were presented for roustabout, mechanic and risk register. For the roustabout vision, people at a current location should be aware of risks such as active or pending work permits; current drilling status; and proximity of hazardous areas involved with electrical, fire and explosion, and dropped objects. For the mechanic vision, they could prioritize and schedule tasks based on real time feedback measurements and analysis, reliability information, well construction status, and weather. Mechanics could also prepare for a certain job using job safety analysis, safe work permit, maintenance procedure, and parts requirements. For the risk register vision, they should be aware of the risks that people on the rig are exposed to and report near-misses.
Dr. Scott Socolofsky (Texas A&M University): Research in Modeling of Subsea Oil Well Processes

Dr. Socolofsky gave a summary of various experiments conducted to study subsea oil well processes, starting with the Deepwater Horizon blowout. Further, he explained that for studying near-Field dynamics of subsea accidental oil spills, certain factors like stratification and cross flow are important. In this study, various experiments like pure stratification, pure cross flow, and plume parameterization were conducted, and empirical models were developed. A study where Deepwater Horizon was validated using integrated plume and discrete bubble models was also described. Dr. Socolofsky also mentioned the Texas A&M Oil spill Calculator (TAMOC) which is available free of charge and can be used for oil spill evaluation.

In this area, the challenges and goals include improved knowledge on bubble and droplet size distribution and the efficacy of subsea dispersant injection, mass transfer rates and the role of hydrates and oil films, effects of cross-flows, and effect of ice cover in Arctic conditions. Working on these challenges will improve the risk analysis and hazard prediction in response zone.

The presentation ended with some conclusions. First, integral models are standard tools to predict near field spill dynamics, and entrainment hypothesis and dynamics were validated to limited experiments. The fate of a blowout plume depends on many factors like the solubility of complex mixtures at high pressure, the mass transfer reduction by hydrate films, the mass transfer effects by oil films, the tip streaming under subsea dispersant application, and when do particles act like a plume and when do they rise independently. Finally, in addition to this research team, GISR and C-IMAGE, among many others, are also working on these problems.

Q&A

To Dr. Banerjee: What is the optimum size of nanoparticles? The optimum size for thermal storage applications, which relies on enhancement of specific heat capacity, is 5 - 10 nm. For cooling applications that primarily rely on enhancement of thermal conductivity, the optimum size is 50 - 100 nm. Functionalizing nanoparticles can result in reducing the optimum size range of nanoparticles to below 50 nm - that way the same set of nanoparticles can be used both for cooling and thermal energy storage. However, while functionalized nanoparticles have a lower range of operating temperatures, non-functionalized nanoparticles (i.e., pristine nanoparticles) typically have the advantage of a higher range of operating temperatures.

To Dr. Banerjee: Does shape of nanoparticles affect the performance of these nanomaterials? For the nanofluids - the shape of nanoparticles has a significant effect. The surface adsorption of fluid molecules on the nanoparticle surface leads to formation of a semi-solid layer of fluid with a higher density than the fluid itself. This is a layer that behaves like "ice" (i.e., a compressed layer). This ice-like layer controls the net property values of the nanofluid. The shape of the nanoparticle determines the amount of ice that is
formed per unit mass of the mixture. A disc-shaped nanoparticle has the highest surface area per unit volume and therefore leads to the formation of the largest ice-layer per unit volume (than say a tube shaped nanoparticle). The tube-shaped nanoparticles form more ice layers per unit volume (or per unit mass of the nanofluid) than a spherical nanoparticle. Also, in electron microscopy images (not confocal microscopy) his team observed that these ice-layers develop tentacles, or finger-shaped growth patterns, which connect with the ice layers that exist on neighboring nanoparticles. Hence, the nanoparticles serve to nucleate these ice layers that grow into the surrounding volume, and depending on the shape of the nanoparticles, (such as tube shaped nanoparticles) more of these tentacles can form per unit volume (or per unit mass).

To Dr. Socolofsky: Are operators using the predictive model that you developed? Other operational models are available like the near-field model of SINTEF, deepflow, or SAS. All of these models have the paradigm that the cross-flow is predominant. Industry uses the integral model. The deep-spill experiment is the only available material, so all models are validated against this dataset.

In the case of a deep spill, the main question is how quickly the oil will rise to the surface. But this is not the most important question. People should ask where they need to go to clean it up. It is important to know if there may be an explosion in the near-field and implement a contingency plan.

What are the gaps that exist on which more funding should be put?

- A system level model to understand risk worldwide, to understand how actions and resource allocation will affect the global situation. A high level model is needed, without too much detail.
- Descriptions of problems are changing with time, so modeling techniques should change accordingly. Therefore, probabilistic risk assessment should be used more and guidance should be provided as these methods allow one to actually understand risk. Consistency of modeling techniques is needed, and calculating the worst case discharge is not sufficient.
- Corrosion costs 2% GDP to industry. The effect of nano-coating for corrosion prevention is a relevant topic to study and is multi-disciplinary. Nanoparticle additives to be used in smart fluids to tune the properties and be used as tracers are another important area of research, especially for high-pressure/high-temperature (HPHT) environments. Finally, development of nano-sensors for performance characterization is a third area that requires more research. All of these areas could be good research projects (for OESI).
- Application of the models of near-field dynamics to a drilling scenario to better plan for incidents and see if they can be overcome/prevented. Research should be done on when the plume rises individually through water to better understand the conditions under which the cross-flow blows the plume apart. Targeted field experiments could help answer key questions about the physics.
- Improvement in the BOP risk model requires better knowledge of the probability of failure. Building risk models based on history and calculating mean time to failure rates
is important for proactive maintenance. But in this area, both the lack of existing data and reluctance of companies to share data with others are problematic. The International Association of Oil and Gas Producers (OGP) have started an initiative in this area, in conjunction with seven drilling contractors and operating companies, and already have agreed on taxonomy.

Session IV

Moderator:
David Moore – AcuTech

Speakers:

Howard Mall (ECS Incorporated): Lessons for Energy from Military Simulation
Howard Mall started the presentation by listing several common characteristics shared by Energy and Military; both have highly critical and dangerous jobs that need to be performed without interruption. In both disciplines mistakes are costly in equipment and lives, in addition to money. Finally, both require a highly skilled workforce that changes often.

Many lessons can be learned from the military’s approach to training and preparedness: simulations save lives and money, and training should be performed continuously and be innovative. These lessons were demonstrated by many examples like the flight simulators and horse simulators used in World War I, and the link trainers used during World War II. More recently, commercial video games, which also provide innovative ways to train people in Energy, have been modified to help train the military.

Dr. Eric Van Oort (University of Texas): Real-Time Monitoring for Improved Offshore / Arctic Safety
The presentation focused on an overview of deepwater drilling and completions R&D at the University of Texas (UT) at Austin. Due to three combined factors – large water columns, high geo-pressures, and low fracture gradients, narrow drilling margins on deepwater wells (for example, the Macondo wells) are giving rise to a number of serious drilling challenges. Two fundamentally different methods have been proposed: Wellbore Stress Augmentation (WSA) and Fracture Propagation Resistance (FPR).

Dr. Van Oort introduced several research aspects included in the UT Drilling and Completion R&D Program: zonal isolation, lost circulation and fracturing, well manufacturing, drilling fluids design and automation, drilling automation and the Real Time Operations Center (RTOC). With several advanced equipment labs - a state-of-the-art zonal isolation lab, an active (ultra-) deepwater cementing R&D program, Human-in-the-Loop (HIL) simulator, and Real-time collaboration center, Dr. van Oort’s group conducted research to study the effect of SBM contamination, the benefits of slag cement, and contributing factors to US offshore blowouts.
After demonstrating current real-time capabilities in BOP reliability testing, formation strength testing and zonal isolation, Dr. van Oort also envisions an OESI project in which operators and regulators co-develop a program to effectively monitor offshore activities.

Finally, Dr. van Oort concluded that data quality is going to be imperative along with the need for reliable and accurate sensors and sensor data algorithms that exploit redundancy in sensor readings, for the future of automation. Automation might also include mud rheology and early influx detection algorithms which are particularly important for deep wells, for early kick detection.

**C. Vipulanandan (University of Houston): Smart Cement for Real-Time Monitoring of Oil Well Cementing**

Dr. Vipulanandan introduced his research about smart cementing materials and drilling muds for real time monitoring of Deepwater Wellbore enhancement. Well cementing is an important process that ties the man-made materials and nature, implying great responsibilities toward the industry in ensuring isolation via a two-inch maximum thickness layer of cement. A number of factors might affect wellbore integrity and cementing is one of the most important ones. Looking at Australia’s worst oil spill in 2009 and the Macondo deepwater blowout in 2010, a similarity between the two accidents was the cement failure. Technologies that could identify cementing related issues are therefore very important. Currently, installation operations cannot be completely monitored, nor can the performance of cemented wells during their service lives.

The objective of this research, sponsored by RPSEA and DOE/NETL, is to improve the performances of drilling mud and well cement using smart materials with sensing capabilities. The basic concept for cementing material is to create smart cement that can sense contamination effects. Since cement has some unique properties, enhancing stress-chemical-thermal-electrical resistive behavior is worth studying to determine changes with time and with contamination. Cement is pumped into a well as a liquid and solidifies due to chemical reactions; and drilling mud starts as a liquid and but stays liquid as it circulates. For cementing, major issues related to the materials are cement solidification, fluid loss, contamination, cracking, and stresses.

For human sensing models, there are mainly six components: the four senses (sight, smell, hearing, and taste), the skin (temperature, stress, and damage), and the brain (control system). By analogy, an oil well system is mainly skin and brain so the objective of this work is to create smart materials that are as sensitive as human skin and have the capability to monitor and control just like the human brain. There are many properties that could be monitored, like physical, chemical, thermal, magnetic, and electrical. Among these, resistivity and conductivity measurements are the unified sensing for cements and drilling muds.

The typical resistivity-time relation for cement was found to be similar in all of the tested specimens; its electrical resistance decreased and later increased sharply. Numerous experiments were performed to measure the resistive properties of cement under varying
conditions, such as sensing salt contamination and piezoresistive behavior, using DC and AC measurements. Adding nanoparticles and carbon nanotubes to smart cement could help to change the sensing properties.

An important finding of the research was that the resistivity changed with time during its curing time. Within the first 24 hours (RI24) the change varied from 50 to 300% depending on the type and amount of additives. Piezoresistive behavior was enhanced by over 400 times with the addition of less that 0.1% conductive fibers compared to measured strain without the addition. Real-time monitoring of the lab models was successful. The results of this work could help might eventually result in improvements in monitoring and predicting the cement conditions in wells.

**Dr. James Done (National Center for Atmospheric Research): Offshore Engineering for Climate Extremes**

Dr. Done provided an update on ongoing research at the National Center for Atmospheric Research in Colorado with the objective to understand future hurricane activity in Gulf of Mexico and its impact on the industries. This work is being conducted under NCAR's Engineering for Climate Extremes Partnership – an interdisciplinary partnership bringing together engineering, scientific, cultural, business and government expertise to develop robust, well-communicated predictions and advice on the impacts of weather and climate extremes in support of society. Key to this vision is the development of resilient responses to current and future climate extremes and an approach that acknowledges that all systems will fail at some level and incorporates uncertainty about the predicted magnitude of the impact at the planning and design stage, following a systematic ‘graceful failure’ approach.

There is consensus in the research community that there will be a larger proportion of the most intense hurricanes in the future, and that average hurricane wind speeds will increase. As a consequence, coastal and offshore facilities might be under-designed. The objective of this new RPSEA sponsored work is to predict future hurricane impacts on the offshore energy industry that account for wind, waves and currents. The first step in addressing this objective was to develop a simple impact index using atmospheric conditions only. A Cyclone Damage Potential (CDP) index was developed, which is a measure of duration of damaging winds. The second, ongoing step is to explore full dynamical modeling of extreme meteorological conditions and investigate actual impacts on offshore structures in order to estimate loading due to wind, waves and currents. An example of a simulation was shown for hurricane Katrina that captured wind, waves and anti-cyclonic flow around the loop current and loop current eddies, was provided.

Dr. Done concluded his talk with some remaining research questions: there is still uncertainty about the n-year current impact due to a scarcity of historical records. In addition, studies have shown that climate has changed over the last 20 years, so there is a need to understand how the n-year impact changes over the design lifetime, as well as how impacts to offshore structures will change in the Gulf of Mexico. Finally, the benefit of specific engineering advances will require more assessment. With regard to all of these questions, OESI could facilitate research activities by providing data.
Q&A

What are the gaps that exist on which more funding should be put?

- More research should be done on spill prevention, and zonal isolation is one of the key solutions that should be investigated further.
- Serious video games should be further investigated, as they could help to improve safety.
- Improved monitoring and sensing technologies, and developing materials for monitoring are areas in need of more study.
- Improving communication between atmospheric scientists and engineering designers is imperative, as both disciplines are strongly related and could benefit from one another.

To Dr. Van Oort: How is the Bayesian network of sensors being used?  

Modeling the sensors in a Bayesian network can help to assess the data quality and detect faulty data. The usual approach to assess sensor quality and faulty response is sensor redundancy, but this approach is very costly. Therefore, there is a strong need for quality assessment of data, especially if the data are later used for automation. Another example of importance of high accuracy for flow monitoring is related to early kick detection which requires downhole measurements, and real time monitoring with Coriolis or other flowmeters.

Real time monitoring is a logical extension of control systems. Managed pressure drilling is a very efficient active control system that can help operators immediately react to events and that could have prevented the drilling problems that occurred in the Macondo incident. Future research in this area should include active downhole pressure control.

Comment to Howard Mall: The gaming approach that has been applied to military training should be investigated for offshore operations, and military experiences (learnings and practices) could be used to improve its effectiveness. Rethinking the way people learn using cognitive science to understand how people learn and how they can be better engaged is a very important issue.

To Dr. Vipulanandan: The presentation explained that resistivity is affected by porosity, ionic solutions or temperatures. Will you be able to monitor changes in these parameters from a resistivity measurement? Yes, resistivity is very sensitive to all changes and looking at rates of change of resistivity allows one to identify problems from contamination to setting, and even to detect the water-to-cement ratio.

To Dr. Vipulanandan: Is there already an actual application of this system? Currently the technology is under development, and model tests are being performed to better understand various aspects of conditions, such as temperature changes, applying loads, or fracturing the cement.
Forum Day 2

Opening remarks – Dr. Sam Mannan

Dr. Mannan started by thanking the presenters from the first day for providing a summary on the current activities of main organizations like API, RPSEA, DeepStar and NAS, but also more specific and technical research presentations. Each of the four sessions also provided interesting discussions about future research needs. In addition, the report prepared by OESI and distributed to the attendees provides the potential main stage of the institute, and is open for discussion; inputs from everyone were encouraged.

Dr. Mannan then detailed the agenda of the second day, which is an important day to start developing a list of future research projects through the breakout sessions. But this list will not be written in concrete, as developing a research roadmap, as experienced by many organizations, is not an easy job. The efforts of this workshop will be used to develop a first version of the roadmap. Then, an iterative process will start by providing this first version to the attendees and to interested people who could not attend the event for further input. OESI will organize a second forum in next spring, around March or April, to refine the roadmap. Before that event, discussions will be ongoing through email or conference calls to gain more understanding regarding the research roadmap’s strategic direction.

Q&A:

What is the scope of each session? What are we supposed to deliver?

Session I will be led by Dr. Van Oort (UT) and Mel Whitney (Cameron) in room 2405 and will discuss “drilling safety”. Session II will be facilitated by Dr. Ramanan Krishnamoorti (UH) and Holly Hopkins (API) in room 2404 and will discuss “Containment issues”. Finally, Session III will discuss “spill response” in room 2401 and will be led by Dr. Rashid Hasan (TAMU) and Charlie Williams (COS). Facilitators will moderate the discussion. Summarize their respective discussions, and deliver the important issues during the general session after lunch. Attendees will be randomly distributed among the sessions to ensure equal number of participants at each session.

This is the 3rd OESI forum: what has already been done from the other two events?

After each event, OESI produced proceedings summarizing the presentations and discussions of the event and identifying actionable items. The proceedings for the Risk Forum are available, and the proceedings for the Data Sharing Forum will be published soon. From the proceedings’ action items, if a project can be handled within a reasonable budget, OESI is starting it. For those action items requiring funds that are currently outside of the initial OESI budget, they will be discussed once the governance structure is put into place.
Breakout Sessions

After the first day of presentations related to Ocean Energy Research, the audience was randomly divided into three breakout sessions, to continue the discussion. Each breakout was facilitated to ensure the efficiency of the discussions. The objective of these breakouts was to identify the roadmap for future research projects related to drilling safety, containment, and spill response.

Breakout Session 1: Drilling Safety
Facilitators: Eric Van Oort – University of Texas Austin, Mel Whitby - Cameron

The overarching idea of this breakout session was to focus on issues with research potential in the field of drilling safety. Importantly, it was noted that the most effective means of defining these research opportunities may be to identify where research has focused, considering all relevant sources, and then look for the gaps in the current research where OESI may be able to fill in the gaps between ideas and deliver a more synergized product, while avoiding duplication of current research efforts.

Three key points that were identified during the discussions are that:
- An OESI roadmap for research and development is premature,
- A governance model for the OESI needs to be developed before the research direction should be determined,
- and The OESI technology maturation model needs to be sorted out.

Ideally, the research roadmap could be defined immediately, but the general feeling is that this may need to be an iterative procedure requiring more discussion as the direction and governance of the organization becomes more defined in the future. As these details are set, the areas of capability of the OESI will become more lucid, and projects from which the most benefit can be derived will become more apparent.

Several broad opportunities for research were identified and discussed. These include:
- Real-time drilling systems and decision-making: drilling margin management and parallels between drilling and other industries in the field of automation were discussed. How can available information be integrated into a format that aids decision-making?
- Human factors related to drilling: minimization of disconnect or lag time between driller competency and utilization of future automated systems, but also simulator training and evaluation of situational awareness, particularly in the case of training for highly unlikely scenarios.
- Situational awareness in automation: as automation increases, the awareness of available information of an operator may go down. How can this information be presented in an effective way so as to keep the operator properly informed?
- Automation and training/experience: Can automation be used as an effective safeguard against a lack of experience and education while they being acquired, as
by a new hire? What is the most effective method to train people to use these automated systems?

- Other industries/application of automation: what are the proper applications of automation? How could it change the dynamic of human-machine or human-human interaction?

- Information integration: Hard-coding of triggers may be difficult due to the unavailability or difficulty in obtaining of key points of data (pore pressure estimation as an example), or possibly more that the information is there, but the real-time interpretation of the data is difficult and there is a lag time.

- Systems reliability: How does one ensure integrity of data inputs to automated systems? Can communications standards and interfaces be made more consistent to avoid loss of integrity due to differences in systems?

- High pressure/high temperature: Opportunities for new materials, standardized testing and protocols on new and existing materials, and management of situations arising from new materials during the lag time between adoption of the new materials and the time that an applicable standard is adopted.

- Technical challenges: Challenges discussed include HP/HT kick behavior, handover between drilling and completions, robustness of electrical components, methodical development of software, and machine automation.

- Shearing: Opportunities for correlating the shear blade integrity to the flow rate that they are exposed to, testing and verification of parameters, developing new methods of shearing, scalability, and computer modeling.

- Cementing: How can a lasting bond be achieved for the life of the well, and how can the existing bond be verified and evaluated?

- Alternative methods for hole-making: Are there any credible alternative methods for hole-making that are worth research time and money investment? What are the risks associated with new methods and what is the expected gain in safety performance (value proposition)?

- Acceptable level of risk and risk communication: Prevention and mitigation strategies, safety culture considerations, when to reevaluate systems for risk acceptance and risk acceptance criteria (e.g., too far away from goals, not moving toward goals at an adequate pace). How can risk be communicated to the public in an effective manner?

- New technology/regulation risk assessment: Is there a methodology or metric to find out how new technologies, before they are implemented, will affect safety? Could new policies be treated in the same way to evaluate the gains and relative losses in safety?

- BSEE-industry interface (data-sharing): There is reluctance to share data because of the intertwining of safety and performance in the data – companies don’t want to give up a competitive advantage, so there is a reluctance at times to share data. Safety data could be decoupled from performance data, but it is possible that the safety data would lose context without performance data. Can data be efficiently
transferred between companies and industries without disclosure of sensitive information? Is this something OESI would be able to do?

- OESI in a training role in conjunction with BSEE: Can OESI provide training services in conjunction with BSEE, particularly for inspector training?

**Breakout Session 2: Well Control and Containment**

**Facilitator:** Dr. Ramanan Krishnamoorti – *University of Houston*, Holly Hopkins – *API*

This breakout session first broadened the topic of identifying research and technology gaps in both “Well Control” and “Contamination”. Some other entities are suggested to be added into the “Portfolio Summary of Ocean Energy Safety Research Efforts”, for example Government Research, ITF, Norway entities, Drilling Engineering Association (DEA) Europe, Subsea Well Response Project (SWRP), Marine Well Containment Company (MWCC), Helix Well Containment Group (HWCG), and other academia such as University of Tulsa Drilling Research Projects (TUDRP) and Colorado School of Mines (CSM). In addition, this session also suggested engaging Subject Matter Experts (SME) to identify current research and gaps.

Then, based on gaps related to containment identified by API, this breakout session further discussed the gaps in well control and contamination, and divided them into two categories: the gaps requiring technology development, and others which would require research.

**Suggested Research**

- Effect of Hydrates on Containment/Interference of Hydrates during Containment (Hydrate Consortium exists and would need to be consulted, Heriot-Watt, CSM, TUDRP, Rice University)
  - Alternate Hydrate Inhibitor Formulations (broad-based Low Dosage Hydrate Inhibitors (LDHI) likely to work in most oils)
  - Computational Fluid Dynamics (CFD) of flow inside and immediately outside containment during deployment
- What could make this not work? Translating fundamental results to technology applications
- Decrease the time it takes to contain an uncontrolled well
- Enhanced methods and equipment for subsea well control and containment
- Evaluate new and evolving ideas for subsea containment, including open capture devices that would have separation capability

**Potential Technology Development**

- Dispersant use during deployment of containment.
- Develop new methods to release the lower marine riser package (LMRP) without riser tension.
- Develop methods for high angle LMRP release without damage and also high angle reconnects.
- Develop new quick release for risers at or above the flex joint/stress joint.
Extend containment concepts to subsea producing operations and equipment.
Remove a damaged or non-functioning BOP stack. Be able to use an ROV and surface intervention vessel to unlatch and remove a BOP stack to gain access to a subsea wellhead.
Evaluate possibilities to regain full control over all important BOP functions in the event that the rig has released the BOP stack, but the LMRP is in place and there is no control connection to the pods and/or pods are inoperative.
Effect of plume generated forces on ROV activity and containment deployment.

Breakout Session 3: Spill response
Facilitator: Dr. Rashid Hasan – Texas A&M University, Charlie Williams – COS

The area of discussion was spill response, and the key identified issues included response by containing oil as well as controlling and/or stopping the source of the spill. Spills can occur from vessels, pipelines, platforms and/or wells, the latter representing the biggest challenge given the sometimes remote conditions and locations of wellheads, the usually large amount of oil/gas in a well, as well as many other parameters which are not always known. Therefore, most of the discussion during this session focused on research areas to respond to spills from deepwater and ultra-deepwater blowouts.

Summary of discussion
Spill R&D and technologies were discussed and, as much as possible, discussions about policies were avoided. In response to a crisis, no single company or regulatory agency has the man-power to respond to a large-magnitude spill, such as Macondo. For this reason, there needs to be good crisis prevention and preparedness to work in a consortium to respond to a spill. In the Macondo incident, for example, there was a lack of logistics in which there were no clear leadership roles and work strategies, at least for the early response. Along this similar topic, it is unknown if the training and response drills consider scenarios such as the Macondo one which required over 90 days to cap. Relief wells are one of the most efficient ways to stop a spill. However, the need for this type of well occurs under different circumstances than regular production wells: the relief wells need to be drilled faster and safer than production wells and be precise in their target location. Research could help determine the optimal or quickest way to drill a relief well.

Most of the potential research discussed was framed on the mitigation side, or the right hand side of the bowtie. Current oil recovery methods are inefficient; recovery rates are very low (less than 10%). For this reason the need to devise new mechanical separation systems for cleanup is important. Similarly, the use of chemical dispersant is a topic for areas of improvement; there is no way of knowing what happens with some of the oil that gets dispersed, if it eventually is degraded or if it resides in the seafloor, which could have a long term impact. The application of dispersant has been to basically inject it near the leak source. A question asked was whether we are sure we are placing dispersant in the optimal location and are we using the correct amount. Finally, there was uncertainty about the roles and responsibilities of who ultimately approves the use of certain types of technologies.
Given the variety of tools to respond to a spill, there is uncertainty about the best suited technology to respond to a particular spill. In this context, studying current spill response methodologies and their operational limits, as well as their scalability, would shed light onto the best alternative(s) for a given type of response (small scale, deepwater, surface, large scale, etc.). In-situ burning could be studied under this category as well. The example of the top hat used in the Macondo was given: the top hat attempted to capture the oil/gas from the wellhead but the force from the flow was too large and the conditions of the seabed caused the top hat to be pushed aside and fail.

Well and environmental data was brought up as a key player in the spill response efforts. The question of “what information is needed to identify and respond to the next spill?” developed into a discussion regarding how data can be remotely measured under challenging conditions and the possibility of having real-time monitoring. Knowledge of this data could enable a quicker and more efficient response. To help determine what type of data would be needed, a suggestion was made to arrange a workshop with the responders of the Macondo blowout to discuss their experiences, tools used, and data availability that would have helped in the response. This last suggestion, arranging a workshop with the Macondo responders, would be a benefit to several research areas beyond the data acquisition suggestion.

A comment to be considered throughout the discussion was that research needs to be relevant to industry, not simply interesting. Therefore a cost-benefit analysis comparing risk mitigation to cost of the effort for different identified research areas would help to identify the strongest areas of research for the OESI.

**Research areas**

In summary, the areas of research that were discussed as the most relevant are later described. This, however, does not mean that the OESI should or would have the resources to work on all of them:

1. **In-situ burning:** need to improve decision making on what conditions are best applicable for the technique
2. **Relief well drilling:** need of methods and technologies to get close, faster access to the well
3. **Oil dispersant research and approval process:** investigate mixing of dispersants directly in the plume
4. **Remote sensing:** wide area, in-well/ near well, well flow rate
5. **Mechanical clean-up:** top hat, skimmers, separation
6. **Wellbore collapse:** induced, why did not occur
7. **Near shore cleanup:** development of technology and science-based decision process
8. **ROV:** data collection-swarm, spill mitigation, buoy-on location data
9. **Health impacts monitoring**
10. **Fracturing out around a well to release pressure/ wellbore integrity around a well**
11. **Emergency response:** convene workshop of the responders to discuss issues of planning, communication, leadership/decision, local communities, what data or science can improve decisions, and bow-tie mitigation
Conclusion and Future work

The dialogue that took place in this Ocean Energy Safety Research Roadmap for the 21st Century workshop was very successful, since the primary objective of OESI is to promote dialogue, so that all stakeholders can meet and talk about ocean energy safety related topics.

A first discussion theme involved the role of OESI and its interaction with other institutions already involved in Ocean Energy Safety Research. Participants agreed that OESI could initially play a role by constructing a document summarizing the current state of Ocean Energy Safety Research already being performed by key players, and identifying gaps and needs for future research from available publications and reports. A report was distributed during the event as a first iteration for future summaries, but it was recognized that this report will require further input from subject matter experts and stated that comments and remarks are welcome.

Another common theme among the different breakout sessions was that the OESI cannot perform research to fill all gaps identified during this event. It is, therefore, important to classify needs in terms of research in technology development or in more abstract research for concepts that will require further investigation before being tentatively developed and directly applied by the industry. It will also be necessary to prioritize the needs. An improved version of the summary of research efforts will, together with another forum to further develop and finalize the roadmap that will be organized in 2015, help the OESI determine its role in R&D activity.

Finally, the attendees agreed that the research gaps should be relevant to industry needs, and a cost-benefit analysis of the improvement in overall safety is very important and should be performed for all future research topics.

Future OESI forums

Upcoming forums will include topics such as “Human Factors” and “Best Available and Safest Technologies (BAST)”. More information on these forums will be announced as details become available.
Appendices

Appendix A: Full Agenda

Tuesday, October 7, 2014

7:30AM - 8:30AM – Registration - Continental Breakfast

8:30AM Welcome – Jim Pettigrew, Director of Operations, Ocean Energy Safety Institute

8:40AM Opening Remarks and Introduction – M. Sam Mannan, Principal Investigator, Ocean Energy Safety Institute

8:50AM Portfolio Summary of Ocean Energy Safety Research Efforts – MKO Process Safety Center (MKOPSC) – Delphine Laboureur

9:10AM Current and Planned Topics of Ocean Energy Safety Research – Research Partnership to Secure Energy for America (RPSEA) – Charlotte Schroeder

9:30AM OESC Review and Risk/Safety Management Systems Research Overview – Center for Offshore Safety (COS) – Charlie Williams

9:50AM Questions and Answers – David Moore, AcuTech

10:10AM Morning Break and Student Poster Session

10:40AM American Petroleum Institute Post-Macondo Research Efforts and Programs – American Petroleum Institute (API) – Holly Hopkins

11:00AM Research to Advance Oil System Safety, Human Health, and the Environment in the Gulf of Mexico – Kim Waddell, National Academy of Sciences


11:40AM Questions and Answers - David Moore, AcuTech

12:00AM Break for Lunch and Student Poster Session

1:15PM Nano-Devices for Enhanced Thermal Energy Storage, Cooling and Sensing - Debjyoti Banerjee, Texas A&M University

1:35PM Quantifying System Reliability for HIPPS and SCSSV Subsystems - J. Eric Bickel, University of Texas

1:55PM An Ideal Rig-One Vision – Jeff Sattler, Lloyds Register Energy, Informing the BOP Pull Decision with the LR BOP Risk Model – Scotty Roper, Lloyds Register Energy

2:15PM Research in Modeling of Subsea Oil Well Processes – Scott Socolofsky, Texas A&M University

2:35PM Questions and Answers - David Moore, AcuTech

2:55PM Afternoon Break and Student Poster Session

3:25PM Lessons for Energy from Military Simulation – Howard Mall, ECS Incorporated

3:45PM Real-Time Monitoring for Improved Offshore / Arctic Safety – Eric Van Oort, University of Texas

4:05PM Smart Cement for Real-Time Monitoring of Oil Well Cementing – C. Vipulanandan, University of Houston

4:25PM Offshore Engineering for Climate Extremes – James Done, National Center for Atmospheric Research

4:45PM Questions and Answers - David Moore, AcuTech
Wrap-up of Day 1 – M. Sam Mannan
Social – University Club – Rudder Tower

Wednesday, October 8, 2014
Check-In - Continental Breakfast
Opening Remarks and Breakout Session Discussion – M. Sam Mannan
Parallel breakout sessions to discuss and identify research area gaps
Breakout group 1: Drilling Safety: Eric Van Oort - UT, TBD
Breakout group 2: Well Containment: Ramanan Krishnamoorti – UH, Holly Hopkins - API
Breakout group 3: Spill Response: Rashid Hasan – TAMU, Charlie Williams - COS
Lunch
General Session Begins - Report back from groups/Formulate Research Agenda/Funding Possibilities/Collaboration Opportunities
Afternoon Break with refreshments
Final Discussion/Workshop Wrap-up
Ocean Energy Safety Institute Research Committee/OESI Working Group meeting
Appendix B: Participants Biographies

Dr. Debjyoti Banerjee is an Assistant Professor of Mechanical Engineering and Faculty Fellow at the Mary Kay O Connor Process Safety Center at Texas A&M University. His research interests include thermal-fluids sciences (TFS), MEMS (RF-MEMS, Optical-MEMS, and Bio-MEMS), micro/nano-fluidics, bio-nanotechnology and renewable energy technologies.

Dr. J. Eric Bickel is an Assistant Professor of Operations Research and Petroleum and Geoscience Engineering at The University of Texas at Austin. In addition, Dr. Bickel is a fellow in the Center for International Energy and Environmental Policy and the Center for Petroleum Asset Risk Management.

Michael Crosby joined the BOP Risk Model project at ModuSpec (Lloyd's Register) in 2012. Previously, he worked with Aker Solutions subsea service group, where he assembled, troubleshooted and repaired multiplex control systems for subsea production trees, performed SIT's and FAT's of controls systems and subsea trees, and UTAs.

Dr. James Done is a research scientist at the National Center for Atmospheric Research, Boulder Colorado, engaged in an active research program on future changes in extreme weather and societal impacts. He is a founding member of ‘Engineering for Climate Extremes’ – a partnership between industry and the National Center for Atmospheric Research with the goal to encourage joint activities aimed at developing new, robust, and well communicated responses to our increasing vulnerability.

Dr. A. Rashid Hasan is a Professor of Petroleum Engineering at Texas A&M University. Dr. Hasan, an expert in the areas of production engineering, focuses on modeling complex transport processes in various elements of petroleum production systems. He applies heat and fluid flow modeling to the analyses of production safety, wellbore integrity, flow assurance, wellbore solids deposition, flow metering, and pressure transient testing. His book on Fluid and Heat Transfer in Wellbores is considered a definitive work in the area and is used as a text in many institutions.

Holly Hopkins is a senior policy advisor in Upstream and Industry Operations of the American Petroleum Institute (API). In her current role with API, she staffs the Drilling and Production Operations Subcommittee including Upstream Safety, and staffed two of the four Joint Industry Task Forces post-Macondo, the Offshore Equipment Task Force and the Subsea Well Control and Containment Task Force.
Dr. Ramanan Krishnamoorti has held the position of chief energy officer at the University of Houston since February 2013. He is a professor of chemical and biomolecular engineering with affiliated appointments as professor of petroleum engineering and professor of chemistry.

Dr. Greg Kusinski is the Director of DeepStar, a global deepwater technology R&D consortium and serves as Chevron Senior Advisor to that organization. Since 1998 he has worked in various corporate capacities focusing on technology development, acceleration and commercialization. Dr. Kusinski currently serves on several university advisory boards and is a chair of the OTC-TMS Program Committee.

Dr. Delphine Laboureur received her PhD from the Université Libre de Bruxelles (ULB) for the work she performed at the von Karman Institute in collaboration with the Ecole des Mines d’Alès. She is currently a research scientist at the Mary Kay O’Connor Process Safety Center, working on a broad range of process safety research including offshore safety, dust explosions, DDT, jet fires, and incident investigations.

Howard Mall is Vice President of Engineering at Engineering and Computer Simulations, Inc. He has spent the last nine years at ECS building various kinds of training systems. He has lead efforts for the Navy to develop training solutions deployed on cell phones and hand-held computers. For the Army, he delivered the Tactical Combat Casualty Care (TC3) Simulation used by combat medics to learn triage and medical decision-making on a virtual battlefield.

Dr. M. Sam Mannan is Regents Professor in the Chemical Engineering Department at Texas A&M University and Director of the Mary Kay O’Connor Process Safety Center at the Texas Engineering Experiment Station. His experience is wide ranging, covering process design of chemical plants and refineries, computer simulation of engineering problems, mathematical modeling, process safety, risk assessment, inherently safer design, critical infrastructure vulnerability assessment, aerosol modeling, and reactive and energetic materials assessments.

David Moore is the President and CEO of the AcuTech Consulting Group. He is recognized as a global expert on process safety, chemical security, and risk management. He advises many of the world’s leading energy, petroleum, and chemical companies on how to develop, evaluate and improve risk management systems for reducing risk in their operations.
James (Jim) Pettigrew has held the position of Director of Operations for the Ocean Energy Safety Institute since May 2014. As a former Navy Captain, he has worked in operational oceanography, surface warfare and information dominance.

Jeff Sattler recently accepted a position within Lloyd’s Register – Energy as VP Technology, which provides direction for the Efficiency and Uptime and Life Cycle Extension research programs for Lloyd's Register Energy's Global Technology Center in Singapore, and serves as their Americas Upstream Technology Ambassador.

Charlotte Schroeder has worked as a petroleum engineer in the upstream E&P business for over 30 years. Her expertise is in reservoir engineering and she has spent the majority of her career as a reservoir engineer on multidisciplinary teams of engineers, geologists, field operators, and technologists.

Dr. Scott Socolofsky joined the faculty in Civil Engineering at Texas A&M University in 2003. His research in ocean energy safety concentrates on the fate and transport of oil and gas released from subsea accidental spills and blowouts.

Dr. Eric van Oort holds a PhD in Chemical Physics from the University of Amsterdam. He joined Royal Dutch Shell in 1991 and has spent 20 years with Shell in a variety of technical and managerial roles, starting out as a research scientist in The Hague and ending his career at Shell as Wells Performance Improvement and Onshore Gas Technology manager in Houston. He joined UT Austin in early 2012 to return to his passion for teaching and R&D as B.J. Lancaster Professor in Petroleum Engineering.

Dr. C. Vipulanandan is a professor of civil and environmental engineering at the University of Houston. He is the Director of the Center for Innovative Grouting Materials and Technology (CIGMAT) and the Texas Hurricane Center for Innovative Technology (THC-IT) at the University of Houston.

Dr. Kim Waddell is a senior program officer with the Ocean Studies Board. Dr. Waddell recently rejoined the NRC after a 6-year hiatus during which he was a research associate professor at the University of the Virgin Islands and Texas A&M University working on building marine and environmental research capacity in the Caribbean. Dr. Waddell’s research interests are broad and include sustainable agriculture, capacity building in small island developing states, and fisheries management.
C.R. (Charlie) Williams II is the Executive Director for the Center for Offshore Safety. Charlie recently retired from Shell as Chief Scientist - Well Engineering and Production Technology after a 40 year career. Charlie serves on the Department of Interior Offshore Energy Safety Committee, is a 40 year member of Society of Petroleum Engineers, and is a registered Professional Engineer. He has been a Board Member for the Marine Well Containment Company and part of the Project Management Committee.
Appendix C: Abstracts of Poster Session

Mary Kay O’Connor Process Safety Center – Texas A&M University

Monir Ahammad LNG Source Term Modeling - Cryogenic Boiling and Pool Spreading on Land

Boiling and pool spreading is one of the major areas of concern in source term modeling. Realistic estimation of cryogenic hazards (e.g., LNG and LN₂) primarily depends on the accurate determination of its boil-off rate due to the heat transfer from the substrate. Computational estimation of the boil-off rate after a release is not trivial because of the complicated physics of boiling regimes, the time dependent nature of pool spreading, the nature of the substrate, etc. The aim of this study is to simulate pool boiling of cryogenic liquids and studying on land pool spreading for more accurate estimations of source term modeling. CFD is used as the tool to simulate and observe the effect of important parameters.

Alberto Benavides: A Reliability-P-Median formulation for optimization of gas detector layout in process facilities

A large number of variables influence the risk associated with gas leaks in process facilities. These variables include leak conditions, fluid properties and dispersion characteristics, process equipment geometry, detection equipment, environmental factors, and safety considerations. Given this large number of variables, the task of gas detector layout in the process industries is challenging. Mixed-integer linear programming (MILP) has been proposed as a quantitative approach for numerical optimization of gas detector layout. Legg et al (2012c) proposed a stochastic programming formulation that seeks a sensor placement that minimizes the expected time to detection across any number of leak scenarios. Extensions to this MILP formulation were proposed to improve the resilience of the solution placement to unforeseen scenarios (Legg et al, 2012a) and the tail-behavior of the distributions of detection times (Legg et al 2012b).

However, this previous work assumed the use of perfect gas sensors; in reality gas sensors are prone to false-positives and false-negatives. In the process industries, two solutions are usually implemented. First, additional confirmation from other detectors may be required before emergency actions are triggered, and several voting logic schemes are used. Second, the Probability of Failure on Demand (PFD) of the detectors should be considered in the placement strategy. In this work, we present an MILP that performs optimal gas detector placement while considering sensor failure and voting. This problem formulation is closely related to the Reliability-P-Median Problem (RPMP) proposed by Snyder and Daskin (2005) for the facility location problem.

Here, we show the relationship of our stochastic programming formulation to the RPMP formulation. Scenario data for this problem is generated with rigorous CFD simulations of a real process geometry using FLACS with different leak locations and conditions (provided by GexCon). The effectiveness of placement results are analyzed and compared with the previous formulation that ignores sensor reliability and voting.
**Prerna Jain: Resilience Engineering Framework for Offshore Safety**

In the oil and gas industry, various risk assessment and management methods have been studied and developed to reduce unwanted events. However, offshore incidents still happen so a better understanding of the risks and system safety aspects is necessary. In order to understand system complexities and develop methods to make the system survive, adapt and organize into new configurations as per demand, there is a need to develop a resilience engineering framework for offshore safety. Resilience is the ability of a system to anticipate, survive, adapt, and recover in the face of disruptions which may lead to catastrophic events. A resilient plant system would have the capacity to overcome disruptions and continually transform itself to meet the challenging needs and changing expectations over time. The main focus of this paper is to propose a framework for process operations in offshore safety. This approach is based on basic four abilities of a system to be resilient which are anticipate unknown and uncertain initiating events, monitor routine operations, learn from past events and respond to events for quick recovery. This includes defining resilient system components, dynamic risk assessment models, integration of leading and lagging process and operational indicators, tracking human and organizational factors for effective systems safety to avoid unexpected events.

**Ruochen Liu: Modeling of Uncontrolled Fluid Flow in Wellbore and Its Prevention**

Uncontrolled fluid flow in wellbore includes petroleum seepage, gas-kick, and blowout. Without proper control strategies, a kick might turn into a blowout event quickly. It is always the most unwanted disaster for all the well operations, such as the Macondo incident. Blowouts have been considered as one of the major risks during drilling and completion operations owing to the severity of consequences. Consequences of the blowout include the damage to the environment, equipment, and materials; personnel injuries and fatalities; loss of production; and liability issues.

At present, there are some papers that investigate the risk and consequence analysis of a blowout, but only few of them address the mechanism of a blowout with respect to the flow rate of a blowout and the total amount of hydrocarbons discharged to the environment. Therefore, the purpose of the research is to establish an analytical mathematical model of uncontrolled fluid flow based on the basic physical phenomenon, including heat transfer and fluid dynamics, to estimate the blowout rate and total production loss. Such model studies the onshore and offshore oil, gas, and oil/gas well blowout behaviors. Depending on the conditions of reservoir and well configurations, sonic velocity might be achievable for some of the blowout events. In addition, after fully understanding the mechanism of blowout behaviors, some suggestions are given to monitor and control the blown-out wells.

**Josh Richardson: Facility Layout Optimization for Offshore Operations**

The initial and ongoing layout of any facility is a key component of safe operations. Offshore operations present unique challenges due to tight spacing and remoteness of the platform, leading to the chance that any process safety event could turn catastrophic. In order to minimize this probability and the consequence should an event arise, an MINLP formulation has been created to optimize the layout of equipment with respect to fire, explosion, and...
toxic dispersion hazards on an offshore platform. This formulation allows for equipment of user-defined footprint areas and operating conditions to be placed in a multi-floor environment, minimizing a risk-based objective where both probability of an event and consequence of the event are considered. Further, the model optimizes muster points and escape routes to avoid particularly hazardous areas. The model can be used for initial layout, placing new equipment, and sensitivity analysis when considering changes in parameters such as building larger platforms, platforms with more or less floors, and changing footprint areas of equipment. Mitigation systems and extended applications of the model are being implemented as part of future work.

Tony Rocha-Valadez: Well Integrity Diagnostics and Risk Assessment Based of Pressure Transient Modeling

Compromised well integrity can have catastrophic consequences on both environmental and safety aspects. The consequences of not detecting and managing well integrity issues can go from the activation of rupture discs to a release of oil/gas, fire and/or explosion during a blowout. Sustained Casing Pressure (SCP) is any pressure that builds up after having bleed-off any gas in the casing. Most diagnostic testing of SCP and other casing pressure problems require long testing periods, arbitrary criteria from qualitative assumptions and, in some cases, specialized equipment. The goal of this research is to develop analytical models that can mimic the behavior of the gas migrating though the casing and generating SCP, as well as other phenomena that lead to increase casing pressure that may compromise the integrity of the well, such as faulty gas-lift valves in gas-lift operations. With this type of model, early time diagnostics can be provided and the estimation of important no-measurable parameters, such as cement effective permeability and flow rate, is possible without the need of specialized equipment. An earlier diagnostic and parameter estimation that reflects the integrity of the well barriers, can serve as tools for risk based decision making by identifying the severity of a leak and evaluating the risk for a release and its safety and environmental impact.

MD Nafiz E Tamim: Leading Indicator Analysis for Offshore Operations with Emphasis on Drilling

Offshore oil and gas operations have always been very challenging due to technological and operational complexity in combination with harsh environmental conditions. Geological uncertainties, high pressure flammable fluids in presence of ignition source, complicated structural layout, limited response time allowance, difficulty of control and communication are some of the critical factors that possess clear threats towards safe operations and may result in high consequence events. As we move to harsher environments in search of energy, these threats are only going to increase. Developing well specified risk indicators for robust safe work guidelines is quite a difficult job to achieve due to such highly correlated factors and multifaceted operations. This research work primarily undertakes the task of defining and analyzing leading risk indicators specific to offshore energy industries. Blowouts and drilling incidents will be analyzed in terms of addressing the technical aspects of leading risk indicators and a database containing information on root causes with observed parameters prior to failure will be constructed. Additionally,
successful technologies and approaches adopted by the industry will also be studied for understanding effective barrier performances. With analyzed incident and operational control data, advanced algorithms of incident path from initiating events will be developed with optimal use of preventive barriers. Finally, methodologies for identifying and killing of gas kick, which is considered to be a major leading indicator for blowout, will be proposed with analysis of some potential response scenarios.

**Ming Zeng: Integration of Human Factors in Offshore Risk Assessment**

Human failures often contribute to major offshore incidents, but they are usually not considered in traditional offshore risk assessment. Several human reliability analysis methods have been developed so far in aviation and nuclear industry and some of them have been applied in offshore, but the efficiency of these approaches is still questionable. Also, there is no uniform category to classify human factors in offshore industry. If the important factors are not identified, it could overestimate the risk. Therefore, the appropriate human factors need to be included in the risk assessment. The objective of this research are to: 1) Category of human factors in offshore industry. 2) Develop models to incorporating human factors in offshore risk assessment quantitatively. 3) Perform a sensitivity analysis to identify the most influencing factors 4) Provide guidance to effectively improve human performance.

**Bin Zhang: Mitigation Effect of High Expansion Foam on LNG Vapor Hazard**

The growing production and consumption of natural gas due to the advancement of technology, e.g., hydraulic fracturing, has accelerated the inter-regional trade. Liquefied Natural Gas (LNG) provides the flexibility of the transportation in the natural industry; however, it causes a safety concern in terms of flammable vapor cloud and fire associated with a potential spill in LNG facilities. High expansion foam is recommended as a mitigation measure for an LNG incident by NFPA 11 and NFPA 471, and was proved to be effective for the LNG spill emergency response through field tests. The mechanisms of the physical interaction in the high expansion foam and LNG system is essential to develop CFD models, which help assess the risk and provide guidance on emergency response for vapor dispersion and fire scenarios due to an accidental LNG spill. The LNG vapor hazard, i.e., a huge flammable vapor cloud on the ground, can result in a more hazardous scenario, fire, if it is not properly mitigated. High expansion foam can mitigate LNG vapor hazard through a blanketing effect to reduce vaporization rate (source term) and warming effect to enhance vapor buoyancy. The blanketing effect was studied through tests conducted in a wind tunnel, in which convection and radiation were provided manually. The reduction of vaporization rate of liquid nitrogen by high expansion foam was determined quantitatively for heat convection and radiation. The warming effect is conducted with a test apparatus and a foam generator, which are newly designed and built with features contributing to the study of warming effect and parametric analysis.
Daehak Kim, Polymer Grafted Nanoparticle-based Oil Dispersants

Particle-based oil dispersants mainly composed of inorganic nanoparticles such as silica nanoparticles are considered as environmentally friendly oil dispersants due to their biocompatibility and relatively low toxicity. The oil-water interfacial tension is reduced when nanoparticles segregate to the oil-water interface and this segregation is improved by grafting interfacially active polymer brushes. In this study, surfactant-like amphiphilic block copolymers (POEMA-b-PS) and gradient copolymers (PAM-g-PMMA) were grafted from silica nanoparticles using a living radical atom transfer polymerization (ATRP) method in order to increase their interfacial activity. We have studied the interfacial activity of such hybrid nanoparticles using pendant drop interfacial tension measurements, and their structure using small angle X-ray scattering. Amphiphilic copolymer grafted nanoparticles significantly reduced oil–water interfacial tension compared to the interfacial tension reduction induced by homopolymer grafted nanoparticles or the corresponding free ungrafted copolymer and it is believed that hydrodynamic particle size and copolymer composition are controlling variables to determine the oil dispersion ability of nanoparticles. Moreover, hard and stable oil–water emulsions were formed by applying the block copolymer grafted nanoparticles due to the formation of interparticle network structures, which were observed by cryo-scanning electron microscopy (SEM). These polymer grafted nanoparticles with improved interfacial activity are expected to be effective emulsion forming and stabilizing agents.

Yang Ning: Natural Gas Transport in Organic-Rich Shale Formations Using Kinetic Based Simulation Techniques

Shale gas is attracting increasing attention as a rising energy supply and numerous successful production plays have been achieved. Natural gas flows either through nano-scale pores or fractures during production period in shale formations. However, accurate reserve estimation and production projection are still challenging and require a sound understanding about mechanisms of natural gas transport. In contrast to conventional reservoirs, more than 80% of pores in shale formation are micro- or meso-pores, where the length scale of pores is smaller than 30 nm. Gas permeability through nano-porous media is ultra-low and the transport behavior remains poorly understood because continuum theory breaks down at these length scales. Moreover, the majority of shale gas is stored as adsorbed gas in organic matter. Consequently, the interactions between natural gas and the organic matter molecules may affect the flow of natural gas through nano-pore structures. One technique, molecular dynamics, provides theoretical foundation for modeling the transport of gas through shale that requires fundamental understanding of the interaction between molecules. Another simulation technique based on gas kinetic theory is lattice Boltzmann method that is derived from the continuous Boltzmann equation. These two simulation techniques are to be carried out to understand the flow and storage mechanisms for shale formations.
First, molecular dynamics simulation is used to describe natural gas storage and transport through nano-pore structures. Organic matter molecules found in shale formation exhibit complex molecular structures. As one alternative, the molecular structure can be replaced by a simpler existing carbon structure. Shale exhibits a complex pore network structure. Using digital rock reconstruction techniques, we statistically model 3-D nano-pore structure in organic matter from scanning electron micrographs of shale rock sample. To study gas transport behavior through shale nano-porous media, we employ methane to model natural gas. Lennard-Jones intermolecular potential is applied to model the methane-methane and carbon-carbon interaction. Methane-carbon interaction is modeled by taking the average of the two interactions based on Lorentz-Berthelot mixing rule. Simulations are conducted using LAMMPS. We measure the amount of methane molecules in the adsorbed layer as a function of the free gas pressure to obtain the adsorption isotherm, which obeys the Langmuir isotherm and is in good agreement with experimental data from literatures; this finding indicates that adsorption is single-layer adsorption and adsorbed sites on the surface are energetically homogeneous. Complexity and specific surface area of the pore structures are found to be influencing factors for the amount of storage in shale formations. To characterize the flow behavior, the velocity profile and the relation between the average velocity and external body force are simulated using non-equilibrium molecular dynamics simulation based on the intermolecular interaction from equilibrium molecular dynamics simulation. The results represent the flow dynamics in realistic nano-porous media and yield new insights into gas transport in carbon nano-porous media.

Second, kinetic-based lattice Boltzmann method (LBM) becomes a strong alternative of simulating organic-rich shale reservoir that contains a large amount of nano-scale pores. For gas flows in such tiny pores, Darcy's law may not effectively describe such transport phenomena due to its continuum assumption. As discussed earlier, molecular dynamics tracks individual molecules in the system, while LBM tracks the distribution functions of a group of molecules, which significantly reduces the computational costs and increases the scale of simulation. In LBM, molecule's movements are divided into its propagation to next possible site and its collision with another molecule with different probabilities. In nano-pores, the dimensionless number, Knudsen number ($K_n$) defined as the ratio of the molecular mean free path length to a representative physical length scale, becomes important to describe the flow regime. For the gas flow in an extremely confined system, its mean free path depends on not only the size of the confined system, but also the distance of gas molecules from solid walls. Gathering the information from molecular dynamics and available experimental data, we incorporated the adsorption into LBM model in order to capture the natural gas flow in organic nano-pores. Many factors are believed to control the flow mechanism in such pores, such as the size of organic pores, specific surface area, adsorptive strength, and so on. LBM results show a great agreement with available data for high Knudsen flows between two-dimensional parallel plates. Accounted the effect of adsorption, flow phenomena are investigated by varying different controlling factors.

A big challenge in shale formations is coexisting of natural/hydraulic fractures and nano-scale porous media. Stokes-Brinkmann equation has been shown to describe multiple flow
mechanisms in complex networks effectively for conventional reservoirs. However, it needs to be further studied for shale formations. For either molecular dynamics or lattice Boltzmann method, extending simulations to reservoir scale is rather difficult even though they are easily parallel-able in high performance computing environments. A potential strategy is to apply LBM using the representative elementary volume (REV) technique into the Stoke-Brinkmann equation. Therefore, we can perform numerical reservoir simulation on shale formations with much larger scale.

**Misra Shobhit: A model-based approach for predicting gas well leaks and identifying well construction factors responsible for such leaks**

Gas leaks from natural gas wells can create severe environmental and safety problems, as the leaked gas may end up in the air or water. Poor cementing of gas wells may allow gas from one rock formation zone to migrate into another and eventually leave the well. Therefore, it is important to ensure that natural gas well construction prevents such unwanted events. The design objective is known as zonal isolation and has been the subject of intense study recently.

In well construction jobs that do not ensure zonal isolation, natural gas may move through the small channels created in the cement sheath in the annulus between the well casing and well wall, and may eventually reach the well head. To detect whether a continuous flow of gas reaches the wellhead a simple procedure is followed, namely a pressure gauge followed by a needle valve are installed, and the needle valve is temporarily opened to lower pressure by bleeding off a small amount of gas, if pressure increase is detected by the pressure gauge. If gas pressure builds up again after the gas bleed off and closing of needle valve, there is clear indication that there is communication between the well head and producing sections of the well through the cemented well wall. The resulting pressure is called sustained casing pressure (SCP) and is undesirable. The objective of this work is to determine what factors contribute toward SCP, and prevent such factors from creating measurable SCP values. Because the effect of all relevant factors on SCP is complicated, the proposed approach relies on statistical analysis of a large volume of data. Through such analysis, a model is built that captures quantitatively the effect of related factors on SCP. These factors are associated with well drilling, cementing and hydraulic fracturing parameters. A statistical technique called partial least squares (PLS) regression was used to create the model. The model structure involves a number of latent variables, which are linear combinations of the original variables, and which are determined through leave-one-out cross-validation in such a way, that correlation between model inputs and outputs is maximized.

Based on VIP scores, SCP is found to be most sensitive to bottom hole circulation temperature (BHCT), namely the temperature experienced by the cement at the bottom of the well, as the cement circulates to fill in the annual space, during well completion. Deviations in cement slurry temperature and water temperature from the desired range contribute significantly to SCP as well. Because many of the cement properties such as settling time, viscosity and density are temperature dependent, it is recommended to
modify cement/slurry based on BHCT conditions, so as to produce good cement jobs and avoid subsequent well leaks during gas productions. It is also recommended to keep the slurry and water temperatures in the optimum range during the cementing operations.

Panjwani Shyam: Ensuring Environmental Friendliness of Horizontal Shale Gas Wells through Zonal Isolation: A Model-Based Approach

Shale gas production from horizontal wells faces potential problems related to gas leakage from various zones of a well into the air and water reserves. Avoiding such leaks, and thus achieving better environmental friendliness as well as well safety and productivity, is one of the biggest challenges for shale gas production. To avoid gas communication between well zones in a rock formation penetrated by a well (i.e. to achieve zonal isolation) the integrity of the cement placed in the annulus between the metal casing and the borehole wall must be ensured at all times. Various physical factors i.e. casing properties (internal diameter, centralizers and casing-hole relationship), cement and drilling mud properties (density, viscosity, additives), and operating conditions such as temperature and pressure, affect the quality of cement bond [1]. Cement bond quality is analyzed in terms of sustained casing pressure (SCP) for this study. The SCP value was used to categorize horizontal shale gas wells as leaking or not leaking. The problem addressed was how to predict whether a well will leak or not based on the values of the various physical factors mentioned above.

To address this problem we performed statistical analysis on data from actual wells. The outcome of the analysis was a predictive classification model. The model was built using dimensionless groups of the physical factors mentioned above as inputs to the model, and the multivariate statistical technique PLS-DA (Partial Least Square Discriminant Analysis) [2]. The output of the model is a prediction of whether a shale gas well will exhibit annular gas leakage or not. The VIP (variable importance in projection) variable selection method and leave-one-out cross-validation method were used to determine the optimal PLS-DA model structure. It was found that not all dimensionless numbers affect classification in similar fashion; only few of them play a major role in classification of wells. Separate models were built from data available for intermediate casing and production casing. These models were able to correctly classify 73% and 71% of wells in cross-validation tests for intermediate and production casing, respectively.

The types of data-driven models developed are capable of predicting whether annular gas leakage will occur given a number of physical factors. The predictive ability of such models is expected to increase as more data becomes available, in addition to these used in this study. This predictive ability can be helpful in regulating physical parameters for better zonal isolation, resulting in reduced undesired gas leakage and cutting down remedial cementing cost.
Appendix D: OESI Contact Information

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MISSION STATEMENT

The Ocean Energy Safety Institute will provide a forum for dialogue, shared learning and cooperative research among academia, government, industry, and other non-governmental organizations, in offshore energy-related technologies and activities that ensure safe and environmentally responsible offshore operations.

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