Research Highlights

...helping enable safer and environmentally responsible offshore energy operations

2016-2017
Introduction

2016 was another outstanding year in the development of and operations of the Ocean Energy Safety Institute. OESI not only focused discussion on relevant and important ocean energy industry topics, but also delivered its first round of collaborative research projects. Additionally, training sessions were developed and presented so that the regulator can continue their professional and technical development. OESI also began a review of BSEE’s Training Program for their engineers, with delivery of the study results expected in 2017. With new additions to the Advisory Committee, along with the leadership of long-time members, the committee continued to provide sound advice on the efforts of the OESI.

These Research Highlights provide a cross-section look, across the three OESI partner universities, into the research efforts that are related to the mission: ‘further enable safer and environmentally responsible offshore operations.’

Mission

Help further enable safer and environmentally responsible ocean energy operations.

Vision

To be the Center of Excellence for process safety related issues impacting ocean energy operations through:

• Stakeholder dialogue
• Science-based research closing stakeholder-identified gaps
• Training opportunities from the deck plates to the boardroom
In the wake of the Deepwater Horizon disaster that killed 11 people and spilled 5 million barrels of oil, then Secretary of the Interior Ken Salazar proposed the concept of establishing an “Ocean Energy Safety Institute” designed to facilitate research and development, training, and implementation in the areas of offshore drilling safety, blowout containment and oil spill response. The creation of the Institute also stems from a recommendation from the Ocean Energy Safety Advisory Committee, a federal advisory group comprised of representatives from industry, federal government agencies, non-governmental organizations and the academic community.

On November 7, 2013, BSEE announced that the team of Texas institutions led by the Texas A&M Engineering Experiment Station’s (TEES) Mary Kay O’Connor Process Safety Center had been selected to manage the Ocean Energy Safety Institute (OESI). The press conference was attended by US congressman Bill Flores (R-Texas) who praised the collaboration between government and academia. Also in attendance was BSEE Director, Brian Salerno who traveled with his team to College Station for the announcement, tour the facilities and meetings with university professors, TEES researchers and officials from the University of Houston and University of Texas.

OESI was tasked with three primary efforts. First, create opportunities for dialogue between all stakeholder groups in the ocean energy realm. Second, develop collaborative research opportunities to help fill knowledge and technology gaps pertinent to enabling safer and environmentally responsible operations offshore. And third, create and provide training opportunities for the regulators, to help them stay up to date on new technologies, processes and procedures. This document is intended to give an insight into our research efforts related to the OESI mission.
Dr. Camille Peres (TAMU)

**Human Factors and Ergonomics in Offshore Drilling and Production: The Implications for Drilling Safety**

This paper presents a summary of the literature investigating human factors issues in the O&G industry and how (and to what extent) the findings from those investigations are currently being incorporated into O&G operations offshore. Further, we articulate gaps in the knowledge and application for the topics identified in these reviews. From these reviews, three main themes can be articulated regarding needed focus for the O&G industry in Human Factors to facilitate efficient, effective, and safe work: the need to identify the specific elements of the human-machine interaction that will support this type of work; the need to utilize modeling and management systems to allow industries to most effectively leverage knowledge regarding human factors into the process of human systems integration; and finally, the need to create the environment for this type of work to occur. Offshore drilling and production rigs contain hundreds of computing systems to operate systems such as drilling, generators, remotely operated vehicles, etc. Further, there are multiple aspects of 40 rig operations such as crane operation, casing and string management, mechanical repairs, etc., that may be supported by computing systems but still have primarily humans doing the basic work. Thus, simply identifying each instance of human-machine interactions can be non-trivial—let alone optimizing those thousands of interactions for the humans who are supposed to use them.

Further, given that a drilling rig is a complex sociotechnical system (STS) where all systems impact all other systems, designers cannot simply optimize the interactions between each human and the technology each of those humans use, they have to optimize the interactions of the entire system—how those technologies and people interact and design systems that support those interactions as well. This is referred to as Human Systems Integration and is necessary for these types of complex system. Norman has recently discussed some design processes for complex STS and although the specific example is couched in the medical domain, many of the issues can be easily generalized to O&G (Norman & Stappers, in press). For instance, he discusses how ineffective methods for bringing patients into the hospital can lead to routine, but lifesaving, procedures not being done because the duty nurse did not know that a new patient was on the floor. Whether the procedure was not followed, not set up correctly, or the method for doing the procedure was confusing and thus led to input errors will not matter to the patient who does not get the appropriate care. O&G has effective modeling and management systems for building phenomenally
complex technology. Those systems now need to be adjusted with collaborated efforts to include Human Factors and Human Systems Integration. Some of the research regarding the environment is more mature than others in O&G. For instance, the importance of safety culture/climate research and its applications have been known since 1998. However, the causal mechanisms between safety culture/climate, safety behavior, and incidents have not been clearly established. Further, the reviews presented here suggest that other variables may remarkably influence the environment and safety culture/climate, such as training (i.e., CRM), stress, and risk perception. One of the most profound and indeed disturbing findings regarding the review of the safety culture/climate literature is that this is the content domain of human factors that the offshore O&G industry seems to have the longest history with and yet it is the issue identified as a primary cause of the Macondo incident in 2010 where 11 lives were lost, clearly indicating that knowledge of the problem within the offshore O&G industry does not indicate resolution of that problem. This paper has presented that there are risks in O&G when human factors is not included in the design, construction, operation, and management of these systems. The mitigations of these risks are not easy or obvious but the paths to identifying these mitigations methods are obvious. They are illustrated in the successful programs reviewed here—interdisciplinary industry/academic partnerships focused on solving industry problems with scientifically valid, empirical findings and solutions that can be quickly deployed. Possibly the most important work for the O&G industry then is to decide what are the primary roadblocks for implementing good Human Factors information and effective tools that have been available. It is only then that the good work of those authors reviewed here can be fully leveraged.

---

**Dr. Eric van Oort (UT)**

**Advanced Modeling of Cement Displacement Complexities**

Cement job success is largely determined by fluid displacement efficiency. Optimum displacement requires understanding of flow patterns, frictional pressure losses and mutual interactions of mud, spacers and cement in annular spaces. Modeling this complex behavior is very difficult, but understanding it is essential to guarantee displacement success. A state-of-the-art cement displacement study was carried out using the very latest in computational fluid dynamics (CFD) modeling techniques, to identify practical guidelines and solutions to cement displacement challenges.

A state-of-the-art 3D “3-phase” (i.e. mud-spacer-cement phases) CFD model was created and simulations were carried out, featuring tracking of fluid interfaces during displacement, calculation of frictional pressure drops, and characterization of complex flow profiles. These simulations accounted for the effects of such complexities as non-Newtonian rheological behavior of all fluids involved, eccentric / narrow annuli, and pipe movement / rotation. The integrated study clearly identifies the root cause(s) of cement displacement failures and highlights comprehensive practical solutions, which are proposed for implementation in field operations.

There are many causes for cement displacement problems and failures, including poor borehole conditioning, inappropriate displacement flow rates, insufficient casing centralization, viscosity contrast mismatches between mud-spacer-cement leading to interface instabilities, etc. Our high-resolution finite element study quantifies the effects of many of these causes and highlights parameters that can improve displacement, such as avoiding high shear strength in non-Newtonian mud and cement rheology, reducing pipe eccentricity and applying pipe rotation during displacement. The modeling approach is used to identify optimum parameters values, and studies interdependencies between factors, for instance determining optimum rheology, flow rate and pipe rotation speeds when pipe is placed eccentrically in the hole, in order to maximize the probability of displacement success in the field. Particularly revealing are the non-intuitive results obtained while modeling mud, spacer and cement as non-Newtonian yield power law (YPL) fluids, which has never been done before.

This paper presents: (1) a new, state-of-the-art 3D CFD model; (2) advanced numerical analysis of cement displacement, taking into account complexities such as non-Newtonian rheology, borehole enlargement, pipe eccentricity, and pipe movement during displacement; (3) practical guidelines derived from the modeling results that can be used for improved cement job pre-planning and field application.
This paper documents the development of an advanced CFD model for cement displacement, which has been used to simulate 3D laminar flow and displacement of Newtonian and YPL fluids in concentric annuli without making limiting simplifying assumptions to numerically solve the Navier-Stokes equations. The model was verified using various simple validation cases and applied in a preliminary study on the displacement of a 13 5/8” deepwater intermediate casing string. Its results emphasize the highly beneficial effect of casing rotation in improving cement displacement efficiency and slightly lowering displacement pressures. The beneficial effect of rotation extends to the point where it can almost completely compensate for the negative effects of casing eccentricity, of evident importance for field cementing in deepwater tight clearance casing schemes (but also for other displacement operations, such as cementing long horizontal casing string in unconventional shale wells). The key behind the CFD model development is that cement displacement complexities such as non-Newtonian rheologies, casing eccentricity and rotation, etc., can now be quantitatively modeled and readily be studied to aid in cement displacement planning using software that is more readily available. It thereby will help improve cementing success, which is expected to result in turn in better zonal isolation, longer productive well life, and improved rig safety.

Jehova Arenas (TAMU)

Human Factors in the Selection of New Technology for the Oil and Gas Industries

Technology, human behavior and processes evolve every day in order to provide safer and more efficient operations, but in many cases the equipment or technology are not the best solution for the organization. When discussing Human Factors, an important issue is that there is no model or guide to explain which elements require more attention or where to invest more resources in order to select the best technology to reduce human error and improve the productivity. Moreover, it is difficult to identify, evaluate, and select new technology that can help people in organizations to facilitate the goals of reducing the likelihood of accidents. Therefore, the objective of this work is to develop a methodology for the identification, evaluation and selection of a new technology focused on Human Factors in order to achieve the next goals: present key elements about Human Factors related to the selection of new technology; impact Human Factors during the early process of selection of the new technology; and inform about the Human Factors and Ergonomics that can be considered in the selection of new technology.

Zohra Halim (TAMU)

Cumulative Risk Assessment Model to Analyze Increased Risk Due to Impaired Safety Critical Elements in Offshore Resources

Safety critical elements act as barriers to prevent major accident hazards. Several barriers may work conjointly to reduce risks to acceptable levels. However, it may not always be possible to immediately identify and repair or replace impaired barriers due to various reasons including supply and administrative delays and required equipment downtime. Evaluating multiple impairments and their associated cumulative risk remains a challenge given that information about these individual impairments need to be brought together and presented in a way that would enable realization of the overall picture of cumulative risk. The objective of this research is to determine the cumulative risk arising from impaired barriers such as safety critical elements under maintenance or changes in offshore resources. A cumulative risk assessment model is to be developed to provide an assessment of when an increased risk could occur that would help make decisions to reduce risks to ALARP.
Prerna Jain (TAMU)

Resilience Engineering Framework Incorporating Prediction, Survival and Recovery Analysis

In the oil and gas industry, various risk assessment methods have been studied and developed to reduce undesirable events. However, incidents still happen so a better understanding of the risks and system safety aspects is necessary. A resilient facility would have the capacity to predict instabilities, overcome disruptions and continually transform itself to meet the challenging needs and changing expectations over time. The main focus of this research would be to propose a resilience analysis framework including prediction, survival and recovery models. The framework developed would be applicable to both onshore and offshore installations primarily focusing on detection of unsafe zones, assessment of cumulative risks and prioritization of safety barriers during abnormal situations and reduction in response time resulting in mitigation of consequences. This approach is based on four basic abilities of a system to be resilient: anticipate unknown/uncertain events, monitor routine operations, learn from past events, and respond to events for quick recovery. It is important to understand the complexities involved and develop methods to make the system survive, adapt, and organize into new configurations.

Pranav Kannan (TAMU)

Development of a Smart Sensor for the Detection and Mitigation of Microbiologically Influenced Corrosion (MIC)

Microbiologically Influenced Corrosion (MIC) is a form of corrosion that is either caused or accelerated by the presence of microbiota on the surface of metals and other materials of construction. It is a widespread problem in multiple industries, such as oil and gas, chemical, nuclear, power, water networks and utilities. MIC control is achieved primarily through the use of biocides, which come with associated economic and environmental costs. Hence, an early-detection system which is real-time/pseudo real-time would be a great tool to help combat MIC at an early stage before it becomes widespread through bio-film formation. The objective of my research is to develop a sensor-based on a nano-wire matrix which is functionalized with bio-molecules which can detect these microorganisms on a real-time basis. These sensors are aimed towards high precision and specificity owing to their large surface areas functionalized with bio-molecules. The sensors may be mounted on pigs (devices used in maintenance of pipelines) or at locations where MIC is suspected and the local concentration of biota could be monitored.

Ruochen Liu (TAMU)

Modeling of Uncontrolled Fluid Flow in Wellbore and its Prevention

Uncontrolled fluid flow in wellbore includes gas-kick, blowout, and hydrate formation. Without proper control strategies, a kick might turn into a blowout event quickly. This is always the most unwanted disaster for all the well operations, an example being the Macondo incident. Consequences of a blowout include damage to the environment, equipment, and materials; personnel injuries and fatalities; loss of production; and damage to the companies’ credibility. At present, there are research 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 in the environment. Therefore, the purpose of the research is to establish an analytical or semi-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 a model studies the onshore and offshore oil, gas, and oil/gas well blowout behaviors. Considering the uncertainties of geological parameters, such as permeability, porosity, and reservoir pressure, a site specific blowout risk picture is depicted by using the blowout model and the distribution of geo-uncertainties. In addition, after fully understanding the mechanism of blowout behaviors, suggestions will be made concerning the monitor and control of blown-out wells.
Leading Indicators 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. 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 operations emphasizing on drilling. Blowouts and gas kick incidents have been analyzed to identify key causal factors divided into four categories – technical, operational, human and organizational factors (HOF) and system of organizations. Primary focus is made on validating technical and operational aspects of leading risk indicators with available drilling safety and reliability data. With the proposed set of leading indicators and physical observables, interactive algorithms will be constructed relating the indicators with causal factors and other process elements. Finally, leading indicators based risk modeling approach will be developed to identify critical events with relevant barriers and actions to prevent offshore incidents.

Field Test for Real Time Monitoring of Piezoresistive Smart Cement to verify the Cementing Operations

With some of the reported failures and growing interest in environmental and economic concerns in the oil and gas industry, integrity of the cement sheath is of major importance. The disaster at Macondo claimed eleven lives and caused severe injuries and record-breaking sea pollution by the release of about five million barrels of crude oil. Therefore, proper monitoring and tracking the process of well installation and the performance during the entire service life has become important issue to ensure cement integrity. Smart cement has been developed, which can sense any changes going on inside the borehole during cementing and during curing after the cementing job. The smart cement can sense the changes in the water-to-cement ratio, different additives, temperature and any pressure applied to the cement sheath in terms of piezoresistivity. The failure compressive strain for the smart cement was 0.2% at peak compressive stress and the resistivity change is of the order of several hundreds making it over 500 times more sensitive. In this study, a field well was installed and cemented using the smart cement mixture with enhanced piezoresistive properties. The field well was designed, built, and used to demonstrate the concept of real time monitoring of the flow of drilling mud and smart cement and hardening of the cement in place. A new method has been developed to measure the electrical resistivity of the materials using the two probe method. LCR meters (measures the inductance (L), capacitance (C) and resistance (R)) were used at 300 kHz frequency to measure the changes in resistance. The well instrumentation was outside the casing with 120 probes, 18 strain gages and 9 thermocouples. The strain gages and thermocouples were used to compare the sensitivity of these instruments to the two probe resistance measure in-situ in the cement. Change in the resistance of hardening cement was continuously monitored since the installation of the field well for over 500 days. Also, a method to predict the changes in electrical resistance of the hardening cement outside the casing (Electrical Resistance Model - ERM) with time has been developed. The ERM predicted the changes in the electrical resistances of the hardening cement outside the cemented casing very well. In addition, the pressure testing showed the piezoresistive response of the hardened smart cement and a piezoresistive model has been developed to predict the pressure in the casing from the change in resistivity in the smart cement.
Niousha Amani (UH)

Behavior of Nano Calcium Carbonate Modified Smart Cement Contaminated with Oil Based Drilling Mud

Production is expanding in oil and gas around the world; hence, there are challenges in well construction. There are several benefits in using oil based drilling mud (OBM) in drilling operations especially in shale formations, but there are concerns about the potential contamination of the cement. Recent case studies on cementing failures have clearly identified some of these issues that resulted in various types of delays in the cementing operations. At present there is no technology available to monitor cementing operations and also to determine the potential of contamination in real time during the installation of the oil and gas wells. In this study, the effect of adding up to 1 percent of Nano CaCO3 (NCC) to the smart cement was investigated in order to protect the smart cement against oil based mud (OBM) contamination. Variation in the electrical resistivity of the smart cement with curing time was monitored from the initial time of mixing to 28 days of curing under water. Results showed that contamination of smart cement with OBM reduced the long term resistivity of the smart cement but adding NCC enhanced the electrical resistivity of the contaminated smart cement cured under water. In order to evaluate the piezoresistive behavior of the smart cement, 0.075 percent (BOWC) of conductive filler (CF) was added to the cement to enhance the piezoresistive behavior of the cement. Results showed that change in resistivity at compressive failure for the smart cement was over 1000 times more than compressive strain and addition of 1% NCC further enhanced it by about 37% after 1 day and 28% after 28 days of curing under water. The OBM contaminated smart cement showed less change in piezoresistivity at maximum compressive stress at failure than the smart cement but addition of 1% of NCC enhanced the piezoresistivity of OBM contaminated smart cement.

Xiangyu Liu & Qian Wu (UT)

Improved Zonal Isolation in Ultra-Deepwater Wells

Establishing cement as a barrier and achieving long-lasting zonal isolation (ZI) behind casing is one of the main goals on any well, and is particularly challenging on today's deepwater wells. Arguably, with the construction of 35,000+ ft wells drilled into progressive deeper water and in high-pressure / high-temperature (HPHT) geological environments, the industry has progressed to the point where wells can be drilled that can no longer be competently cemented and the ZI barrier can no longer be guaranteed. As illustrated by the Macondo blow-out, a devastating event that had insufficient zonal isolation as one of its main root causes, the penalty for not containing and isolating hydrocarbon flow zones can be severe. UT Austin is meeting the (ultra-)deepwater ZI challenge with a very diverse team operating a state-of-the-art deepwater HPHT cementing lab. The aim is to develop new cement-related technologies that can help prevent the next Macondo, and make cementing in (ultra-)deepwater dependable for all stages of well life. Topics that are being covered include:

- Improving current portland cement formulations and avoiding its contamination by muds
- Developing alternative, non-portland cements with improved ZI qualities
- Developing formulations and additives for harsh deepwater environments (ultra/extreme HPHT)
- Developing cementing sensor technologies, for cement integrity monitoring and verification
- Improving cement displacement efficiency
- Developing mud-to-cement conversion and set-on-demand technologies
Susana Leon Caceras (TAMU)

**Process Safety Problems Caused by Hydrate Formation in Deepwater Production Operations**

Hydrate formation has been seen as one of the most challenging problems in deepwater production operations because of the low temperatures and high pressures found in deepwater environments. Hydrate formation and its agglomeration in subsea production equipment can cause severe operational issues, lead to substantial asset damage (i.e., high economic cost), and most importantly, hydrate formation can cause significant process safety and environmental issues. Examples of the problems caused by hydrates include blockage in wells, risers, flowlines and manifolds. These blockages can increase the pressure in the system causing equipment damage (e.g., rupture) and potentially resulting in loss of hydrocarbon containment into the environment. This research analyzes common subsea production systems in order to identify different scenarios in which hydrate formation could occur and lead to safety and environmental problems. The goal is also to identify potential measures to prevent and control the formation of hydrates in order to increase the reliability and safe operations of deepwater subsea production systems.

---

Ala Eddine Omrani (UH)

**Gas Kick Early Detection**

Using data-driven modeling for drilling system condition-monitoring. Real-time sensors’ sampled data is analyzed and processed to determine the well condition and early detect gas influxes. In addition to kick prediction, real-time downhole gas volume can be determined allowing then the adjustment of the control strategy. A multiphase flow transient model is developed and used to estimate the gas flowrate using the sampled data. Key Words: Blowout Preventer, Multiphase Flow Modeling, Gas Influx Early Detection, Influx Control, Numerical Modeling.

---

Junxiao Zhu (UH)

**Development of PZT based Impact Detection System for Subsea-Tree Structures**

Structural impact events, such as impact events on structures by foreign object debris always endanger the integrity of the structures and lead to serious consequences, which highlight the structural health monitoring with the capability of detection and location of the impact events in a rapid pace. An innovative algorithm and investigated the sensing model of piezoelectric ceramic sensors was developed to estimate the propagation distances of versatile ultrasonic guided waves, thus both detect and locate the impulse events for various structures.

---

Ankit Bhowmick (UH)

**Determining Pressure Drop and the Minimum Fluidization Velocity across a Gravel Pack Completion to confirm its Integrity**

In a gravel pack completion, a non-uniform reservoir inflow with very high velocity could be capable of eroding the sand screen or may fluidize the gravel. Hence, it is crucial to maintain the integrity and avoid the failure of a gravel pack completion along with optimizing the well production. Previously, works have been carried out to address the risks of fluidizing the gravel pack in high flow rate - deepwater wells, however, there is an absence of formulas or verified safety cutoff velocity values below which a well should be produced to avoid damaging the gravel pack completion.
OESI Leadership

**Principal Investigator**
Dr. M. Sam Mannan
TAMU, Regents Professor
Executive Director,
Mary Kay O’Connor
Process Safety Center

**Co-Principal Investigator**
Dr. Ramanan Krishnamoorti
University of Houston
Chief Energy Officer

**Co-Principal Investigator**
Dr. Rashid Hasan
Texas A&M University
Larry Cress Fellow

**Co-Principal Investigator**
Dr. Eric Van Oort
University of Texas-Austin
Petroleum Engineering

**Director of Operations**
James Pettigrew
CAPT, USN(Ret)

**Program Manager**
Paul Robinson
The Ocean Energy Safety Institute (OESI) is a collaborative initiative between the Texas A&M Engineering Experiment Station’s (TEES) Mary Kay O’Connor Process Safety Center, partnering with Texas A&M University, University of Texas and University of Houston. The institute provides 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. While there have been efforts to identify scientific and technological gaps and to recommend improvement of drilling and production equipment, practices and regulation, the OESI will strive to coordinate and focus these products. Initial funding of the Institute came from the Department of the Interior and the Bureau of Safety and Environmental Enforcement (BSEE).