The National Academies of SCIENCES ENGINEERING MEDICINE

GULF RESEARCH PROGRAM

# Safer Offshore Energy Systems 3 Final Report

**Project Title:** Experiments on Multiphase Flow of Live Muds in a Full-Scale Wellbore with Distributed Sensing for Kick and Gas-in-riser Detection/Mitigation
**Award Amount:** $4,910,159
**Awardee:** Louisiana State University
**Award Start Date:** 12/01/17
**Award End Date:** 12/31/20
**NAS Grant ID:** 2000008861


**Project Director:** Mauricio Almeida*
**Affiliation:** Louisiana State University

**Project Key Personnel:**
- Babak Akbari, Louisiana State University
- Yuanhang Chen, Louisiana State University
- Rashid Hasan, Texas A&M University
- Otto L. A. Santos, Louisiana State University
- Jerome Schubert, Texas A&M University
- Paulo Waltrich, Louisiana State University
- Robert Ziegler, Weatherford


## I. PROJECT SUMMARY (from proposal)


A primary systemic risk is created by a well control event. Undetected or poorly understood well control events have created a multitude of hydrocarbon release incidents during drilling and workover operations, like the Deepwater Horizon incident. Offshore operations typically use oil based and synthetic muds where there is currently little flow dynamic data for verification and validation of drilling hydraulic simulations. Available data come from old types of muds that are rarely employed in offshore drilling nowadays, especially in deep water operations. Fundamental questions abound with regards to how gas bubbles form and migrate in the wellbore and in the riser. The gas breakout from muds in the wellbore or riser could potentially lead to blowout or unloading creating an uncontrolled hydrocarbon release. There isn't a clear understanding of the behavior of saturated muds in the wellbore and the dynamics of gas in this multiphase mixture. There is a potential ability for oil based and synthetic muds to mask gas influx and exacerbate the hazards. Significant heat exchange between the wellbore fluid and the surrounding reservoir further complicates the scenario. This could make conventional early kick detection very difficult, as well as, prediction/detection of gas in the riser.

This project will create an instrumented full scale well at the facility that previously performed the Drilling Engineering Association (DEA) test, a test that generated mud with gas circulation datasets in a controlled field scale well environment. Utilizing lessons learned and modernized instrumentation, this


* Wesley Williams was awarded this grant; it was transferred over to Mauricio Almeida.

project will retrofit the existing 5800' deep well (the Gulf Research Well) with the distributed pressure and temperature sensing system to properly characterize muds with gas under full scale circulation and in simulated well control scenarios (kicks and gas bubble migration). The facility has the ability to inject controlled high-pressure gas at 4200 psi up to 20MMSCFD to simulate and handle gas kicks.

The resulting dataset from the field scale experiments will produce detailed pressure, temperature, and flow rate behavior of drilling fluids under normal, well control scenarios. The data can be immediately utilized to verify and validate essential models utilized in wellbore hydraulics simulators, managed pressure drilling systems, and for creating operational thresholds for well control scenarios. Such validation is essential. Proposed data will be combined with laboratory scale evaluation of the drilling fluid properties and multiple small-scale dynamic systems in order to create refined models and physics of the wellbore with these kinds of drilling fluids.

The resulting outcome would be a dataset and analysis to create verified and validated models of multiphase physics in the wellbore for offshore drilling and workover operations. It would also create a facility that will be available for performing large-scale multiphase flow experiments in a highly instrumented controlled well environment that can realistically simulate drilling and workover operations, the Gulf Research Well. There are no other academic facilities like this available. It will be a highly needed university research center for large wellbore multiphase flow that would be available for academic and private research and testing, something that is unique.

## II. PROJECT SUMMARY (from final report)

The goal of the project is to develop experimental infrastructure and research expertise in riser gas management that can be impactful towards the long-term safety needs of the offshore oil and gas industry, both locally in the Gulf and internationally. Included in this goal is the creation of various data sets and a knowledge base that can be impactful towards the long-term safety needs of the offshore oil and gas industry.

The objectives of this project can be divided into the following:

a) performing a workover of Well No.2 at the Louisiana State University (LSU) Petroleum Engineering Research & Technology Transfer Laboratory (PERTT Lab) and conducting full-scale riser-gas circulation and migration experiments
b) developing or improving smaller-scale experimental setups and studying different aspects of riser-gas behaviors
c) understanding modeling and scalability for future work

## III. PROJECT RESULTS

**<u>Accomplishments</u>**

To achieve one of the most important objectives of this project, a workover was performed on Well No.2 in PERTT Lab. Figures 1-3 show the field-scale PERTT Lab located at LSU, the crew working during the well workover and the final well schematic for Well No.2.

To simulate key mass transfer and hydrodynamic processes between gas influx and non-aqueous fluids during riser-gas events, a state of the art high-pressure riser-gas mass transfer apparatus was developed as shown in Figure 4.

The following describe the other anticipated accomplishments of this project:

- Multiphase flow experiments conducted in this research demonstrate the capability of downhole fiber optic sensors to detect a potential gas influx in real-time in a 5000+ ft. deep wellbore. Figure 4 illustrates the gas rise signature in the annulus observed in the Distributed Acoustic Sensor (DAS), Figure 5 shows the gas rise signature as seen in Distributed Temperature Sensor (DTS), and Figure 6 shows the gas signature in the DTS gradient plot with respect to time.

- Gas rise velocities estimated independently using fiber optic DAS, DTS, downhole gauges, surface measurements, and multiphase flow correlations show good agreement in each case, demonstrating reliability in the assessment.

- Real-time data visualization was implemented on a secure cloud-based platform to improve computational efficiency.

- The low-frequency component of DAS demonstrates the capability to detect gas signatures both inside the tubing and the annulus of the well, even at small gas volumes. DAS data may also be used to quantitatively estimate the gas distribution profile in a riser.

- Multiphase flow experiments that addressed gas migration in a closed well indicated that the gas does not carry the bottomhole pressure when it migrates upward; the downhole pressures reduces during the initial stages of the gas migration; the pressure build-up rates are the same at any depth and at any moment during migration; and the final stabilized build-up pressure depends on the volume of gas inside the well.

- Developed and commissioned for this project, the small-scale high-pressure riser-gas mass transfer apparatus at LSU, as shown in Figure 4, successfully enabled, performed and collected data from mass transfer experiments using various combinations of gases ($CO_2$, methane) and fluids (water, internal olefins, etc.).

- Experimental data were collected for evaluation of the effects of pressure, gas velocity, gas superficial velocity, and bubble size distribution on key mass transfer coefficients. The coupled gas migration and mass transfer dynamics were visualized and video recorded through the sapphire observation windows on the test sections of the high-pressure apparatus using a high-speed camera. A snapshot of one of the videos is shown in Figure 7.

- The co-principal investigators of this project from Texas A&M University (TAMU) worked on both developing models and lab-scale experimental set-ups to develop and/or validate these models. These experimental set-ups included (1) a High-Temperature and High-Pressure (HTHP) fluid properties laboratory, (2) a dual gradient drilling laboratory that houses a scaled model of a

Marine Riser, and (3) a vertical loop that allows investigation of liquid and gas flow through an annulus.

- The HTHP laboratory work was primarily dedicated to characterizing the mechanical and rheological behavior of base-fluids, original muds, aged muds, muds with contaminants, and formation-gas/mud mixtures.

The following describe the unanticipated accomplishments of this project:

- LSU also developed two additional indoor low-pressure mass transfer apparatuses (one of them is shown in Figure 6), to better understand the mass transfer kinetics on an even smaller scale and lower pressure. These experiments improved the procedures prior to scaling up the high-pressure and field-scale experiments. These also allowed the study of desorption kinetics of dissolved gas from solution to be included in the scope of research. Combinations of various gases ($CO_2$, propane, and Methane) and fluids (diesel as base fluid for oil based mud [OBM], internal olefins as typical base fluids for synthetic oil based mud (SOBM) used in the Gulf of Mexico, and emulsions with diesel and internal Olefins with different oil water ratios that covers the range that are typical for the muds being used for offshore drilling applications) were used. Based on numerical simulations performed using field data obtained from an onshore MPD well drilled used OBM in Canada, the mass transfer coefficients obtained from experiments agree well with the coefficients obtained using the field measurement data; either neglecting or assuming instantaneous mass transfer leads to large errors in estimating the pressures and gas flow rates in a well.

- Two computer programs were developed to match the full-scale experimental work results. One matches the experimental tests nitrogen gas was injected into the well through the chemical line (injection sub-model shown in Figure 9) and the other where the nitrogen was injected through the tubing and subsequently bullheaded to the annulus (bullheading sub-model shown in Figure 10). Both programs yielded very good predictions that matched the experimental results for the gas-in-riser experiments using Well No. 2. Both computer programs were written to model the gas circulation out of the well with a backpressure applied at the surface. The descriptions of these programs and the comparisons between their predictions and the experimental results can be seen in the manuscript SPE 204115.

- A third computer program was written to predict the pressure behavior inside the riser and the output flow rates (gas and mud) from the riser during a gas circulation from the riser following a gas-in-riser incident. Figure 11 shows one of the model predictions. The application of this computer program to an actual deepwater scenario were reported in the manuscript SPE 204115.

**Implications**

Current kick detection methods primarily utilize surface measurements and do not always reliably detect a gas influx. The proposed application of distributed fiber optic sensing overcomes this key limitation of conventional kick detection methods, by providing real-time distributed downhole data for accurate and reliable monitoring.

The two-phase flow experiments conducted in this research provide critical insights for understanding the flow dynamics in offshore drilling riser conditions, and the results provide an indication of how quickly gas can migrate in a marine riser scenario, warranting further investigation for the sake of effective well control.

The time dependent gas influx absorption and desorption from non-aqueous muds (used in the most riser gas events) were investigated in the project, and the findings have indicated the potential for minimizing peak gas discharge rate at the surface through optimization of the operational parameters.

Numerical modeling of flow experiments resulted in three computer programs to predict pressure behavior and gas and drilling fluid flow rates from the test well during the circulation of the injected gas. These computer programs can be very useful for the deepwater rig crews to properly handle a gas-in-riser event or to help professionals develop operational procedures or standards regarding gas-in-riser operations.

**Education and Training**

Number of students, postdoctoral scholars, or educational components involved in the project:

- K-12 students: 0
- Undergraduate students: 2
- Graduate students: 18
- Postdoctoral scholars: 2
- Citizen Scientists: 0
- Other Trainees: 0

## IV. DATA AND INFORMATION PRODUCTS

This project produced data and information products of the following types:

- Data
- Information Products
- Scholarly publications, reports or monographs, workshop summaries or conference proceedings
- Models or simulations

**DATA**

**Data Management Report:**

See Data Management Report below.

**Relationships Between Data Sets:**

The independent datasets acquired from fiber-optic DAS, DTS, four downhole pressure/temperature gauges, and surface measurements for the different experimental trials were used to cross-validate and verify gas rise velocity and surface arrival time.

**Additional Documentation Produced to Describe Data:**
N/A

**Other Activities to Make Data Discoverable:**
N/A

**Sensitive, Confidential, or Proprietary Data:**
N/A

## INFORMATION PRODUCTS

**Information Products Report:**
See attached Information Products Report.

**Citations for Project Publications, Reports and Monographs, and Workshop and Conference Proceedings:**

- de Sousa, P. 2020. The Dynamics of Drilling Fluid Rheology, Wellbore Flow, and Formation Pressure in Well Control. PhD Dissertation. Texas A&M University. College Station, USA.

- Williams, W. C., Taylor, C. E., Almeida, M. A., Sharma, J., Waltrich, P. J., Chen, Y., Feo, G., Kunju, M., Santos, O.L.A., Ogunsanwo, O.A., Paulk, D., Kortukov, D. 2020. Distributed Sensing and Real Time Visualization of Gas Kick Dynamics in a Full-Scale Wellbore. Presented at 2020 SPE Annual Technical Conference and Exhibition. October 26-29. Virtual conference.

- Nwaka, N., Wei, C., Ambrus, A. and Chen, Y. 2020. Gas in riser: On modeling gas influxes in non-aqueous drilling fluids with time-dependent desorption considerations. Journal of Petroleum Science and Engineering, 195, p.107785.

- Nwaka, N., Wei, C. and Chen, Y. 2020. A Simplified Two-Phase Flow Model for Riser Gas Management With Non-Aqueous Drilling Fluids. Journal of Energy Resources Technology. 142(10). https://doi.org/10.1115/1.4046774.

- Ojedeji, D., Perry, S., Nielsen, J. and Chen, Y. 2020. Experimental investigation of desorption kinetics of methane in diesel and internal olefin for enhanced well control. Greenhouse Gases: Science and Technology, 10(2), pp.364-379.

- Ojedeji, D., Nielsen, J., Perry, S., Chen, Y. Experimental Investigation on Mass Transfer Kinetics of Hydrocarbon Gas Influx for Enhanced Offshore Well Control. SPE Latin American and Caribbean Petroleum Engineering Conference, Columbia. April 2020.

- Perry, S., Wei, C., Chen, Y. Absorption Kinetics of Gas Influxes into Oil and Synthetic Base Fluids During Well Control Events. 2020 AADE National Technical Conference and Exhibition, Houston, Texas. April 2020.

- Ojedeji, D., Chen, Y. Effect of the Concentration of Viscosifier on Desorption Kinetics of Methane From Synthetic Based Fluids. ASME 2020 39th International Conference on Ocean, Offshore and Arctic Engineering. Fort Lauderdale, USA. June 2020.

- Sharma, J., Cuny, T., Ogunsanwo, T., Santos, O. 2020. “Low-Frequency Distributed Acoustic Sensing for Early Gas Detection in a Wellbore”. In IEEE Sensors Journal, vol. 21, no. 5, pp. 6158-6169, 1 March 2021. https://doi.org/10.1109/JSEN.2020.3038738.

- Sharma, J., Santos, O., Feo, G., Ogunsanwo, O., Williams, W. 2020. “Well-Scale Multiphase Flow Characterization & Validation Using Distributed Fiber Optic Sensors for Gas Kick Monitoring”. Optics Express 28(26): 38773-38787.

- Feo, G., Sharma, J., KortuKov, D., Ogunsanwo, T. Williams, W. 2020. “Distributed Fiber Optic Sensing for Real-Time Monitoring of Gas in Riser during Offshore Drilling”. Sensors, 20(1): 267.

- Feo, G., Sharma, J., Santos, O., Ogunsanwo, T., Williams, W. 2020. “Multiphase Flow Characterization and Modeling Using Distributed Fiber Optic Sensors to Prevent Well Blowout.” in Optical Sensors and Sensing Congress. OSA Technical Digest (Optical Society of America, 2020). Paper EM3C.5. https://doi.org/10.1364/ES.2020.EM3C.5.

- Williams, W. C., Taylor, C. E., Almeida, M. A., Sharma, J., Waltrich, P. J., Chen, Y., Feo, G., Kortukov, D. 2020. “Distributed Sensing and Real Time Visualization of Gas Kick Dynamics in a Full-Scale Wellbore”. SPE Annual Technical Conference and Exhibition. 26-29 October, 2020. https://doi.org/10.2118/201539-MS.

- Feo, G., Sharma, J., Williams, W., Kortukov, D., Ogunsanwo, T. 2019. “Application of Distributed Fiber Optics Sensing Technology for Real-time Gas Kick Detection.” SPE Annual Technical Conference and Exhibition, Calgary, Canada, September. https://doi.org/10.2118/196113-MS.

- Santos, O. 2018. “Literature Review on Gas in Riser”. 2018. GRP (SOES3) Annual Report.

- Marques, D., Ribeiro, P., Santos, O. and Lomba, R. 2018. “Thermodynamic Behavior of Olefin and Methane Mixtures Applied to Synthetic Drilling Fluids Well Control”. Article published in the SPE Drilling & Completion.

- Marques, D., Ribeiro, P., Santos, O. 2020. “Mathematical Correlations of Olefin and Methane Mixtures to be Applied to Synthetic Drilling Fluid Well Control”. Manuscript SPE-199169-MS presented at the 2020 LACPEC, Bogota (Virtual Conference).

- Santos, O., Williams W., Sharma, J., Almeida, M., Kunju, M., Taylor, C. 2021. “Use of Fiber Optic Information to Detect and Investigate the Gas-in-riser Phenomenon”. Manuscript SPE-204115-MS to be presented in March at the 2021 SPE/IADC International Drilling Conference (Virtual Conference)

- Kaldirim, Omer, Kaldirim, Ebubekir, Geresti, Cameron et al. 2020. 2-D Computational Fluid Dynamics Modeling of Riser Gas and Unloading in Various Pipe Diameters and Lengths. Presented at the SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition, Denver, Colorado, USA. 2020/10/29. https://doi.org/10.2118/200523-MS.

- Kaldirim, Omer and Schubert, Jerome J. 2018. Experimental Study on Riser Gas Expansion and Unloading. Presented at the SPE/IADC Managed Pressure Drilling and Underbalanced Operations Conference and Exhibition, New Orleans, Louisiana, USA. 2018/4/17. https://doi.org/10.2118/190004-MS.

- Manikonda, Kaushik, Hasan, Abu Rashid, Barooah, Abinash et al. 2020. A Mechanistic Gas Kick Model to Simulate Gas in a Riser with Water and Synthetic-Based Drilling Fluid. Presented at the Abu Dhabi International Petroleum Exhibition & Conference, Abu Dhabi, UAE. 2020/11/9. https://doi.org/10.2118/203159-MS.

- Manikonda, Kaushik, Hasan, Abu Rashid, Kaldirim, Omer et al. 2020. Estimating Swelling in Oil-Based Mud due to Gas Kick Dissolution. Proc. ASME 2020 39th International Conference on Ocean, Offshore and Arctic Engineering. https://doi.org/10.1115/OMAE2020-18115.

- Manikonda, Kaushik, Hasan, Abu Rashid, Kaldirim, Omer et al. 2019. Understanding Gas Kick Behavior in Water and Oil-Based Drilling Fluids. Presented at the SPE Kuwait Oil & Gas Show and Conference, Mishref, Kuwait. 2019/10/13. https://doi.org/10.2118/198069-MS.

- Manikonda, Kaushik. 2020. Modeling Gas Kick Behavior in Water and Oil-Based Drilling Fluids. Master's thesis, Texas A&M University. Available electronically from https://hdl.handle.net/1969.1/192525.

**Websites and Data Portals:**
GRIIDC Data Portal: https://grp.griidc.org/research-group/about/909

**Additional Documentation Produced to Describe Information Products:**

- Santos, O., 2020, Fortran Computer Program for Modeling Nitrogen Injection Experiments at PERTT Lab Down to the Chemical Line.

- Santos, O., 2020, Fortran Computer Program for Modeling Nitrogen Injection Experiments at PERTT Lab Down to the Tubing and Subsequent Bullheading to the Annulus.

- Santos, O., 2020, Fortran Computer Program for Modeling Actual Gas-in-riser Operations in Deep Waters.

**Other Activities to Make Information Products Accessible and Discoverable:**
N/A

**Confidential, Proprietary, Specially Licensed Information Products:**
N/A

## V. PUBLIC INTEREST AND COMMUNICATIONS

### Most Exciting or Surprising Thing Learned During the Project

Several exciting and surprising things were learned during this project:

- The same optical fiber which has revolutionized high-speed internet, can also be used for sensing temperature, strain, and vibrations with high sensitivity.

- How much the potential for creativity and innovation increases when a mix of highly academic trained specialists with good experienced people, from different areas of expertise, are working closely.

- Academic research people involved in the project are highly motivated when their work is primarily focused on understanding and solving issues related to real problems faced by the oil and gas industry.

- In science, paradigms exist to be broken. For many years, the oil and gas industry worked with a paradigm that we must avoid the presence of gas in the riser no matter what. The results of this work show contribution to the development of new technologies that will allow us to manage the presence of gas in risers in our favor as part of normal operational practices.

### Outcomes Achieved During the Project

- The publications produced in this project have been cited by a few other publications, even before the completion of the project.

- The Gas-in-Riser project has provided Safekick with useful information to confirm some of the results obtained by the simulations to understand the gas in riser event as a starting point.

- From the TAMU collaboration, the effect of gas on the rheological and mechanical properties of the drilling fluid was investigated experimentally. TAMU worked on multiple scaled test rigs to create a more detailed understanding of the scalability of wellbore/riser processes to the intermediate lab scale.

### Communications, Outreach, and Dissemination Activities of Project

Over the span of the 3-year project, we communicated our results quarterly to the International Association of Drilling Contractors Underbalanced Operations and Managed Pressure Drilling subcommittee and participated in leading their Riser Gas subcommittee and even chaired the committee for one year. These interactions helped guide in the creation and curation of the best practices of the drilling industry. The project provided multiple opportunities to interact with local and national media through interviews and articles. This project was highlighted in the Journal of Petroleum

Technology (JPT) in the Well Control column. There was also the opportunity to present the project and some results in front of ExxonMobil with several hundred engineers in attendance.

Dr. Otto Santos (LSU Professional in Residence) was a member of the JPT Editorial Committee from 2013 to 2020. The Journal of Petroleum Technology is the flagship publication of SPE. His job duties in this position included authoring a text about the state-of-the-art in well control and well integrity issues and selecting three technical papers in that area to be synopsized and published in the January issue of JPT within the Technology Focus section. For the January 2019 issue, Dr. Santos wrote a text about gas in the marine riser and the GRP project underway at LSU (see the link: https://onepetro.org/JPT/article-abstract/71/01/63/208369/Technology-Focus-Well-Integrity-January-2019?redirectedFrom=fulltext). It was a very good opportunity to present to all segments of the oil industry the importance, scope, and benefits of the project. It is important to note that SPE has more than 140,000 members worldwide currently (144 countries) and its members receive a complimentary subscription to JPT. He also mentioned the GRP program in the January 2020 issue as shown in the following link: https://jpt.spe.org/well-integrity-6411.

Academic Outreach [taken from 2019 Report]:

Press release content from Globe Newswire and published by AP News as shown in the following link: https://apnews.com/press-release/globenewswire-mobile/5342e747f4e660c898c8246453faeffa

Press released material published by the Baton Rouge newspaper The Morning Advocate on December 2017 emphasizing the importance of the grant awarded to LSU project aiming to reduce risk in offshore oil industry, by focusing studies on gaps in understanding the behavior of riser gas under high temperature and pressure:
https://www.theadvocate.com/baton_rouge/news/business/article_dc499488-db70-11e7-a651-4b665471f7ec.html

The Advocate article: "LSU gets millions in BP oil settlement money to study how to make drilling in Gulf safer": https://www.theadvocate.com/baton_rouge/news/environment/article_e6e1248c-db85-11e7-9bfe-978a38866c89.html

Two articles were published in the Engineering College Website and the Petroleum Engineering Department Website at Texas A&M University. These articles were shared by the Engineering School and the Petroleum Engineering Department in email newsletters, LinkedIn and Facebook:

https://engineering.tamu.edu/news/2018/02/lsu-and-tamu-receive-award-to-research-offshore-drilling-risk.html

https://engineering.tamu.edu/news/2020/03/student-revitalizes-huge-vertical-lab-hidden-inside-Texas-AandM-building.html

IDEA Academy Tour:

A tour was arranged and given to the IDEA Academy High School of Edinburg, Texas. Students were from historically underrepresented groups in engineering, and were given a tour of the Engineering Building and discussed with the PI, Wesley Williams, about engineering and how engineers protect the safety of our communities and environment. Discussion included the importance of energy as part of our Gulf economy. The group had approximately 98 students and travelled nearly 10 hours to come tour LSU (see Figure 12).

# Figures

**Figure 1:** Petroleum Engineering Research & Technology Transfer Laboratory well scale facility at Louisiana State University.

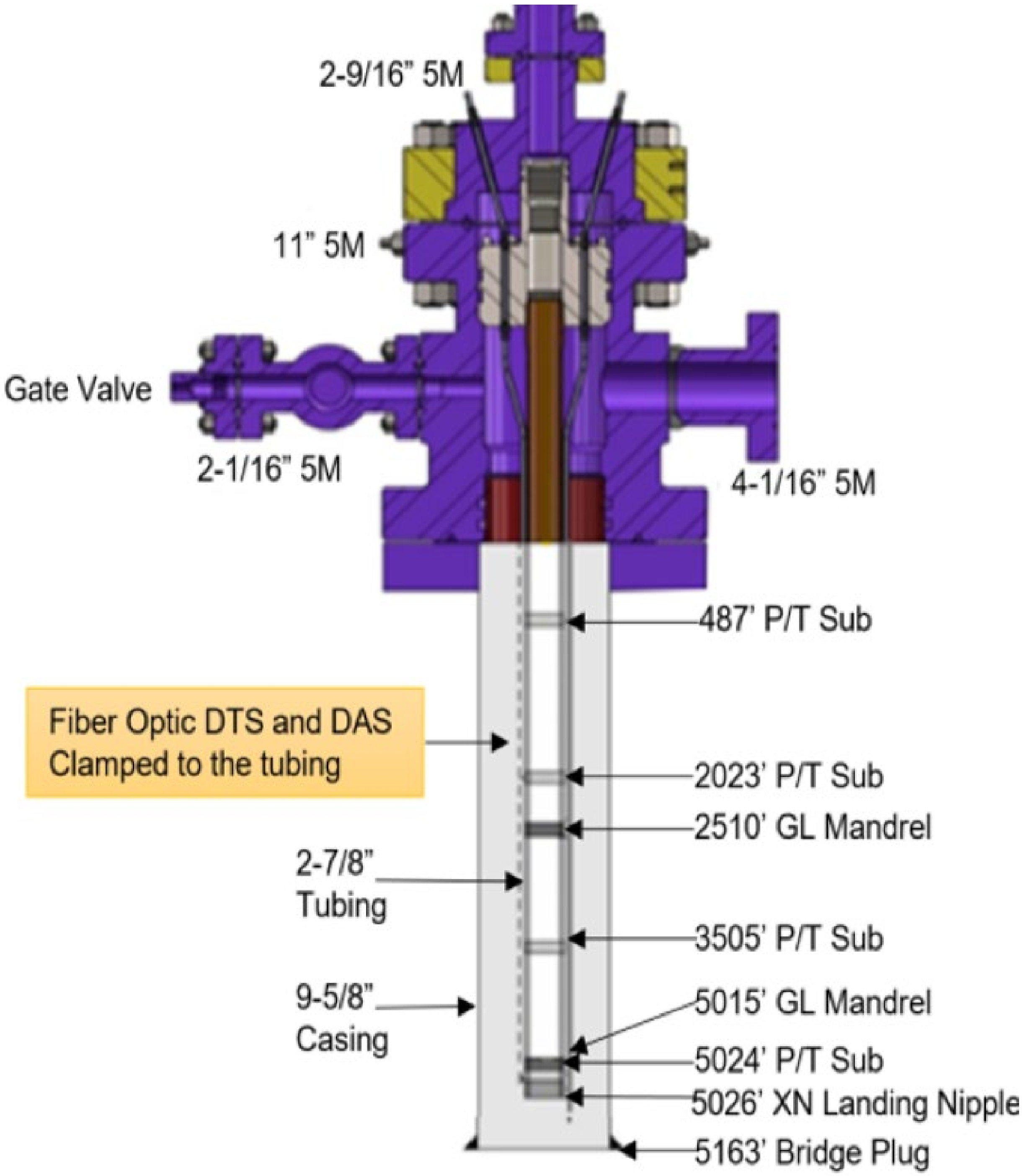


**Figure 2:** Test Well No.2 schematic.

**Figure 3:** Workover done on Well No.2 to install Distributed Acoustic Sensor, Distributed Temperature Sensor and downhole pressure-temperature gauges.

**Figure 4:** High Pressure Riser - Gas Mass Transfer Apparatus developed and commissioned under this project.

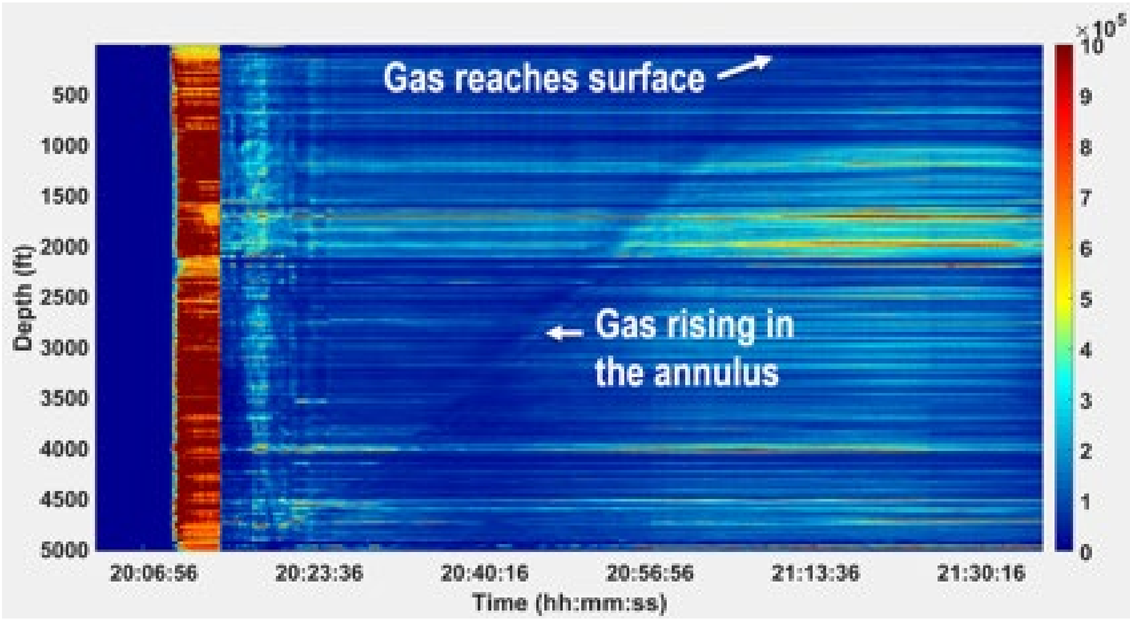


**Figure 5:** Gas signature seen in Distributed Acoustic Sensor.

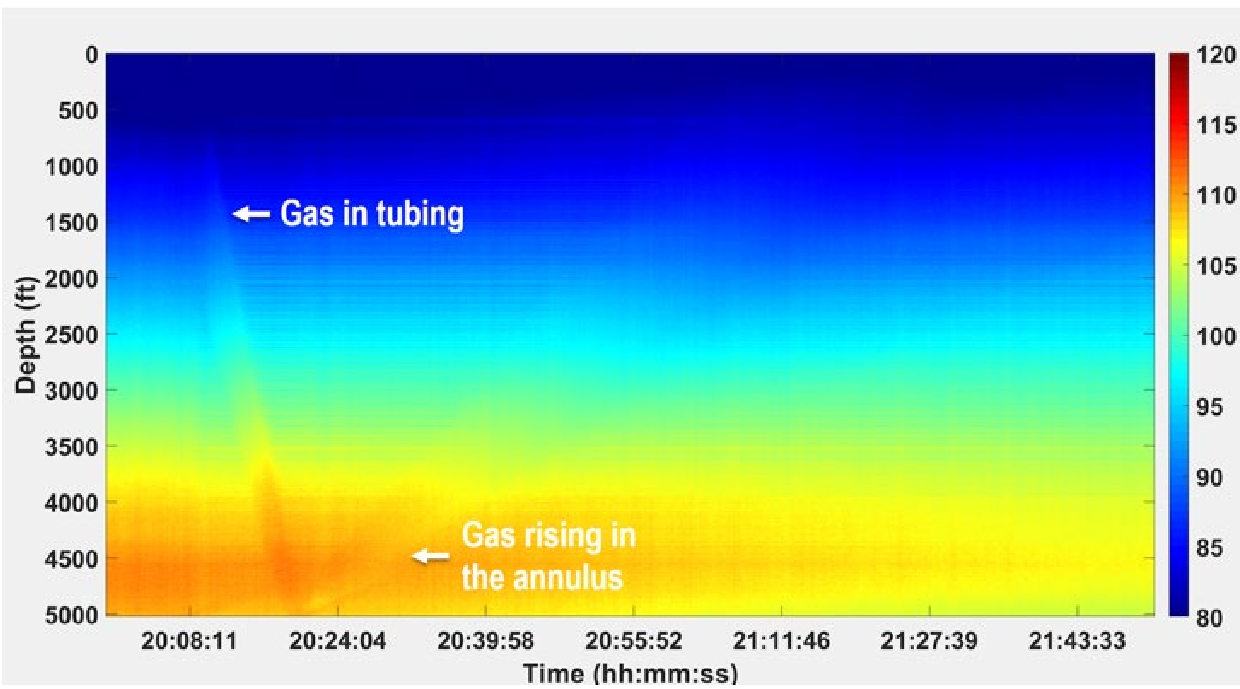


**Figure 6:** Gas signature seen in Distributed Temperature Sensor.

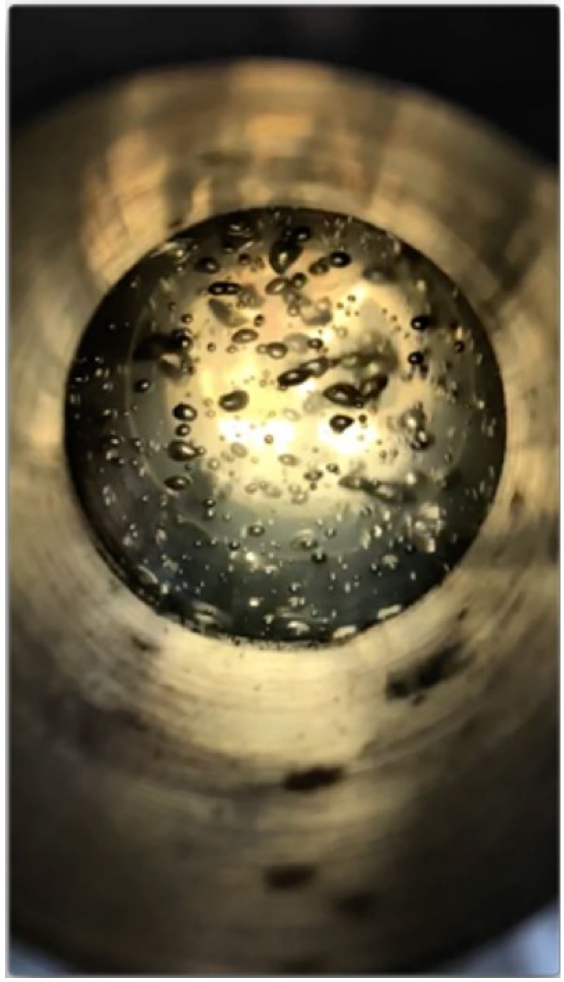

**Figure 7:** A snapshot of a video recorded through the sapphire observation window on the outdoor high-pressure mass transfer apparatus for the assessment of gas velocity and bubble size distribution.

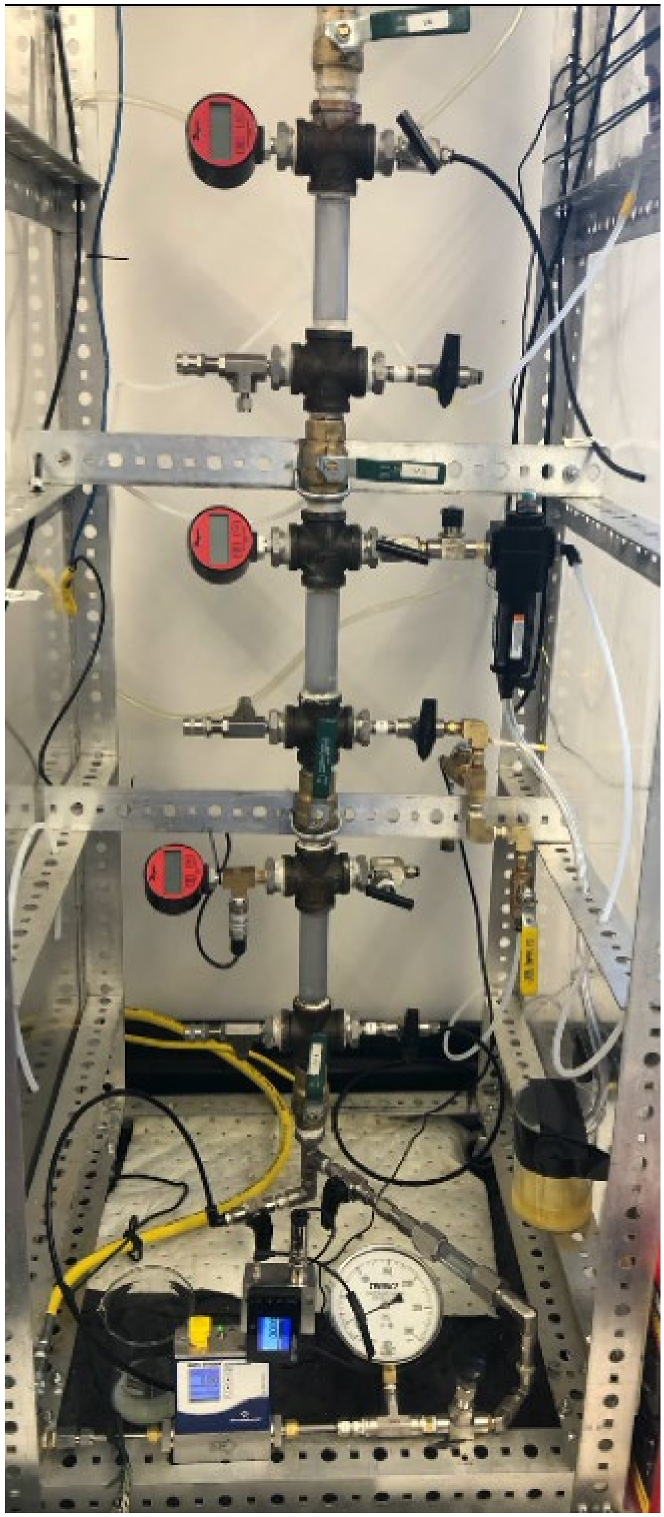

**Figure 8:** One of the indoor low-pressure mass transfer apparatuses with 1-inch inner diameter test section and 300 psi.

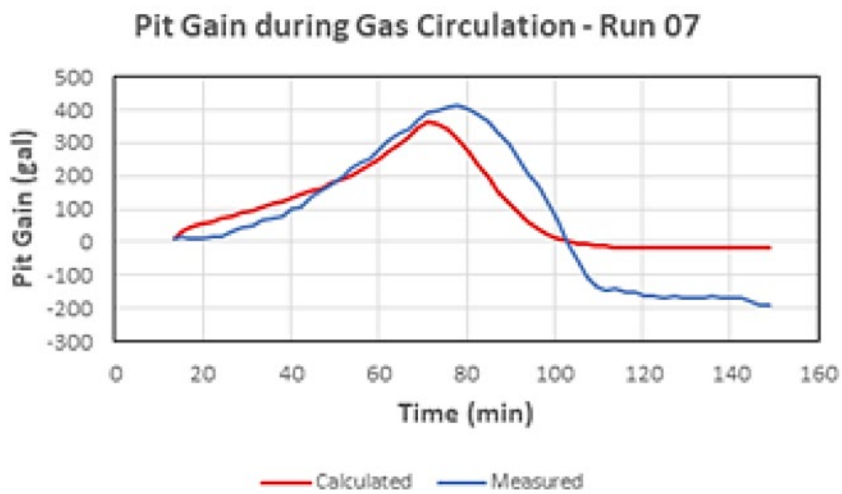


**Figure 9:** Model results for the injection sub-model.

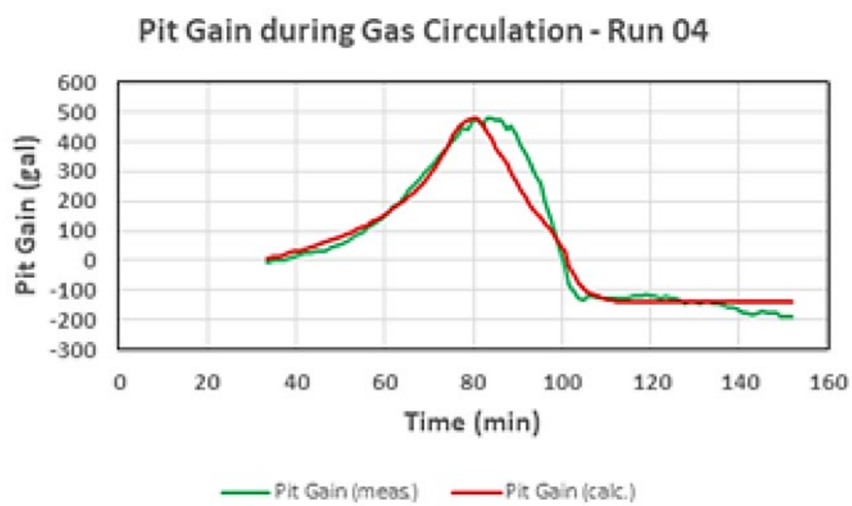


**Figure 10:** Model results for the injection sub-model.

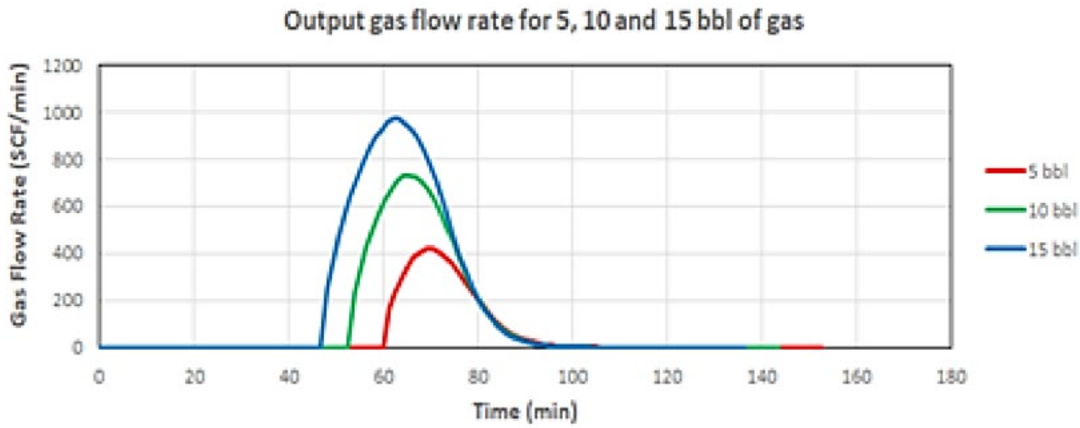


**Figure 11:** Computer program predictions for the gas flow rate as a function of the kick size.


**Figure 12:** IDEA academy tour of Louisiana State University.

**Data Report**

| DataType | DigitalResourceType | Title | FileName | Creators | PointofContact | PublicationYear | RepositoryName | DOIorPersistentURL | Keywords | Publications |
|---|---|---|---|---|---|---|---|---|---|---|
| Education and Training | Images | Exhibition Booth at SPE/IADC Conference and Exhibition | Figure 3.1 | Wesley Williams | | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Cross-section diagram of field-scale test well | Figure 6.1 | Wesley Williams | | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Well Diagram | Figure 6.2 | Wesley Williams | | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Experiment Process Flow Diagram | Figure 6.3 | Wesley Williams | | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | (a) Suspended gas fraction from a large number of tests with two water-based muds in an annular drilling geometry (Johnson et al., 1995). (b) Potential Gas Volume in Suspension in Deepwater Riser (LLoyd et al., 2000). | Figure 7.1 | LLoyd et al., 2000 and Johnson et al., 1995 | yuanhangchen@lsu.edu 225-578-4394 | 2000 and 1995 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Pit gain versus time for the same influx scenario using Standing's correlation model (blue) and tables based on a compositional PVT model tuned against experimental data (orange) (Knut S. Bjørkevoll et al., 2018). | Figure 7.2 | Knut S. Bjørkevoll et al., 2018 | yuanhangchen@lsu.edu 225-578-4394 | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | | |
| Engineering | Images | Choke pressure versus time for the same influx scenario using Standing's correlation model (blue) and tables based on a compositional PVT model tuned against experimental data (orange) (Knut S. Bjørkevoll et al., 2018). | Figure 7.3 | Knut S. Bjørkevoll et al., 2018 | yuanhangchen@lsu.edu 225-578-4394 | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Evolution of pit gain with dense phase conditions included (Knut S. Bjørkevoll et al., 2018). | Figure 7.4 | Knut S. Bjørkevoll et al., 2018 | yuanhangchen@lsu.edu 225-578-4394 | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Evolution of choke pressure with dense phase included (Knut S. Bjørkevoll et al., 2018). | Figure 7.5 | Knut S. Bjørkevoll et al., 2018 | yuanhangchen@lsu.edu 225-578-4394 | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | High Pressure Convection and Absorption Apparatus P&ID. | Figure 7.6 | Yuanhang Chen | yuanhangchen@lsu.edu 225-578-4394 | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Equipment and trailer location at PERTT. | Figure 7.7 | Yuanhang Chen | yuanhangchen@lsu.edu 225-578-4394 | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Schematic of the test facility. Labels are as followed: 1) Liquid tank, 2) Blender, 3) Centrifugal pump, 4) Water flowmeter, 5) Air compressor, 6) Gas tank, 7) Pressure gauge, 8) Control valve, 9) Air flowmeter, 10) High speed camera, 11) Inner pipe, 12) Outer pipe, 13) Rigid structure, 14) Collect tank, 15) Pressure transducer, 16) Acquisition system. | Figure 8.1 | Herman "Kam" Von Holt | hvonho2@lsu.edu 225-578-8457 | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Table from Rader et al (1975) consolidating significant previous results. | Figure 9.1 | Rader et al (1975) | babak@lsu.edu 225-578-6044 | 1975 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | Photographs of Taylor bubbles rising through 76.2 mm inside-diameter pipe filled with different viscosity liquids: (a) water (b) silicone oil (3900 mPa s). Viana et al (2003) | Figure 9.2 | Viana et al (2003) | babak@lsu.edu 225-578-6044 | 2003 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |
| Engineering | Images | (a) Pictures of bubble wrap around inner pipe of annulus. Introduction of the idea that as the inner pipe decreases to a very thin pipe, the bubble continues its 'wrap' geometry. Das et al (2002) (d) Description of Nose Section of bubble. Semi-major (a) and semi-minor (b) axes of bubble for use in equation [24]. Agarwal et al (2007) | Figure 9.3 | Das et al (2002) and Agarwal et al (2007) | babak@lsu.edu 225-578-6044 | 2002 and 2007 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | | Annual Report 2018 | |

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|---|---|---|---|---|---|---|---|---|
| Engineering | *Images* | *Main Flow Annulus Schematic* | *Figure 9.4* | Babak Akbari | babak@lsu.edu<br>225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Schematic of Experimental Setup* | *Figure 9.5* | Babak Akbari | babak@lsu.edu<br>225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *A typical experimental run* | *Figure 9.6* | Babak Akbari | babak@lsu.edu<br>225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *0 psi System Pressure Relationship between bubble velocity & fluid yield point* | *Figure 9.7* | Babak Akbari | babak@lsu.edu<br>225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *30 psi System Pressure Relationship between bubble velocity & fluid yield point* | *Figure 9.8* | Babak Akbari | babak@lsu.edu<br>225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *60 psi System Pressure Relationship between bubble velocity & fluid yield point* | *Figure 9.9* | Babak Akbari | babak@lsu.edu<br>225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Schematic drawing of experimental setup.* | *Figure 10.1* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Rheo 7000 control panel.* | *Figure 10.2* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Test matrix for oil- and water-based drilling fluids.* | *Figure 10.3* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Isobars of dial reading vs. shear rate for UBF3 (a), PBF3 (b), and U3D (c) for a fixed temperature of 200 °F.* | *Figure 10.4* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *10-second and 10-minutes gel-strengths for U3D for a fixed temperature of 300 °F.* | *Figure 10.5* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Schematic of 27-ft Flow loop (Kaldirim and Schubert 2018)* | *Figure 11.1* | Kaldirim and Schubert 2018) | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Simulator Design (Kaldirim and Schubert 2017)* | *Figure 11.2* | Kaldirim and Schubert 2018) | jschubert@tamu.edu<br>979-862-1195 | *2017* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Riser Model at 0° angle from the vertical (Kaldirim and Schubert 2017, Kaldirim 2015)* | *Figure 11.3* | Kaldirim and Schubert 2017 and Kaldirim 2015 | jschubert@tamu.edu<br>979-862-1195 | *2017 and 2015* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *500 mL Gas canister option for gas injection (Kaldirim and Schubert 2018)* | *Figure 11.4* | Kaldirim and Schubert 2018 | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Schematic Diagram of the Tower Lab Flow Loop (Waltrich and Barbosa 2011)* | *Figure 11.5* | Waltrich and Barbosa 2011 | jschubert@tamu.edu<br>979-862-1195 | *2011* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *500 mL Gas canister option for gas injection (Kaldirim and Schubert 2018)* | *Figure 11.6* | Kaldirim and Schubert 2018 | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *CFD Multiphase Flow Simulation Phase Ratio Gas injection at 0.2 CFM. Captured photos 0.5 seconds apart.* | *Figure 11.7* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *CFD Multiphase Flow Simulation Phase Ratio Gas injection at 0.2 CFM. Captured photos 0.5 seconds apart.* | *Figure 11.8* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *CFD Multiphase Flow Simulation Phase Ratio Gas injection at 0.2 CFM. Captured photos 0.5 seconds apart. (5 – 7 Seconds)* | *Figure 11.9* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *CFD Multiphase Flow Simulation Phase Ratio Gas injection at 0.2 CFM. Captured photos 0.5 seconds apart. (7.5 – 10 seconds)* | *Figure 11.10* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *CFD Multiphase Flow Simulation Phase Ratio Gas injection at 0.2 CFM. Captured photos 0.5 seconds apart. (10.5 – 13 seconds)* | *Figure 11.11* | Jerome Schubert | jschubert@tamu.edu<br>979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Case 1a – Total Pit gain with time for a single 5 bbl gas bubble at BH conditions with no circulation.* | *Figure 11.1* | Rashid Hasan | rhasan@tamu.edu<br>979-847-8564 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Case 1b – Pit gain vs. time for a single 5 bbl bubble at BH conditions with 702 gpm mud circulation.* | *Figure 11.2* | Rashid Hasan | rhasan@tamu.edu<br>979-847-8564 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Case 2a – Total Pit gain with time for a constant gas influx rate of 12 Scf/sec with no circulation.* | *Figure 11.3* | Rashid Hasan | rhasan@tamu.edu<br>979-847-8564 | *2018* | https://lsu.box.com/s/dv9lhuon<br>oytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |

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|---|---|---|---|---|---|---|---|---|
| Engineering | *Images* | *Case 2b – Pit gain vs. time for a constant gas influx rate of 12 Scf/sec with 702 gpm mud circulation.* | *Figure 11.4* | Rashid Hasan | rhasan@tamu.edu 979-847-8564 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Case 3a – Pit gain with time for a single 5 bbl bubble at BH conditions with circulation and no circulation cases.* | *Figure 11.5* | Rashid Hasan | rhasan@tamu.edu 979-847-8564 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Case 3b – Pit gain with time at a constant gas influx rate of 12 Scf/sec comparison with circulation and no circulation cases.* | *Figure 11.6* | Rashid Hasan | rhasan@tamu.edu 979-847-8564 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Comparison of the Articles in Gas-in-Riser* | *Table 5 1* | *Wesley Williams* | | 2018 | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Equipment Components.* | *Table 7_1* | *Yuanhang Chen* | yuanhangchen@lsu.edu 225-578-4394 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Mass of methane in each vessel for varying rheological properties and pressures.* | *Table 7 2* | *Yuanhang Chen* | yuanhangchen@lsu.edu 225-578-4394 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Characteristics of base oils to be investigated.* | *Table 7_3* | *Yuanhang Chen* | yuanhangchen@lsu.edu 225-578-4394 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Mass of methane in each vessel for different base oils and varying injected methane mass.* | *Table 7_4* | *Yuanhang Chen* | yuanhangchen@lsu.edu 225-578-4394 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Mass of methane in each vessel for different base oils and varying injection velocity.* | *Table 7_5* | *Yuanhang Chen* | yuanhangchen@lsu.edu 225-578-4394 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Mass of methane in each vessel for varying saturation levels in V2.* | *Table 7_6* | *Yuanhang Chen* | yuanhangchen@lsu.edu 225-578-4394 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Experimental research of two-phase flow in annulus* | *Table 8_1* | Herman "Kam" Von Holt | hvonho2@lsu.edu 225-578-8457 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Experimental matrix of non-Newtonian two phase flow in vertical annulus.* | *Table 8 2* | Herman "Kam" Von Holt | hvonho2@lsu.edu 225-578-8457 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Experimental Design Matrix* | *Table 9_1* | Babak Akbari | babak@lsu.edu 225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Experimental results made on fluids of comparable concentrations* | *Table 9 2* | Babak Akbari | babak@lsu.edu 225-578-6044 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | *Test parameters.* | *Table 10 1* | Jerome Schubert | jschubert@tamu.edu 979-862-1195 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2018* |
| Engineering | *Images* | Attachment # 1 – Well # 2 Actual Schematic | Attachment # 1 | Mauricio Almeida | malmeida@lsu.edu 225-578-0412 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2019* |
| Engineering | *Images* | Attachment # 2 – PERTT Lab Plan View | Attachment # 2 | Mauricio Almeida | malmeida@lsu.edu 225-578-0412 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2020* |
| Engineering | *Images* | Attachment # 3 – Vendor must provide the below outlined Workover Unit Minimum Specification Requirements | Attachment # 3 | Mauricio Almeida | malmeida@lsu.edu 225-578-0412 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2021* |
| Engineering | *Images* | Attachment # 5 -LSU PERTT Lab Hydrostatic Testing Procedure | Attachment # 5 | Mauricio Almeida | malmeida@lsu.edu 225-578-0412 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2022* |
| Engineering | *Images* | Attachment # 6 - Well #2 Hydro test results | Attachment # 6 | Mauricio Almeida | malmeida@lsu.edu 225-578-0412 | *2018* | https://lsu.box.com/s/dv9lhuonoytkq9wycp83hnmk9qbrey9u | *Annual Report 2023* |