Eighth Quarterly Report
Phase II
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THE UNIVERSITY OF MARYLAND AND THE PETROLEUM INSTITUTE OF ABU DHABI, UAE

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Introduction

This quarterly report provides an overview of the achievements of the various activities of the past two years of EERC Phase II. The research activities are organized in the main part of the report, while all other activities, including educational and administrative, are reported in the introduction.

Summer Internship Program

The EERC Summer Internship Program is an important part of the educational arm of the EERC, providing PI students with the opportunity to study with UMD professors who are world leaders in their fields, to interact with graduate students from UMD's culturally diverse Clark School of Engineering, and to experience life in the United States, if only for a short time. The program began in 2008 during Phase I of the EERC and has successfully continued each summer through Phase II.

Summer 2009



Student	Department	Professor	Project
Alaa Khalil	Mechanical Engineering	Serguei Dessiatoun	Microreactors for Oil and Gas Separation Processes Using Microchannel Technologies
Abdalla Mohamed El Shawadfi Helal	Mechanical Engineering	Serguei Dessiatoun	Microreactors for Oil and Gas Separation Processes Using Microchannel Technologies
Bilal Bassam Sarris	Mechanical Engineering	Reinhard Radermacher	Waste Heat Utilization in Oil and Gas Industries
Nabil Hirzallah	Electrical Engineering	Shihab Shamma	Segregation of Speech Using the Cortical Model
Waled Saeed	Mechanical Engineering	Bala Balachandran	Dynamics and Control of Drill Strings
Ahmed Khalil	Mechanical Engineering	S.K. Gupta and Avram Bar-Cohen	Thermally Enhanced Polymer Heat Exchangers
Saleh Al Hilali	Mechanical Engineering	Reinhard Radermacher	Solar Powered Cooling Systems for Houses in Abu Dhabi
Abdallah Helal	Mechanical Engineering	Serguei Dessiatoun	Study on Microchannel-Based Absorber/Stripper and Electrostatic Precipitators for CO_2 Separation from Flue Gas

Mohammed Abudaga	Mechanical Engineering	Mohammad Modarres	Risk Analysis and Probabilistic Study on Corrosion on X-70 Steel
Abdullah Tamimi	Mechanical Engineering	Mohammad Modarres	Development of a Probabilistic Model for Degradation Effects of Corrosion-Fatigue Cracking in Oil and Gas Pipelines
Nalah Amoodi	Chemical Engineering	A.K. Gupta	

For more details about the Summer 2009 program, see the [EERC Phase II Second Quarterly Report].

Summer 2010

Student	Department	Professor	Project
Omar Al Suwaidi	Mechanical Engineering	Bala Balachandran	Dynamics and Control of Drill Strings
Ghadayer Al Kaabi	Mechanical Engineering	Bala Balachandran	Dynamics and Control of Drill Strings
Yahya Qaroot	Mechanical Engineering	Serguei Dessiatoun Amir Shooshtari	Microreactors for Oil and Gas Processing Using Microchannel Technologies
Anouar Zebidi	Mechanical Engineering	Serguei Dessiatoun Amir Shooshtari	Microreactors for Oil and Gas Processing Using Microchannel Technologies
Tariq Al Jallad	Mechanical Engineering	Reinhard Radermacher	Separate Sensible and Latent Cooling with Solar Energy

Taher Abu Seer	Mechanical Engineering	Mohammad Modarres	Development of Probabilistic Model for Degradation Effects of Corrosion-Fatigue Cracking in Oil and Gas Pipelines
Ahamad El Ali	Mechanical Engineering	Bala Balachandran	Studies on Mobile Sensor Platforms
Osama Al Ameri	Mechanical Engineering	Bala Balachandran	Studies on Mobile Sensor Platforms

For more details about the Summer 2010 program, see the EERC Phase II Fifth Quarterly Report.

Arzanah Campus Visits

For the past two years, students from the Arzanah campus at PI have traveled to UMD as a part of the WISE program, in what has been named "Journey of Discovery."

Objectives of the program are to

- Provide an opportunity to visit WISE programs at partner institutions and interact with their female engineering students.
- Expose WISE students to cutting-edge research and technology to develop commitment to science and technology.
- Participate in laboratory experiences.
- Attend lectures by leading scientists (especially females) in different areas of research and technology.
- Develop academic-related travel opportunities for WISE students while taking into consideration the particular nature of the WISE program mission and vision.

Journey of Discovery 1, March 26 – April 3, 2010

Organizers

Dr. Nadia Alhasani, WISE Program and Arzanah Campus Director
Dr. Azar Nazeri, EERC Research Manager

Laboratory Visits

Microelectronics Interconnects Laboratory
A.K. Gupta, Combustion Laboratory
Sara Bergbreiter, Micro-Robotics Laboratory
Amir Baz, Virtual Reality Laboratory
Nanofabrication Laboratory
University Nuclear Reactor

Workshops/Lectures

Dr. Moustafa Al-Bassyiouni lecture on microelectronics
Dr. Sarah Bergbreiter lecture on micro-robotics
Dr. Linda Schmidt workshop on collaboration and Kolb learning
Dr. Nadia Alhasani on "WISE@PI"
Dr. Paige Smith, UMD Director of WIE, and Alana Johnson, Assistant Director of Outreach and Recruitment, WISE/WIE Workshop
Capstone Designs Interim Presentations

Cultural Institution Visits

Smithsonian Center
Smithsonian Natural History Museum
National Air and Space Museum
National Gallery of Art—East Wing

Facts and Figures

- 14 junior and senior students participated
- All participants were UAE nationals
- Participants included 9 ELEG, 4 MEEG and 1CHEG students
- Duration was 7 nights/8 days (March 26 – April 3, 2010)
- Attended 4 lectures, 1 presentation and 2 workshops
- Visited 5 laboratories and 1 nuclear reactor
- Toured 2 campuses (UMD and Georgetown University)
- Visited 3 cities (Washington, DC; Baltimore, MD; Alexandria, VA)

For more information on Journey of Discovery 1, see the EERC Phase II Fourth Quarterly Report.

Journey of Discovery 2, March 26 – April 2, 2011

Organizers

Dr. Nadia Alhasani, WISE Program and Arzanah Campus Director
Dr. Azar Nazeri, EERC Research Manager

Laboratory Visits

Chemical engineering laboratories
Drs. Raghavan and Anisimov, Light Scattering Lab
ME Microelectronics Interconnects Laboratory
Sara Bergbreiter, Micro-Robotics Laboratory
Amir Baz, Virtual Reality Laboratory
Nano-Fabrication Laboratory
University Nuclear Reactor
CALCE Laboratories (MEMS and Microfluids)
Senior Capstone Design Laboratory

Workshops/Lectures

MEMS lecture
Nanofabrication engineering lecture

Cultural Institution Visits

Baltimore Harbor
National Art Gallery—East Wing
Union Station
National Air and Space Museum
Smithsonian Natural History Museum

Smithsonian Center
Tour of Washington monuments
National Cathedral
Washington DC waterfront
Georgetown
UAE Embassy for presentations and luncheon

Facts and Figures

- Duration was 7 nights/8 days
- Toured 2 campuses (UMD and Georgetown University)
- Visited 3 cities (Washington, DC; Baltimore, MD; Alexandria, VA)
- Visited 9 laboratories and 1 nuclear reactor
- Attended 2 lectures

For more information on Journey of Discovery 2, see the EERC Phase II Seventh Quarterly Report.

Educating Future PI Faculty & UAE Executives

The ADNOC Scholars program, initiated in Phase I of the EERC to prepare Ph.D. students to become PI faculty, has graduated three students who are currently PI faculty and UAE government executives.

ADNOC Scholars PI Faculty

- Ebrahim Al Hajri, Assistant Professor at PI
    - Ph.D. dissertation title: "Prediction of Heat Transfer and Pressure Drop of Condensing Refrigerant Flow in High Aspect Ratio Microchannels"
    - Joined ME department at PI in Fall 2009

- Mohamed Al Shehhi, Assistant Professor at PI
    - Ph.D. dissertation title: "Electrostatic Gas-Liquid Separation: Application to Advanced On-Line/On-Demand Separation Techniques"
    - Joined ME department at PI in Spring 2010

- Mohammed Chooka, Director of Licensing, Emirates Nuclear Energy Corporation
    - Ph.D. dissertation title: "Structuring a Probabilistic Model for Reliability Evaluation of Piping Subject to Corrosion Fatigue Degradation"

Current ADNOC Scholars

- Hesham Ismail, Ph.D. student
    - Advisor: Prof. Balachandran
- Husain Al Hashemi, Ph.D. student
    - Advisor: Prof. Radermacher

Faculty Visits and Sabbaticals

Sabbaticals

UMD Professor Mikhail Anisimov from the Department of Chemical Engineering spent his sabbatical at PI for the academic year 2008-9.

PI Advisory Board Meeting

Provost Nariman Farvardin attended the PI Advisory Board meeting December 2009.

PI 2009 Commencement

The following UMD faculty members attended the PI's 2009 commencement:

1. Dr. Azar Nazeri
2. Dr. Yunho Hwang
3. Dr. S.K. Gupta
4. Dr. Greg Jackson
5. Dr. Shapour Azarm
6. Dr. Mohammad Modarres
7. Dr. Avram Bar-Cohen
8. Dr. Serguei Dessiatoun

Visits to PI and ADNOC Companies

- Profs. Shapour Azarm and P.K. Kannan visited PI and ADNOC OpCos, hosted by Prof. Ali Al Mansoori. They visited ADGAS, ADCO, ZADCO, Takreer, and Borouge in August 2009.
- Prof. Radermacher and Dr. Nazeri visited PI, ADGAS and GASCO in May 2009.
- Prof. Balachandran and Dr. Nazeri visited PI and NIC and ADCO in Nov 2009.
- Prof. Bar-Cohen visited Borouge and ADGAS in Jan 2009.
- Prof. A. K. Gupta and Dr. Nazeri visited PI and three operating companies of ADNOC—TAKREER, ADGAS, and GASCO, hosted by Dr. Ahmed Al Shoabi, in May 2010.

EERC Research Presentations to ADNOC and its Operating Companies

PI and UMD collaborators visited the following OpCo's in the past year:

- **ADGAS** (January 2009, May 2009 & August 2009, Ahmad Abbas)
- **GASCO** (May 2009, Abdulla Al Minhali)
- **ADCO** (Nov 2009, Ali Noor Moosavi & August 2009, Dr. Shaheen)
- **ZADCO (**August 2009)
- **Takreer** (August 2009, Fareed Mohamed Al Jaberi, Dr. Haitem Hasan-Beck, Mansoor Mohamed Al-Mehairbi)
- **Borouge** (January 2009, August 2009)
- **NDC** (Nov 2009, Saleh Khalifa)

Visits to UMD

Faculty Visits

- Prof. Cornelis Peters visited UMD March 10-12, 2010 to give a seminar jointly sponsored by the Mechanical Engineering and Chemical and Biomolecular Engineering departments, titled: “Carbon Dioxide, a Nuisance or a Blessing?”
- Dr. Clarence Rodrigues visited UMD March 22-24, 2010 to explore the capabilities of the University of Maryland in the area of Health Safety and Environment and how the EERC can support and help this development at PI.
- Dr. A. Seibi visited UMD in July 2009 and July 2010 to collaborate on research.
- Dr. Nader Vahdati and Dr. Ebrahim Al Hajri visited UMD in January 2011.

Distance Delivery of Courses and Research

Distance Learning Courses

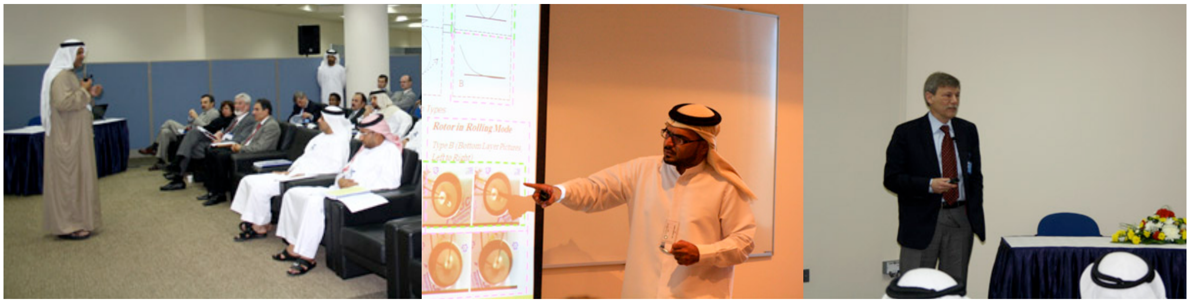
The following courses have been delivered to PI students via distance learning:

- An MTECH Course, Entrepreneurship and Engineering, offered three semesters, co-taught by Dr. Ebrahim Al Hajri at PI.
- Energy Audit (ENME 808D), offered to PI in Fall 2010 and Spring 2011.
- Mechanical engineering courses ENME 635, ENME 712, ENME 690, and ENME 765.

Video or Teleconferences on Projects

- Biweekly conferences by Professors Azarm and Kannan with their counterparts at PI
- Weekly teleconference meetings (via Skype) between PI and UMD by Professors Bar-Cohen and S.K. Gupta and their PI counterparts
- Biweekly videoconferences between Professors Dessiatoun and Shooshtari and their PI counterparts
- Monthly videoconferences between Prof. A.K. Gupta and Prof. Al Shoaibi at PI

PI Annual Research Workshop



The first Annual Research Workshop (ARP) of the PI and its partner universities was conducted in Abu Dhabi, United Arab Emirates on January 6-7, 2010. This workshop was an outgrowth of the two workshops held in 2009 by the Energy Education and Research Collaboration (EERC) of the University of Maryland and Petroleum Institute. More than 28 technical presentations on the collaborative research between PI and partner universities were presented.

University representatives in attendance:

- University of Maryland
- Colorado School of Mines
- University of Minnesota
- Petroleum Institute

Industry representatives in attendance:

- ADCO
- GASCO
- ADGAS
- NDC
- TAKREER
- Borouge
- ZADCO
- Shell
- Conoco-Philips
- Total

University of Maryland attendees:

- Dr. Azar Nazeri
- Dr. Yunho Hwang
- Dr. S.K. Gupta
- Dr. Greg Jackson
- Dr. Shapour Azarm
- Dr. Mohammad Modarres
- Dr. Avram Bar-Cohen
- Dr. Serguei Dessiatoun
- Mr. Ali Alili

New EERC Initiatives

With the encouragement of PI's new Provost, Dr. Ismail Tag, Dr. Nazeri visited PI In October 2010 to consult with senior management and faculty about a more systematic transfer of best practices in administration and education between UMD and PI. The visit resulted in a set of programs called "New Initiatives" that expand EERC activities at PI by engaging PI faculty and students in programs that have been highly successful at UMD. Each initiative has at least one designated sponsor on the PI campus to spearhead the efforts. Many of the initiatives have already begun to be implemented, as detailed in the activities described below.

Transfer of Best Practices

In its efforts to share best practices, UMD has continued to work with PI to streamline the processes that facilitate the collaboration's activities and to help remove obstacles for programs such as the summer internship program, application and admission of graduate students and ADNOC Scholars to UMD, and course delivery to graduate students. PI's EERC coordinator for this effort is Dr. Ebrahim Al Hajri.

To this end, Mr. Amarildo DeMata, the Graduate Study Coordinator of the Mechanical Engineering Department, spent two weeks of the winter break at the Petroleum Institute to exchange experiences between his office and the Office of Graduate Studies at PI. This assignment was part of the collaborative activities between the two institutions to transfer best practices from UMD to PI in research, education and administrative matters.

Women in Engineering Workshop

Dr. Paige Smith, the Director of the Women in Engineering program (WIE) at UMD visited the Arzanah campus March 20-22, 2011 to conduct a three-day workshop. The focus of Dr. Smith's activities was twofold. First, she worked with AUP, WISE and Student Affairs representatives with regard to community outreach and recruiting initiatives. Her first morning session addressed these aspects from a broad perspective. The second session focused more on recruiting students from "minority" backgrounds, which in the PI context is interpreted as Emiratis, as they make up a small portion of the overall population (~15 %) and often have had fewer opportunities to develop their academic skills (they are, however, the majority of the PI's student population). She met with the Recruiting Task Force Committee), presented a workshop on "Planning Strategies for Student Recruitment" (with Recruiting Task Force members), a workshop on "Student Recruitment and Retention" (with WISE students and WISE administration), and a workshop on how to plan, organize and implement summer camps for high school students focused on math, science and English skills (with the AUP Task Force).

Design Workshop



Dr. Linda Schmidt of the University of Maryland visited PI March 20–22, 2011, as part of the Memorandum of Understanding's exchange of best practices. She also consulted with programs and faculty regarding meeting ABET Design Experience requirements, a crucial component of ABET accreditation. Dr. Schmidt was a guest lecturer in several sophomore level design (STEPS) classrooms, where she expanded on current approaches to brainstorming ideas and sketching by facilitating activities with students. During her visit she conducted a series of workshops focused on the following:

- Enhancing and Assessing Design Project Teamwork
- Teaching Sketching
- Scoping Quality Design Projects

She also consulted with programs and faculty regarding meeting ABET Design Experience requirements. Dr. Schmidt was a guest lecturer in several sophomore level design (STEPS) classrooms, where she expanded on current approaches to brainstorming ideas and sketching by facilitating activities with students.

Due to the strong success of this workshop, Dr. Schmidt was asked by PI to spend some time at PI to work closely with PI faculty and students on design classes and projects. Dr. Schmidt has accepted the offer and will be spending Fall of 2011 at PI, working closely with the PI team for the rest of her sabbatical, which will end in the Summer of 2012.

Student Exchange Program

This program allows undergraduate UMD and PI students to study at both campuses for a short period during winter or summer break or for a semester-long stay. Students will take classes and engage in research and other academic and student activities at the host institution. This program offers once in a life-time experience for engineering students at UMD to take courses at PI, interact on a daily basis with people of different cultures, and learn valuable skills for success in college and beyond. After having participated in a study abroad experience, students often return more mature and motivated in their studies and report higher levels of international awareness and intercultural understanding, which are fundamental to fostering peace in our world.

To promote the first study abroad program at the PI this summer, Dr. Sami Ainane, on assignment from UMD to the PI as Director of Student Affairs, visited his home campus on March 18, 2011.

Baja SAE

The University of Maryland participates in the SAE International Student Design Series, in which UMD's SAE chapter (known as Terps Racing) designs, fabricates, and competes a recreational off-road vehicle each year to enhance their engineering education. The Petroleum Institute intends to create a similar student program, and the University of Maryland's Department of Mechanical Engineering plans to transfer the 2007-built vehicle to the PI to foster their new program.

To learn more about UMD's Baja SAE program, its coordinator, Dr. Nader Vahdati, Associate Professor and Associate Chair of the Mechanical Engineering Department at the Petroleum Institute, and Dr. Ebrahim Al Hajri, Assistant Professor at PI, visited the University of Maryland January 25-28, 2011. This visit was aimed at interacting with EERC faculty and students, engaging with faculty conducting research in their respective fields of expertise and becoming familiar with the Society of Automotive Engineering (SAE) Mini-Baja activities at UMD.

Meanwhile, a Baja SAE car from UMD was donated to PI, shown above. This vehicle, which was built by SAE students at UMD and was raced in the tournaments, will be used for educational purposes and to facilitate the construction of another vehicle by PI students.

From April 22-28, a few days following the arrival of the Baja car from UMD, Dr. Greg Schultz and Dr. Nazeri visited PI to kick-start the Baja SAE program. They participated in many meetings with the faculty and staff spearheading the Baja SAE effort at PI. Dr. Schultz gave a PI-wide presentation on the Baja SAE program at PI. He also met with Provost Tag and Dean Aldelmajid.

Individual Project Reports

Thrust 1
Energy Recovery and Conversion

Sulfur Recovery from Gas Stream Using Flameless and Flame Combustion Reactor

UMD Investigators: Ashwani K. Gupta
GRAs: Hatem Selim
PI Investigators: Ahmed Al Shoaibi
Student: Nahla Al-Amoodi
Start Date: October 2006

Objectives

The main objective of this project is to obtain fundamental information on the thermal process of sulfur recovery from sour gas by conventional flame combustion as well as flameless combustion, using numerical and experimental studies. Our ultimate goal is to determine optimal operating conditions for enhanced sulfur conversion. Therefore, an experimental study of the flameless combustion processes of the Claus furnace have been proposed, and the results have been compared with the normal flame process in order to determine the improved performance. In this study we are exploring different operating conditions and performing exhaust gas analyses of both flame and flameless modes of reactor operation in order to attain enhanced sulfur recovery.

Specific objectives are to provide:

- A comprehensive literature review of the existing flame combustion process for sulfur removal with special reference to sulfur chemistry
- Near isothermal reactor conditions and how such conditions assist in the enhanced sulfur recovery process
- CFD simulation of the flame and flameless combustion in the furnace.
- Determination of the chemical kinetics and the major reaction pathways that result in high performance
- Design of a flameless combustion furnace for experimental verification of the numerical results
- Measurements and characterization of the flameless combustion furnace using high-temperature air combustion principles, including the conditions of flameless combustion
- Experiments with different sulfur content gas streams using the flame and flameless combustion furnace modes of operation
- Installation of the appropriate diagnostics for quantification of stable and intermediate sulfur compounds in the process
- Flow and thermal field characteristics in the reactor
- Product gas stream characteristics and evaluation of sulfur recovery and performance in the process

Progress

- Continued to investigate mixing characteristics of the reactants in Claus process, including flow pattern and mixing length.
- Continued validation efforts of the reduced mechanism to enhance its credibility.

- Examined the mixing characteristics and degree of mixing in the flow field of a non-reactive flow field.
- Examined for further reduction the H_2S/O_2 reaction mechanism with the 24-reduced mechanism we developed in a previous report.
- Performed equilibrium analysis for the Claus reactor and detailed kinetic analysis for the H_2S/O_2 reaction mechanism.
- Investigated different mixing geometries to achieve the best mixing conditions for the reactants and hot combustion products.
- Reduced further the detailed mechanism developed by Leeds University using our novel DERE approach. The DERE approach reduced the 24-reaction mechanism to 19 elementary reactions.
- Tested the behavior of the major and minor species to further test the reduced mechanism.
- Conducted examination on the effect of contaminants that accompany hydrogen sulfide on the recovery of sulfur in adiabatic Claus furnace. Results show that both carbon dioxide and water maintain sulfur dioxide in the reactor, the former producing it while the latter preventing its dissociation; however, the effect of each contaminant takes place at a different stage of the reactor.
- Conducted non-reactive simulations to investigate the mixing characteristics of hydrogen sulfide and hot products (produced of CH_4/O_2 reaction). Five mixing configurations were examined where CH_4/O_2 products of combustions were assumed to be only H_2O and CO_2.
- Conducted reactive CFD simulations to examine the diffusion effect on the H_2S/O_2 reaction. The simulations were primarily used for simulating perfectly mixed H_2S/O_2 mixture with different equivalence ratios using Fluent software and comparing it with our Chemkin simulations. The results revealed very good agreement between the Chemkin and Fluent simulations.
- Examined diffusion effect using counter-flow flame of H_2S/O_2. The results highlighted the presence of different localized reaction spots where the reaction has different directions corresponding to the mixture at each spot. On the other hand, the results revealed that hydrogen sulfide dissociates significantly inside the injector into hydrogen and sulfur.
- Conducted an experimental examination for configuration 4, presented in the nonreactive mixing investigation, to identify the mixing uniformity using two different sets of reactant flow rates. The results showed promising mixing uniform characteristics where the change of oxygen mole fraction throughout the mixing chamber axial distance did not exceed 13% of the asymptotic value of oxygen mole fraction.
- Fabricated experimental setup for hydrogen sulfide experiments with optical access for in-situ non-intrusive examination. Setup meets safety requirements for UMD environmental safety department.
- Investigated the effect of H_2S/O_2 equivalence ratio on combustion products. A methane/air mixture was used, under slightly lean conditions, as a heat source into which hydrogen sulfide was injected with different concentrations to obtain the desired equivalence ratio. A gas chromatograph equipped with TDC and FPD was used for combustion products ultimate gas analysis.
- Identified excited sulfuric compounds emissions (SO_2 and S_2) and hydrocarbons radicals (OH, CH, and C_2) non-intrusively using an Acton 300i spectrometer coupled with ICCD-576-S/RB-G camera. Different spectrometer gratings were used according to the required spectral resolution.
- Further investigated the inner blue cone formed in H_2/O_2 flame upon the injection of trace amount of hydrogen sulfide.
- Investigated spectra H_2S/O_2 flame under lean conditions. The spectra showed strong absorption bands of SO_2 within 280-310nm.
- Examined H_2S/air flame chemical speciation under Claus conditions along the reactor axis at two different radial locations. A lower variation in combustion products was observed at R=0.5in compared to results at R=0.5in.
- Analyzed sulfur deposits formed at cold regions of the reactor and inside the sampling line using an x-ray powder diffractometer. These results revealed that the deposits are cyclo-S_8

(α-sulfur) with orthorhombic crystal structure. The formation of α-sulfur is mainly due to the agglomeration of elemental sulfur (S_2) at low temperatures.

- Examined hydrogen sulfide combustion in methane/air flame in a plug flow reactor at different equivalence ratios.
- Prepared laser-induced breakdown spectroscopy (LIBS) setup for sulfur deposit analysis as well as larger sulfur samples to be used in the analysis.
- Submitted two technical papers to The Journal of Applied Energy. Meanwhile, a rebuttal of a previously submitted journal paper, in 2009, was prepared. All three papers were accepted for publication.

Separate Sensible and Latent Cooling with Solar Energy

UMD Investigators: Reinhard Radermacher, Yunho Hwang
GRA: Ali Al-Alili
PI Investigator: Isoroku Kubo
Start Date: August 2007

Objectives

The main objective of this project is to design, fabricate and test a solar cooling system with the highest possible cooling COP measured to date. The approach involves combining a very efficient concentrating PV-T collector with a separate sensible and latent cooling approach developed at CEEE. This solar cooling system is expected to operate under the UAE's harsh climate conditions.

Progress

- Finalized solar sub-system.
- Finalized cooling sub-system based on Abu Dhabi design conditions.
- Completed model of the solar cooling system in TRNSYS.
- Performed parametric study of the solar cooling system in TRNSYS.
- Investigated the performance of sensible vapor compression cycle using the EES.
- Investigated the hybrid solar system performance under Abu Dhabi's climate conditions.
- Explored the optimization capability of MATLAB.
- Coupled the TRNSYS with MATLAB.
- Demonstrated differences between the various optimization approaches used.
- Completed detailed design of the experimental setup.
- Estimated the cost of the experimental setup and found component suppliers.
- Ordered main components of equipment and instruments. The data acquisition system has been received, allowing us to calibrate the instruments.
- Started building the experiment.
- Modeled the evaporator using CoilDesigner, which was also used to find the pressure drops in the refrigerant- and air-sides. The main purpose of this simulation is to ensure that under the current test conditions, no condensation will occur at the evaporator.
- Finalized solar sub-system.
- Finalized cooling sub-system based on Abu Dhabi design conditions.
- Completed model of the solar cooling system in TRNSYS.
- Performed parametric study of the solar cooling system in TRNSYS.
- Finished construction of the duct and installation of the fans.
- Calibrated the refrigerant and the water mass flow meters.
- Finished the hot water loop.
- Connected the instrumentation to the data acquisition system.
- Created a LabView program for the experiment.
- Wired the experimental power supply side and installed it in the power cabinet.
- Created a Labview interface to record the experimental measurements.
- Finished the aluminum frame construction.
- Finished the supply, exhaust and conditioned space ducts.
- Finished construction of the ducts.
- Installed the equipment into the ducts.
- Finished installation of fans.

- Prepared insulation boards for the ducts.
- Calibrated the refrigerant and the water mass flow meters.
- Finished the hot water loop.
- Connected the instrumentation to the data acquisition system.
- Created a LabView program for the experiment.
- Wired the experimental power supply side and installed it in the power cabinet.

Waste Heat Utilization in the Petroleum Industry

UMD Investigators: Reinhard Radermacher, Yunho Hwang
GRAs: Amir Mortazavi, Abdullah Alabdulkarem
PI Investigators: Saleh Al Hashimi, Peter Rodgers
Start Date: January 2009

Objectives

The main objective of this project is to minimize overall energy consumption of gas or oil processing plants by utilizing waste heat and/or improving cycle design. Consideration includes use of absorption chillers and steam cycles, among other options.

Progress

- Modeled the following in ASPEN:
    - GE MS 9001 gas turbine
    - Integration of gas turbines that drive an APCI LNG plant
    - Different waste heat utilization strategies using absorption chillers in gas turbine-driven APCI LNG plant
    - Further enhancements on the absorption chiller models:
        - Seawater heat exchangers for cooling the absorption chillers
        - Introducing pressure drop on the heat exchangers
- Modeled the following in HYSYS:
    - APCI base cycle
    - APCI enhanced with absorption chillers
    - Gas turbine
    - Different gas turbine combined cycle configurations (double pressure, triple pressure with and without reheat)
- Modeled a simplified mixed refrigerant (MCR) cycle using HYSYS.
- Modeled a single pressure combined cycle using HYSYS.
- Optimized a single pressure combined cycle using Matlab-HYSYS code.
- Optimized an MCR cycle using Matlab-HYSYS code.
- Modeled the following in HYSYS:
    - CO_2 liquefaction and compression
    - APCI cycle optimization
    - Optimization of different gas-turbine triple-combined cycle configurations
- Prepared paper for ADIPEC 2010 conference
- Performed GASCO ASAB waste-heat energy audit
- Validated cascade CO_2 liquefaction cycle model
- Investigated the savings from cold CO_2 energy recovery in the APCI LNG plant and the CO_2 liquefaction cycle
- Compared this work optimized MCR refrigerant mixture versus optimized MCR refrigerant mixture in literature
- Optimized of all the configurations of gas turbine triple combined cycle with single pressure steam cycle configurations.
- Modeled the open CO_2 liquefaction cycle.
- Verified the CO_2 liquefaction cycle model with EES.
- Modeled heat pump cycle with different refrigerants.
- Optimized two configurations of gas turbine combined cycle with double-pressure steam cycle.
- Optimized two configurations of gas turbine triple combined cycle with double-pressure steam cycle and absorption chillers.

Thrust 2
Energy-Efficient Transport Processes

Multidisciplinary Design and Characterization of Polymer Composite Seawater Heat Exchanger Module Reactor

PI Investigator: Peter Rodgers
UMD Investigators: Hugh Bruck, Satyandra K. Gupta, David Bigio, Avram Bar-Cohen
GRAs: Juan Cevallos, F. Robinson, T. Hall, W. Pappas, M. Chowdhury
Start Date: January 2009

Objectives

Heat exchangers are extensively used in all oil and gas processing operations with seawater as the preferred coolant in near-shore operations. The performance and cost effectiveness of conventional metallic heat exchangers in such environments are severely constrained by corrosion and scale deposits. Polymer heat exchangers, currently under investigation by the EERC team, offer a promising alternative to metallic heat exchangers for the fossil fuel industry. Recent advances in carbon-fiber polymer composites, yielding polymer materials with thermal conductivities equal to or higher than titanium, can be applied to the development of low-cost and low-weight, compact heat exchangers for corrosive fluids. These attributes, combined with the low energy investment in the formation and fabrication of these polymer heat exchangers and their ease of manufacturing, appear to make near-term applications of seawater polymer heat exchangers viable. Numerical simulations and laboratory experiments, performed by the UMD/PI EERC team in the first phase of this research, strongly support these conclusions.

Progress

- Identified current models for prediction of fiber orientation in molded composites.
- Utilized fiber orientation predictions to predict thermal conductivity of a finned geometry.
- Investigated the effects of utilizing anisotropic thermal conductivity values in the heat transfer rate through a fin.
- Developed first-order metamodels for mold-filling predictions using 1-gate and 2-gate injection molding simulations.
- Integrated the metamodel in the design process of a modular heat exchanger.
- Investigated the mechanical and surface effects of immersing polymer composites in fresh and salt water.
- Patrick Luckow successfully defended his MS thesis, "Minimum Energy Design of Seawater Heat Exchangers."
- Continued investigation on the mechanical and surface effects of immersing polymer composites in fresh and saltwater composites in fresh and saltwater.
- Began investigation on effect of varying injection molding and material conditions on fiber orientation.
- Characterized the suitability of injection molding for creating thermally enhanced polymer heat exchangers.
- Began training on use of equipment for creating and using molds to validate results from Moldflow analysis.
- Integrated the mold-filling meta-model in the design process of a modular heat exchanger.
- Investigated parametrically the use of an effective isotropic thermal conductivity for fins with local anisotropy.
- Commissioned ENGEL Victory Tech 200/70 injection-molding machine at PI.
- Hygrothermally aged specimens in 25°C freshwater and saltwater to complete characterization of moisture absorption and subsequent changes in mechanical

properties to differentiate between the effects of moisture diffusion and aging temperature.

- Developed ANSYS model using hygrothermally aged mechanical properties to determine whether the mechanical response of polymer composite heat exchangers under typical LNG loading conditions will be feasible for replacing metallic heat exchangers at the Das Island liquefied natural gas facility.
- Refined Moldflow® models to develop a better understanding of how varying the injection molding process parameters affects mold filling and fiber orientation.
- Created injection molds to begin Moldflow® validation using experimental testing.
- Improved the mold filling meta-model to reduce false negatives and account for different mold filling failure modes.
- Upgraded experimental PHX test rig currently at UMD.
- Mr. Juan Cevallos successfully completed the PhD qualifying exam at UMD.
- Submitted abstract to the IHTC14 conference.
- Designed and machined injection molds for the selected spiral and L-channel geometries.
- Created injection-molded test samples at fixed system parameters and materials.
- Applied image processing methods to determine fiber orientation in experimental specimens and compared to Moldflow predictions.
- Installed upgraded experimental rig for testing polymer heat exchangers. It can accommodate a larger laboratory heat exchanger with an increased heat transfer rate, which will also increase the temperature differences across the heat exchanger, thereby reducing the relative uncertainty caused by the thermocouple measurements (~5%).
- Constructed a new test apparatus for hygrogthermal aging conditions under load to complement the previous hygrothermal aging studies without load.
- Designed and constructed injection mold for producing specimens complying with ASTM international guidelines that are compatible with clevises of aging apparatus.
- Hygrothermally aged carbon-filled nylon testing specimens under tensile load at 60ºC in an aqueous solution with a salinity of 45g/kg.
- Tensile tested carbon-filled nylon specimens that were stressed during aging to determine mechanical properties.
- Developed a finite element analysis (FEA) model using hygrothermally aged mechanical properties to assess feasibility of replacing metallic heat exchangers at the Das Island liquefied natural gas facility with polymer composite heat exchangers.
- Modified heat exchanger geometry to reduce stresses experienced by polymer composite heat exchanger. The additional water-side fin significantly reduced stresses and strains in the module.
- Assessed feasibility of modeling orthotropic heat exchanger module as an isotropic model with averaged properties. The substantial variation between the isotropic and orthotropic models may be an indication that a full anisotropic model should be developed to determine if the orthotropic model replicates the anisotropic model.
- Investigated the effective thermal conductivity of a PA12-carbon fiber composite used in an injection-molded prototype heat exchanger.
- Developed a technique for characterizing mixing of polymer composites in a twin screw extruder.
- Developed a discretized, mapped-meshed finite element model using hygrothermally aged mechanical properties to assess feasibility of replacing metallic heat exchangers at the Das Island liquefied natural gas facility with polymer composite heat exchangers. Several of the mapped meshes studied had lower sum of squares errors and shorter runtimes relative to the previously accepted free mesh. The final, optimized mesh had 183,500 elements, which was 64% fewer than the initial brick mesh. The reduction in elements significantly reduced computation time.
- Assessed feasibility of modeling orthotropic heat exchanger module as an isotropic model with averaged properties. The results indicate that, over the range of isotropic

properties studied, the stress distributions of isotropic models do not replicate the stress distributions of an orthotropic property. As such, the orthotropic model cannot be simplified to an isotropic material with averaged properties.

- Refined model simplification guidelines and techniques for mold filling metamodel of Plate-Fin polymer heat exchangers.
- Developed new data point selection methodology for improving the accuracy of the mold-filling statistical metamodel. The recommended techniques ensure that any computationally expensive expansions to the dataset are utilized to search the areas of the statistical metamodel that are the sources of most accuracy error.
- Revisited thermal anisotropy of polymer composite fins induced by fiber orientation.
- Developed and used thermomechanical finite element model to assess thermal and structural performance of polymer composite heat exchanger, and assessed feasibility of replacing metallic heat exchangers at the Das Island liquefied natural gas facility with polymer composite heat exchangers.
- Developed accurate mold-filling metamodel using advanced datapoint selection methodology.
- Developed new image processing methodology for identifying fibers in microscope images of sample heat exchanger geometry.
- Developed a technique for characterizing mixing of polymer composites in a Twin Screw Extruder.
- Submitted abstract and draft paper entitled “An Integrated Approach to Design of Enhanced Polymer Heat Exchangers” to DETC Conference to be held on August 29-31 2011 in Washington, DC.
- Submitted abstract entitled “Polymer Heat Exchangers – An Enabling Technology for Water and Energy Savings” to IMECE Conference to be held on November 11-17 2011 in Denver, Colorado.
- Submitted abstract for a technical paper entitled “Modeling and Validation of Prototype Thermally Enhanced Polymer Heat Exchanger” to the 2011 International Mechanical Engineering Congress & Exposition in Denver, Colorado. Paper has been accepted.

Study on Microchannel-Based Absorber/Stripper and Electrostatic Precipitators for CO_2 Separation from Flue Gas

UMD Investigators: Serguei Dessiatoun, Amir Shooshtari, Michael Ohadi,
GRAs: Mohamed Alshehhi
PI Investigators: Afshin Goharzadeh
Start Date: Oct 2006

Objectives

The main objective of this project is to minimize overall energy consumption of gas or oil processing plants with CO_2 capture and sequestration by utilizing waste heat and/or improving cycle design. Consideration will include the use of absorption chillers and steam cycles, among other options. This project is focused on research leading to the development of a high-efficiency CO_2 separation mechanism with application to a diverse range of processes in the oil and gas industry, including CO_2 separation separation/injection in petrochemical and refining processes, gas sweetening, and CO_2 capture for enhanced oil recovery applications. The removal of acidic gases such as carbon dioxide from gas streams is an important process in the natural gas industry. In gas sweetening at least 4% by volume of raw natural gas consists of CO_2 which needs to be lowered to 2% to prevent pipeline corrosion, to avoid excess energy for transport, and to increase heating value. The separation of CO_2 from flue gases and its use for enhanced oil recovery and CO_2 sequestration applications is an increasing area of importance, as evidenced by the large investments in this area by ADNOC and its group companies, as well as affiliated government agencies in Abu Dhabi. A typical CO_2 separation process involves three stages: cooling down the flue gas; separating the solid particles and condensed water droplets; and finally capturing the CO_2 using the absorption process. The microchannel-based CO_2 separator being developed in this project will significantly increase controllability of the thermal state of the reaction and the efficiency of the separation process while decreasing the reaction time and energy consumption, as well as potential substantial reduction of equipment footprint and the associated capital investment.

Flue gas also usually contains many contaminants in solid and liquid forms, the bulk of which are separated in gravity and inertia-driven feed gas separators. However, fine particles are carried on with the flow and can damage compressors, contaminate the gas absorption process, and reduce the quality of gas products. Electrostatic separation is one of the most effective techniques for separation of such particles and will be used in this project. The present project addresses separation of droplets and particles using an EHD gas-liquid separation technique to remove liquid particles suspended in a moving gaseous medium, followed by the proposed microchannel-based separation of the CO_2 from the stream once the fine particles in the flow have been removed.

The project is being conducted jointly by the team at UMD and at PI. The team at PI is focusing on EHD separation process and absorption modeling, while the team at UMD has focused on the experimental work utilizing microchannel-based CO_2 separation and the absorption solution.

Progress

- Continued to improve efficiency of the EHD separator for fine liquid and solid particles.
- Performed visualization study of liquid and solid particle migration in the electrical field.
- Finished building the test setup.
- Tested the separator performance.
- Fabricated wire-tube electrostatic separator.

- Studied the generation and extraction of water droplets.
- Conducted parametric study on the applied voltage, emitter polarity, and air velocity effects.
- Fabricated wire-tube electrostatic separator.
- Studied the generation and extraction of water droplets.
- Conducted parametric study on the applied voltage, emitter polarity, and air velocity effects.
- Performed literature review on separation techniques and the kinetics between CO_2 and alkanolamines in aqueous solutions, and investigated their reaction rate.
- Identified the alkanolamine suitable for experimental study.
- Designed test section and experimental setup.
- Performed flow visualization of the EHD induced flow.
- Identified target alkanolamine suitable for experimental study.
- Designed and fabricated laboratory-scale microchannel-based CO_2 separator.
- Performed experimental study on the absorption in microchannels.
- Developed a numerical/analytical model to enhance understanding of the process.
- Improved experimental setup to eliminate gas bubbles traveling between electrodes; upgraded instrumentation on experimental setup.
- Performed experimental study of absorption of CO_2 in a single microchannel reactor. Results showed a nonlinear trend between the electrical conductivity and the amount of CO_2 absorbed by the amine solution.
- Collected new set of data for lower supply flow rate of DEA solution (i.e. 10 ml/min) into the microchannel. The results showed slightly better absorption performance compared to the results obtained for a twice higher flow rate of DEA solution.
- Improved experimental setup.
- Collected new set of data.
- Improved model.
- Conducted experimental study of absorption of CO_2 in a single microchannel reactor.

Microreactors for Oil and Gas Processes Using Microchannel Technologies

UMD Investigators: Serguei Dessiatoun, Amir Shooshtari, Michael Ohadi, Kyu Young Choi
GRA: Pradeep Kumar Singh
PI Investigators: Afshin Goharzadeh, Ebrahim Al-Hajri
Start Date: April 2009

Objectives

Microfabrication techniques are increasingly used in gas and petrochemical engineering to realize structures with capabilities exceeding those of conventional macroscopic systems. In addition to already-demonstrated chemical analysis applications, microfabricated chemical systems are expected to have a number of advantages for chemical synthesis, chemical kinetics studies, and process development. Chemical processing advantages from increased heat and mass transfer in small dimensions are demonstrated with model gas, liquid and multiphase reaction systems. The objective of this project is to design and fabricate a microreactor capable of realization of selected polymerization processes.

Progress

- Performed literature survey.
- Identified target reaction.
- Conducted literature survey to determine reactions suitable for the petrochemical industry.
- Selected reactions most beneficial for ADNOC to be designed in microreactors.
- Identified the target reaction as polyethylene and polypropylene production
- Selected the target polymerization process of economical significance to the Abu Dhabi
- polymer industry.
- Selected the type and size of catalyst particles to be used in the process as 1-2 μm.
- Began the design and fabrication of a microreactor capable of selected polymerization processes.
- Began visualization study of mixing in microchannels.
- Designed tubular polymerization microreactor
- Initiated study of ethylene absorption in the diluent
- Designed tubular polymerization microreactor.
- Conducted detailed theoretical modeling of polymerization in microreactor

Thrust 3
Energy System Management

Integration of Engineering and Business Decisions for Robust Optimization of Petrochemical Systems

UMD Investigators: Shapour Azarm, P.K. Kannan
PI Investigators: Ali Almansoori, Saleh Al Hashimi
UMD GRA: Weiwei Hu
PI GRA: Naveen Al Qasas
Start Date: Oct 2006

Objectives

The overall objective of this project is to develop a framework for integrating engineering and business decisions. Towards that objective, a robust decision support system is being developed that can be used for multi-objective and multi-disciplinary optimization under uncertainty of oil, gas and petrochemical systems. We proposed to extend AAMORO to a multi-objective multi-disciplinary system. The proposed approach is based on a Multiobjective collaborative Robust Optimization (McRO) and it is called Approximation Assisted McRO (AA-McRO). AA-McRO can be used to optimize the integrated business and engineering decisions in a decomposed fashion. The proposed AA-McRO allows, for example, the petrochemical decision makers in each subsystem to optimize their decision variables and a system level optimizer to coordinate between subsystem optimal decisions. A significant advantage of the proposed AA-McRO approach is that it requires considerably less function calls than a previous McRO approach. Finally, our work on dashboard development is continuing, and we have reported some results on the role of dashboard in coordinating the decisions from different disciplines, e.g., in a chemical process plant, in fulfilling an integrated business engineering decision approach using the proposed AA-MORO approach.

Progress

- Conducted a preliminary investigation on combining business and engineering decisions based on a simple refinery case study model.
- Incorporated the previously developed reactor-distillation model into the business integration framework.
- Applied an efficient Multi-Objective Robust Optimization (MORO) technique to solve the reactor-distillation optimization problem in the engineering model.
- Defined and investigated a stochastic supply chain management problem for a refinery system using an agent-based simulation software Netlogo™.
- Selected and implemented an initial set of key performance indicator candidates in the model.
- Proposed the Multi-objective Collaborative Robust Optimization (McRO) technique as an optimization solver for integrating business and engineering decisions.
- Prepared four papers based on the collaboration
- Continued the focus on integrating business and engineering decisions in the context of oil, gas and petrochemical systems.
- Applied a collaborative optimization technique to decompose business and engineering problems and obtain optimal decisions for a simple case study model.
- Studied the optimal decisions from the case study that provide insights into both business
- and engineering problems.
- Began research on the decision support role of dashboards for the management in the
- integration framework and developed a preliminary dashboard using Matlab Graphical User Interface (GUI).

- Extended the previous deterministic integration framework for business and engineering decisions to non-deterministic multi-objective cases applicable to oil, gas and petrochemical systems.
- Proposed an Approximation Assisted multi-objective Robust Optimization (AARO) technique, which is a significant improvement over a previous multi-objective robust optimization technique and reduces the total number of function calls required for obtaining robust optimal decisions for petrochemical systems.
- Continued research on the dashboard for the management in the integration framework, which has enhanced functions and controllability over a previous version.
- Began work on an oil refinery CO_2 emission optimization/reduction project (collaboration with TAKREER), in which we completed a preliminary literature review with focus on energy intensive processes in the oil refinery industry; identified a set of possible operating variables for CO_2 emission reduction; and provided to TAKREER a definition of the problem. TAKREER is expected to provide some data based on which an analysis model will be built and our methods and models will be demonstrated.
- Proposed an Approximation Assisted Multi-objective collaborative Robust Optimization (AA-McRO) approach for the integration framework.
- Remodeled the reactor-distillation process using process engineering simulation software: Aspen HYSYS:
- Established a computerized connection between Aspen HYSYS and Matlab programs:
- Reformulated the integrated business and engineering decision-making problem and obtained optimized decisions
- Continued developing the Approximation Assisted Multi-objective collaborative Robust Optimization (AA-McRO) approach. Based on the AA-McRO approach, a paper is being prepared and will be submitted to 2010 AIAA/ISSMO MA&O conference. An extended abstract of this paper was recently accepted for this conference
- Conducted preliminary research on extending our recently developed optimization technique to consider both irreducible and reducible interval uncertainties.
- Proposed a simulation model using an agent-based approach for modeling multiple competing petrochemical firms in a market system.
- Improved an engineering simulation model of a reactor-distillation process using Aspen HYSYS.
- Developed and under implementation is a new Kriging meta-model assisted optimization approach for Multi-Objective Robust Optimization (MORO) with both reducible and irreducible interval uncertainty.
- Proposed a decision support model with a dashboard-like interface for a notional refinery problem that can be used for adjusting/predicting critical parameters in a simulation model.
- Revised/implementing the HYSYS simulation model of an o-xylene oxidation process for producing phthalic anhydridex.
- Continued progress on joint publications.

Dynamics and Control of Drill Strings

UMD Investigator: Balakumar Balachandran
PI Investigators: Hamad Karki and Youssef Abdelmagid, Sai Cheong Fok
GRA: Chien-Min Liao (started in Spring 2007)
Start Date: Oct 2006

Objectives

Drill-string dynamics need to be better understood to understand drill-string failures, control drillstring motions, and steer them to their appropriate locations in oil wells. Although a considerable amount of work has been carried out on understanding drill-string vibrations (for example, Leine and van Campen, 2002; Melakhessou *et al*., 2003; Spanos *et al*., 2003; Liao *et al*., 2009), the nonlinear dynamics of this system are only partially understood given that the drill string can undergo axial, torsional, and lateral vibrations, and operational difficulties include sticking, buckling, and fatiguing of strings. In addition, the prior models focus on either bending or torsional or axial motions. Hence, it is important to consider coupled axial-bending-torsional vibrations and contact instability in oil and gas well drilling. A better understanding of these vibrations can help keep the drill string close to the center of the borehole and help realize nearcircular bores during drilling operations.

The overall goal of the proposed research is to understand the nonlinear dynamics of the drill string and develop a control-theoretic framework for its stabilization enabling energy efficient drilling with longer life span for the equipment. Specific research objectives of this project are the following: i) build on Phase I efforts, develop and study control-oriented models for the drill strings through analytical and numerical means, ii) investigate the control of an under-actuated nonlinear system (drill string) with complex interactions with the environment, and iii) use the drillstring test-beds constructed at the Petroleum Institute & the University of Maryland to validate the analytical findings and suggest possible strategies to mitigate drill-string failures in fixed and floating platform environments.

Progress

- Constructed a new reduced-order model formulation, referred to as the Hamiltonian formulation, and obtained preliminary results.
- Initiated horizontal drilling efforts.
- Conducted experiments to examine the system behavior and compare it with predictions obtained through the Hamiltonian formulation.
- Collaborated with Professor S.P. Singh on fundamental studies on the stick-slip interactions and reduced-order models.
- Carried out the system identification of the experimental arrangement at both UM and PI. The experimental results agreed with those determined through simulations with the reduced-order model.
- Studied stick-slip interactions with rotational friction through collaborations with Professor S. P. Singh from the Indian Institute of Technology, Delhi, India.
- Compared results obtained for rotor motion trajectories from experiments with those obtained through numerical integrations of the reduced-order model.
- Focused on torsion vibration of the drill string and studied the effects of mass imbalance for different rotation speeds. It was shown that the current model captures the different

features of the contact and non-contact dynamics better than those reported in the literature.

- Carried out experimental and numerical parametric investigations to gain greater understanding of drill-string dynamics. Experimental results were in good agreement with numerical model.
- Compared UMD's experimental data with data collected from field experiments. Both laboratory and field results captured similar bumping, rolling and sliding motions.
- Conducted parametric studies of a drill-string system. The rotor exhibits regular orbital motions at low driving speeds but this behavior becomes irregular with increase of the drive speed in a moderate speed range. For higher speeds, the rotor is seen to return regular orbital motions before it reverts back to irregular motions at the highest end of speeds used in the present studies.
- Examined motions and trajectories of the rotor through experimental and numerical investigations with a reduced-order model. The initial rotor position is an important determinant of the rotor motions, due to the contact between the rotor and the outer shell.
- Identified rotor movements and characteristic behaviors.
- Developed a distributed-parameter model that may be useful for describing horizontal drill string dynamics.
- Compared model to experimental data from the vertical string experiment.

Studies on Mobile Sensor Platforms

UMD Investigators: Balakumar Balachandran, Nikil Chopra
GRAs: Rubyca Jaai
PI Investigator: Hamad Karki, Sai Cheong Fok
GRAs: Hesham Ishmail (ADNOC Fellow)
Start Date: April 2009

Objectives

Mobile sensor platforms can be employed in a variety of operations including environmental and structural health monitoring operations in harsh and remote environments. In the proposed work, cooperating sensor platforms are to be studied for potential use in oil storage tanks, which are periodically tested for corrosion, cracks, and leaks. These platforms are envisioned for estimating geometrical profile parameters, such as the tank bottom thickness. To this end, simultaneous localization and mapping (SLAM) algorithms (also known in the literature as concurrent mapping and localization (CML) algorithms) for cooperating sensor platforms operating in harsh environments are being investigated. While many solutions have been suggested for the single-agent SLAM problem, multi-agent SLAM is still a difficult problem from an analytical and practical perspective.

The use of multiple agents allows for greater and faster coverage in the exploration and searching tasks and provides a certain degree of redundancy in the completion of tasks. Additionally, map merging using overlapping information from different agents can possibly compensate for sensor uncertainty (Dudek *et al*., 1996).

The overall objective of this project is to carry out a combined analytical, numerical, and experimental effort to develop mobile sensor platforms and appropriate simultaneous localization and mapping (SLAM) algorithms for cooperative sensor platforms to operate in a harsh environment. Research objectives are the following: i) develop SLAM algorithm-based platforms taking into account system constraints such as constrained communication, the type of sensors considered, allowable dynamics, and factors such as sensor failures and reliability of the considered sensors and ii) carry out experimental and supporting simulation studies by using mobile platform test platforms at the University of Maryland and the Petroleum Institute.

Progress

- Collected data on oil tanks and other appropriate information from the industries working with PI
- Carried out numerical simulations.
- Visited industry to get a better understanding of the inspection system, the ultrasonic and magnetic flux sensors used as a part of the inspection system, the harshness of the environment, and the complexity of the system.
- Carried out numerical simulations to examine the EKF SLAM algorithm, which showed that with this particular algorithm, increasing noise leads to increased uncertainty in the system response.
- Studied the algorithm FASTSLAM, which showed that kinematic noise plays a dominant role in influencing the estimation process.
- Studied localization of a static source by using a mobile sensor platform.
- Examined noise robustness of a previously proposed localization algorithm. Using

Lyapunov analysis, it was found that if noise uncertainty is constant and bounded, the adaptive localization algorithm results in bounded localization errors.

- Used adaptive control techniques to make certain that the mobile agents track the desired trajectory and drive the tracking error to zero. Simulation results are also presented for two agents.
- Carried out preliminary experimental work to build a mobile agent that is to be used to verify algorithms.
- Performed numerical simulations to gain fundamental insights. These simulations complement the source localization work reported previously.
- Acquired ground-based mobile agents to perform experimental measurements. The ground-based agent houses a microcontroller, two encoders, infrared sensors and a laser sensor.
- Ran EKF SLAM algorithm and obtained results
- Constructed experimental setup to test SLAM algorithms
- Completed analytical and numerical results obtained for the decentralized SLAM algorithm results presented in the previous report.
- Completed experimental setup.

Development of a Probabilistic Model for Degradation Effects of Corrosion-Fatigue Cracking in Oil and Gas Pipelines

UMD Investigator: Mohammad Modarres
PI Investigators: Abdennour Seibi
GRA: Mohammad Nuhi
Start Date: Oct 2006

Objectives

This research continues Phase I mechanistic modeling of the corrosion-fatigue phenomenon for applications to pipeline health, risk and reliability management. The objective of this study is to perform additional mechanistic-based probabilistic models derived from physics of failure studies and validate them using the state-of-the-art experimental laboratory being developed at the PI as part of the phase I of this study. Where possible, observed field data from ADNOC operating facilities are used to supplement observations from the laboratory experiments based on the well-established Bayesian approach to mechanistic model updating and validation developed in Phase I. Uncertainties about the structure of the mechanistic models as well as their parameters are characterized and accounted for when such models are applied. The proposed models will allow the end users (e.g., maintenance analysts and Inspection crew) to integrate observed performance data from a wide range of pipelines and selected refinery equipment, such as pumps, compressors and motor-operated valves. Admitting the fact that modeling all degradation mechanisms would be a challenging undertaking, the proposed research will additionally address the following degradation phenomena related to the petroleum industry: creep, pitting corrosion, and stress cracking corrosion (SCC).

Progress

- Received and installed the Cortest corrosion-fatigue testing equipment.
- Estimated chloride concentration in seawater.
- Estimated corrosion current of X70 carbon steel in seawater and a solution of seawater plus 500ppm H_2S concentration, and compared the results with tap water plus 250 ppm H_2S in a cyclic votammetry experiment.
- Continued corrosion fatigue test of an X70 specimen.
- Performed corrosion experiments to estimate the distribution of pit depth and pit spatial density for different chloride and H_2S concentrations.
- Repeated the pitting corrosion test with more specimens and additional varieties of chemical densities.
- Developed a preliminary list of physics of failure for pitting corrosion, stress-cracking corrosion (SCC), and creep-fatigue.
- Assessed and justified model developed by Dr. M. Chookah.
- Verified programs written in MATLAB.
- Ran WinBugs and Weibull analyses again to supplement data and further justify results.
- Conducted pitting corrosion experiments in a small-scale corrosion-fatigue chamber.
- Gathered information about requirements for a heating chamber.
- Used Cortest rig to further verify and reduce epistemic uncertainties associated with the corrosion-fatigue model.
- Prepared article manuscript, “A probabilistic physics of failure model for prognostic health monitoring of piping subject to pitting and corrosion fatigue,” to be sent to the *Journal of Reliability Engineering and System Safety*.
- Continued work on literature surveys of creep degradation mechanism and stress corrosion-cracking mechanism.

- Designed, fabricated and tested a small-scale corrosion-fatigue chamber for dog-bone specimens.
- Designed, fabricated and tested a complicated test chamber for CT specimens.
- Designed, fabricated and tested an in-house laboratory chamber for the creep experiment.
- Performed literature review on creep deformation model
- Developed mechanistic model for creep deformation
- Prepared samples for experimental work: aluminum 7075 dog-bone and X70 carbon steel (ASTM-standardized)
- Performed literature review on specifying the stress dependencies of creep curve parameters.
- Reviewed mathematical and statistical methods for creep data evaluation.
- Applied mathematical models and statistical methods for creep data evaluation.
- Applied mathematical methods to pitting corrosion data obtained from Summer 2010 intern program.
- Separated corrosion fatigue WinBugs model program.
- Categorized creep model.
- Designed and made two three-point grips to apply definite stress on the samples.
- Performed literature review specifying the temperature dependencies of creep curve parameters
- Compared empirical and Evan's creep models by applying statistical methods
- Renewed the separation of the Winbugs corrosion-fatigue model to corrosion and corrosion-fatigue parts. This time, we used the pitting corrosion data from the PI intern program to update the Winbugs corrosion model
- Prepared experimental test setup for experimental efforts in support of corrosion and creep model development.
- Compared empirical model with literature (application of Akaike relation).
- Applied model uncertainty approach (Bayesian approach) to compare the models with the experimental strain data.
- Performed creep experiments on Al 7075-T6 in support of corrosion and creep model