THE UNIVERSITY of TULSA

TUFFP

TULSA UNIVERSITY FLUID FLOW PROJECTS NEWSLETTER

February 1999 | A Semiannual Publication | Volume 13, Number 1

Executive Director
James P. Brill (918) 631-5111
brill@utulsa.edu
Co-Principal Investigator - Paraffin
Mike Volk (918) 631-5127
michael-volk@utulsa.edu
Consultant
Yehuda Taitel (Israel) (972 3) 6408220
taitel@eng.tau.ac.il
Staff Engineer
Jerry Wilson (918) 631-5109
wilsonjf@centum.utulsa.edu
Research Associates
Subash Jayawardena (918) 631-5107
subash-jayawardena@utulsa.edu
Holden Zhang (918) 631-5142
zhangh@centum.utulsa.edu
Administrative Assistant
Pamela M. Clark (918) 631-5111
clarkpm@centum.utulsa.edu
Administrative Secretary
Linda M. Jones (918) 631-5110
jones@utulsa.edu
Technical Supervisor
Charles Ingle (918) 631-5120
inglech@centum.utulsa.edu
Senior Electronic Research Technician
Tony Butler (918) 631-5147
flfp_rab@centum.utulsa.edu
Technicians
Steve McCutcheon (918) 631-5133
Howard Rettig (918) 631-5136
Bill Smith (918) 631-5133
Research Assistants
Banu Alkaya (918) 631-5116
alkayab@centum.utulsa.edu
Eissa Al-Safran (918) 631-5119
alsafranem@centum.utulsa.edu
Mandar Apte (918) 631-5145
aptems@centum.utulsa.edu
Ryo Manabe (918) 631-5143
manaber@centum.tulsa.edu
Bazlee Matzain (918) 631-5143
matzaina@centum.utulsa.edu
Weihong Meng (918) 631-5116
mengw@centum.utulsa.edu
Gonzalo Olivares (918) 631-5145
olivaresgj@centum.utulsa.edu
Computer Resource Manager
Trina Lao (918) 631-5115
laotc@utulsa.edu

Fax Number: **(918) 631-5112**
Wax Fax Number: **(918) 631-5140**
Web Site: **www.tuffp.utulsa.edu**

Subash Jayawardena working on oil-water flow project

TUFFP Welcomes Dr. Subash Jayawardena

Dr. Subash Jayawardena joined TUFFP and the Paraffin Deposition JIP as a Research Associate in January 1999, from the University of Houston. Subash holds B.Sc. and Ph.D. degrees in chemical engineering, and has ten years of experience in conducting research on multiphase flow. He received his B.Sc. with first class honors from the University of Moratuwa, Sri Lanka. Upon completion of his undergraduate degree, he stayed at the same university where he taught courses in fluid mechanics and particulate systems as an Assistant Lecturer.

Later, Subash came to the University of Houston to pursue graduate studies in chemical engineering. His research on turbulence modifications in the gas core in vertical annular gas-liquid flow was both numerical and experimental. A combination of optical (LDV) and a conductance based measurement technique was used to study the influence of large disturbance waves on the annular flow liquid film in turbulent gas flow. A finite difference based numerical model of the turbulent gas core in annular two-phase flow was used to complement this experimental study. Subash conducted his graduate research under the guidance of the late Professor Abe Dukler.

Thereafter, Subash received a National Research Council postdoctoral Research Associateship to study two-phase flow splitting at a pipe junction under microgravity conditions. This research was conducted using the reduced gravity aircraft (also known as the "vomit comet") at the NASA Lewis Research Center in Cleveland, Ohio. Later, he continued his research on microgravity two-phase flows at the University of Houston where he was a co-investigator of an ambitious project for the space shuttle to understand the behavior of two-phase flows under extended microgravity conditions. In his research, Subash examined flow pattern transitions and characterization and flow development of wavy liquid films in annular flow, all relevant to the potential use of two-phase flow

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active thermal management systems for long duration, large scale space habitats. In addition to the direct benefits of such systems to space travel, the absence of gravity allows the development of more rigorous models to understand the effects of different forces on two-phase flows, which are some times masked by gravity. The knowledge gained by and techniques developed for various microgravity studies have already been used to improve models and experiments for normal gravity conditions. During his stay at the University of Houston, Subash also taught chemical engineering thermodynamics to undergraduate students.

Subash brings extensive expertise to TUFFP in developing experimental systems to study two-phase flow, especially under severe constraints. He will share his time and expertise between both TUFFP and the Paraffin Deposition JIP. His chemical engineering background, with emphasis on transport processes and thermodynamics, will greatly benefit the paraffin deposition studies.

Brill Editorial

Jim Brill practicing retirement!

At the September 23, 1998 TUFFP Advisory Board meeting, I know that I shocked attendees with my announcement that I would seek early retirement. Since then, I have been able to further define my plans and want to share them with the many companies and individuals that have generously supported my research at Tulsa University.

Since arriving at Tulsa University in 1966, I have truly been blessed to work at an institution that has always been generous with space and given me the freedom to innovate. Without this environment, research consortia such as TUFFP could never have survived for over 25 years. During this period I have been privileged to work with some of the most brilliant and gifted graduate students ever to enter the petroleum industry workforce. I have always felt that being surrounded by inquisitive, bright, young minds helps keep faculty young and productive. TUFFP has also been blessed with a group of exceptionally talented post doctoral research associates, professional engineers, research technicians and secretarial staff. These highly skilled professionals require minimal supervision and are truly self motivated and dedicated to provide all the support help required for operating a successful research program.

As I stated last September, after 26 years I am weary of the administrative tasks required to manage a research program of this scale. In addition, I have reached the point in my career where I yearn for more freedom during the academic year than can be offered by Tulsa University ... freedom to travel, increase participation in leisure activities such as tennis, golf and skiing, and become involved in a church missionary program. This freedom can only be gained by giving up traditional classroom teaching, and this requires giving up my faculty position.

I have given this decision a great deal of thought and am excited at the prospect of early retirement, especially if I can still maintain an involvement with TUFFP and graduate students. Accordingly, I have submitted a proposal to the Tulsa University administration that outlines an orderly progression for my retirement. I currently serve as chairman of my replacement search committee. An advertisement appeared in the December 1998 Journal of Petroleum Technology. Tulsa University's commitment to maintaining TUFFP as a viable research consortium is exemplified by its willingness to hire a senior faculty member as my replacement.

Our goal is to hire a faculty member by July 1, 1999 to replace me as Director of TUFFP. I have been approved for a sabbatical leave during the 1999-2000 academic year. Following my leave, I will return to Tulsa University for the Fall 2000 semester and retire December 31, 2000. This also coincides with the end of two of my significant service activities ... my representation of SPE on the ABET Board of Directors, and my Editorship for the ASME Journal of Energy Resources Technology.

It is my hope that the new TUFFP Director will keep me actively involved in both co-advising graduate students and interfacing with TUFFP member companies. I would like to continue my involvement at the 50% level for several more years. My interest in these activities remains strong, as shown in other parts of this Newsletter where plans are described for both forming a new paraffin deposition research consortium and also participating in a proposed new NSF Engineering Research Center on Pipeline Infrastructure.

TUFFP Research Assistant Update


Gonzalo Olivares

Gonzalo Olivares from Pemex has now been admitted to the M.S. program in Petroleum Engineering at The University of Tulsa. It is likely that his admission will be changed to the Ph.D. program at some time in the future. A research project will be assigned to him later this spring.

Discussions with a potential Ph.D. student from China resulted in him making a decision not to attend The University of Tulsa. A search for a replacement Ph.D. student will soon begin. Elf Aquitaine is considering sending two Visiting Scholars to The University of Tulsa to work with us on various multiphase flow research projects. One student would work in TUFFP on an extension of our low liquid holdup research dealing primarily with wave phenomena in stratified flow. The second student would work in the paraffin deposition area. Neither of these is confirmed but would take place sometime in the second half of 1999.


Weihong Meng

Weihong Meng has agreed to consider staying on at TUFFP in a Visiting Scholar or Post-Doctoral role for a period of approximately one year after completing his Ph.D. degree this spring. This would permit us to further expand our research in the hilly terrain pipeline area.

Computer Support Changes and Additions

Linda Jones has assumed the task of maintaining the TUFFP and Paraffin Deposition JIP computers. She will provide technical support to students and staff on diagnostics, software and hardware installations and operational procedures. She will maintain the software library and will initiate a software and hardware inventory.

Trina Lao was hired in August, 1998 to assist Linda with computer management duties and will be responsible for designing and maintaining the TUFFP and Paraffin Deposition JIP web pages. Trina is pursuing a Masters degree in Computer Sciences. An update on the TUFFP web page is given later in this newsletter.

Linda and Trina will also make recommendations on computer, software and hardware purchases to Dr. Brill.

This arrangement was implemented to free up Jerry Wilson to prepare two safety and operating procedure manuals, supervise remodeling projects in the Drill Building, and design site preparation for the new BP Amoco flow loop donation.

Director Search Committee Status

The Petroleum Engineering Department has established a search committee to find a replacement for Dr. Brill as a result of his announced plans to retire. The search committee consists of Dr. Brill as Chairman and Dr. Ovadia Shoham and Dr. Leslie Thompson as other faculty members on the committee. An advertisement for the faculty opening appeared in the December 1998 issue of the Journal of Petroleum Technology and applications are currently being received. Several excellent applicants have responded and review of the applications will soon begin.

Current plans call for hiring somebody at the Full or Associate Professor level. The target hiring date is June or July 1999 with the successful candidate also taking over the directorship of TUFFP at that time.

Dr. Brill plans to stay involved in both TUFFP and the formation of the planned new focused consortium on paraffin deposition. His involvement will be at the 25 to 50 percent level, depending upon availability of funds and a need for his services.

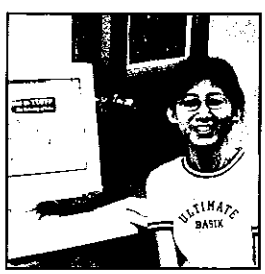
Computer Enhancements

TUFFP has recently purchased five new Dell OptiPlex GX1p computers. The computers were configured with 450mhz Pentium II processors, 128 MB Ram, 100mhz system bus, 10 GB hard drives, Internal Zip Drives and 17"monitors. These computers have been integrated into our Apple network with PC MacLan. PC MacLan enables PC users to access printers on an Ethernet network with a Macintosh Computer Server and permits accessing Macintosh computers for file sharing.

These computers will make the sharing of files within TUFFP and with member companies much easier with no conversion problems.

Three 7500 Macintosh computers were upgraded with G3 accelerator cards to improve performance.

TUFFP Web Page Nearing Completion



Trina Lao

The basic skeleton of the TUFFP web page is finished and the server with the password protected page will be up and running in February. The web page will be located at http://www.tuffp.utulsa.edu. The first item that member companies will be able to download is this Newsletter. Previous newsletters will also be posted on the web. Member companies are urged to evaluate the web page and report any critical comments and difficulties encountered.

BP Amoco Considers Donating Flow Loop to TUFFP

We have recently learned that BP Amoco will probably donate to TUFFP a multiphase flow loop currently located at their Sunbury Research Center, west of London. Discussions on the donation of the flow loop have been underway since December 1997. The flow loop is six inches in diameter, approximately 75 feet long, and low pressure using air and water for the flowing fluids. BP Amoco would disassemble the flow loop in England and move it to The University of Tulsa by Summer, 1999. A significant amount of site preparation would be necessary before reassembling the loop. Our goal would be to have the flow loop operational sometime this summer.

In exchange for the gift, BP Amoco would want permission to utilize the test facility for training purposes in the future. Access to this flow loop will significantly enhance TUFFP research in the hilly terrain pipeline area.

TUFFP Suffers Membership Decline

Three companies have terminated their membership in TUFFP for 1999. These include ARCO Oil and Gas Company, Petronas, and Shell Internationale Petroleum MIJ B.V. (SIPM). All notified us of intent to terminate membership prior to the October 1, 1998 deadline. Three other companies have now informed us of intent to terminate their membership for the year 2000. These include Arabian Oil Company, Ltd., Petrobras, and Pertamina. We also anticipate losing Amoco Production Company and Mobil Research and Development Corporation in the year 2000 as a result of recent mergers. Communications with companies that have informed us of intent to terminate membership have all indicated that these decisions are based on the current financial crisis in the petroleum industry caused by the low price of oil. It is our hope that these companies will decide to retain their membership if the price of oil does improve in the coming months.

We are still optimistic that the above loss of membership can be offset partially with the addition of new members. Current discussions are underway with the U.S. Department of Energy Offices in both Tulsa and Morgantown, West Virginia. In addition, our expanded research activity in both the hilly terrain pipeline area and in gas-oil-water flow is of interest to NKK, Statoil, and Schlumberger. Efforts to solicit TUFFP membership from these companies and organizations will continue.

A list of 1999 member companies appears on this page.

TUFFP Financial Status Stable for 1999

The projected TUFFP reserve fund balance at the end of 1998 is approximately $200,000. The loss of members for 1999 coupled with capital expenditures necessary for the hilly terrain pipeline and oil-water flow research projects will deplete most of the reserve fund by the end of 1999.

Every attempt will be made to control costs during 1999 to improve this financial picture. In addition, efforts are underway for TUFFP to participate as an Outreach University in a new NSF Engineering Research Center. If successful, this would provide an additional $100,000 in funding for hilly terrain pipeline research during 1999 and possibly for several years in the future.

Brill and Mukherjee Complete SPE Monograph

Dr. Brill and Dr. Hemanta Mukherjee have recently completed writing the SPE Monograph on "Multiphase Flow in Wells." Final galley proofs will soon be available for proofing and SPE anticipates that the Monograph will be available for sale by May 1999. The Monograph has been in preparation for over ten years and will contain all necessary technology for engineers to design multiphase wellbore systems. Both historical empirical correlations and modern mechanistic models for describing multiphase flow phenomena are presented. A chapter is devoted to solving practical production problems. Appendices are included for describing both black oil and compositional models for predicting mass transfer between phases and physical properties of the fluids.

Don't Forget!!!

Fluid Flow Projects Advisory Board Meeting

April 28, 1999

Paraffin Deposition JIP Advisory Board Meeting

April 29, 1999

New Paraffin Deposition Research Consortium Plans Underway

In June, 1999 the four-year Paraffin Deposition JIP currently underway at The University of Tulsa will officially end. Final activities dealing with data analysis, modeling and report preparation will continue into the fall. Attempts to seek funding for these final activities from the Department of Energy is currently underway.

With the conclusion of the Paraffin Deposition JIP, The University of Tulsa now has two extremely versatile experimental test facilities that must be used for additional research on paraffin deposition. Plans are underway to form a new focused research consortium to continue our efforts in the area of paraffin deposition. A preliminary proposal has been developed and will soon be shared with several potential member companies. Feedback from these companies will be used to modify the proposal in such a way that it will be of strong interest to the world-wide petroleum industry.

At present, we envision a focused consortium with an annual budget between $700,000 and $800,000. We hope to seek funding at the 50% level from the U.S. Department of Energy with the remainder being funded from membership fees from participating companies. An annual membership fee of $30,000 per year would require membership from 12 to 13 companies. A projected starting date of October 1, 1999 has been established and invitations to participate will be distributed following the Paraffin Deposition JIP Advisory Board meeting on April 29, 1999. This will give us an opportunity for additional discussion on the possible consortium at the Advisory Board meeting.

TUFFP Participates in NSF Engineering Research Center Proposal

For several years an NSF Center dealing with Capsule Pipelines has been underway at the University of Missouri at Columbia under the direction Dr. Henry Liu. Dr. Liu now hopes to expand this into an NSF Engineering Research Center on Pipeline Transportation Infrastructure (PTIC) that would encompass a much broader group of technical problems associated with the use of pipelines to transport products. Dr. Liu invited The University of Tulsa to collaborate with them as an Outreach University in this new center, with the University of Missouri at Columbia serving as the lead institution. In addition, the University of Minnesota and the University of Missouri at Rolla would serve as Core Partner Universities.

A preproposal for forming this center has been submitted to NSF. If successful, the University of Missouri at Columbia will be invited to prepare a full proposal that could be funded as early as mid-1999. Three different projects at The University of Tulsa would be involved in our efforts as an Outreach University with each project being funded at approximately $100,000 per year for several years. TUFFP would receive support to enhance our research on hilly terrain pipelines; the paraffin deposition research program would also be a research thrust area; and, our research efforts in erosion/corrosion at the Tulsa University Erosion/Corrosion Research Center would be the other participant.

TUFFP Schedules 1999 Short Course

The TUFFP short course "Two-Phase Flow in Pipes" is scheduled to be taught again in Tulsa, Oklahoma at the Marriott Southern Hills Hotel on May 10 – 14, 1999. Once again, the course will be taught by Dr. Brill and Dr. Cem Sarica who is now an Associate Professor of Petroleum Engineering at Pennsylvania State University. The course will give participants a well-grounded understanding of the fundamentals of two-phase flow through pipes and restrictions. Completed and current research projects permit teaching the latest technology for designing multiphase flow piping systems for the production and transportation of oil and gas. Upon completion, the participants will be able to apply knowledge gained to design fluid flow conduits encountered in petroleum, natural gas and chemical engineering operations.

Following is the pricing schedule for the 1999 short course.

TUFFP Member Company Course Fee Schedule
$950 per person – regular tuition
$850 per person – group discount

Non-Member Company Course Fee Schedule
$1,595 per person – regular tuition
$1,295 per person – group discount

We urge member companies to enroll engineers as soon as possible. A brochure describing the course is enclosed and has also been mailed to potential participants. Members may enroll by calling The University of Tulsa Department of Continuing Education at (918) 631-3088, sending a fax to (918) 631-2154 or an e-mail to conted_cee@utulsa.edu. Additional information can also be obtained from the Continuing Education website at www.conted.utulsa.edu.

Future Advisory Board Meetings Scheduled

Final plans have now been made for the Spring 1999 TUFFP Advisory Board and related meetings. All meetings will be held at the Marriott Southern Hills Hotel. A request for information form is enclosed with this Newsletter together with information on hotel reservations and travel to and from the airport. Persons attending the meeting should complete the form and return it to us as soon as possible.

The TUFFP Advisory Board meeting will begin at 8:30 a.m. on Wednesday, April 28, 1999 and will adjourn at 4:30 p.m. A tour of test facilities for persons attending the TUFFP Advisory Board meeting but not staying for the Paraffin Deposition JIP Advisory Board meeting will be held at 3:00 p.m. on Tuesday, April 27, 1999. Following the Advisory Board meeting on Wednesday there will be a reception at the Marriott Southern Hills Hotel from 6:00 – 8:00 p.m. and TUFFP members will be joined by those attending the Paraffin Deposition JIP Advisory Board meeting that will be held the following day, April 29, 1999. Immediately after the Paraffin Deposition JIP Advisory Board meeting there will be another tour of test facilities at 5:30 p.m., followed by a barbecue dinner on the North Campus at 6:30 p.m. This arrangement should permit everybody to tour all TUFFP and Paraffin Deposition JIP test facilities during the meetings. The tours should be especially enjoyable since we hope to have six test facilities operating at that time. These include the hilly terrain pipeline, the oil-water flow, the low liquid holdup, the horizontal well, and both paraffin deposition test facilities. In addition, site preparation should be underway for locating the BP Amoco six inch flow loop.

A summary of the dates for the Spring 1999 and Fall 1999 Advisory Board meetings are shown in the table below. The hotel for the Fall 1999 Advisory Board meetings has not yet been determined.

TUFFP Advisory Board meeting brochures will be available for members at the meeting and will be mailed to all members following the meeting. The brochure will contain sufficient information to help each attendee actively participate in discussions on current and future research projects, financial matters, and operating procedures. A brochure containing slide copy for all presentations will also be distributed at the meeting but will not be mailed to members. Both the Advisory Board meeting brochure and Slide Copy will be mounted on the TUFFP web page for use by member companies.

Future Advisory Board Meetings Schedule

April 27, 1999
Tour of TUFFP Test Facilities

April 28, 1999
TUFFP Advisory Board Meeting
Joint TUFFP/Paraffin Deposition JIP Cocktail Reception

April 29, 1999
Paraffin Deposition JIP Advisory Board Meeting
Tour of TUFFP/Paraffin Deposition JIP Test Facilities
Barbecue Reception

Tentative Dates

September 28, 1999
TUFFP Advisory Board Meeting

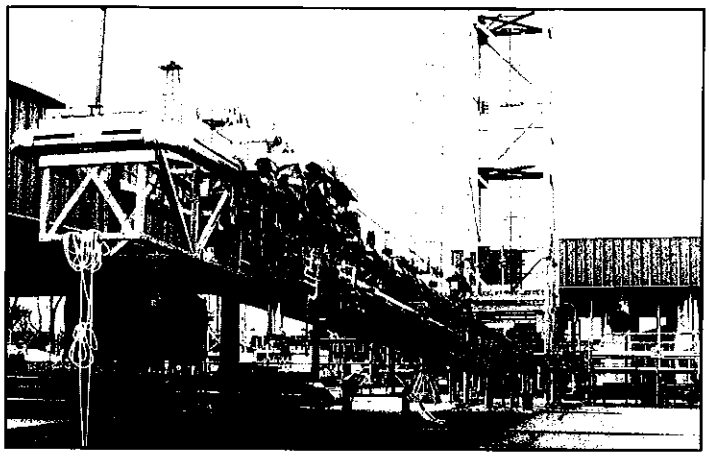
September 29, 1999
TUFFP Advisory Board Meeting

September 30, 1999
Kick-off Advisory Board Meeting for new Project Oriented Paraffin Deposition Research Consortium

BHRG Conference Looking Good

Final plans are underway for the BHRG 9th International Conference on Multiphase Flow called "Multiphase '99" in Cannes, France 16 – 18, June, 1999. Approximately 40 excellent technical papers have been submitted on a variety of subject areas ranging from multiphase pumping, multiphase metering, transient flow, pigging, separation, emulsions, flow assurance and others. This promises to be another excellent technical event that will be of strong interest to TUFFP member companies. A registration brochure will be mailed to potential participants in the near future.

Paraffin Deposition JIP Update



Inclined test section in multiphase wax deposition flow loop

A large Joint Industry Project (JIP) was initiated at The University of Tulsa on May 1, 1995 to investigate paraffin deposition under both single-phase liquid and multiphase flow conditions in pipelines and wellbores. This $4.2 million, four-year project is funded by membership fees and donations from 37 domestic and international oil and gas related companies, DOE, and the US Department of Interior's Minerals Management Service. The JIP is coordinated through five committees chaired by industry members. Deliverables in the form of literature searches, computer programs, experimental data, and reports describing models for predicting deposition phenomena are scheduled throughout the four-year study.

Monitoring of progress in the JIP is accomplished through committee meetings and semi-annual Advisory Board meetings. The next Advisory Board meeting will be held in Tulsa on April 29, 1999. A proposal to initiate a Project Oriented Paraffin Deposition Research Consortium on October 1, 1999 will be reviewed during this meeting.

Analyses of the single-phase wax deposition data using South Pelto crude oil and Garden Banks condensate are now complete. These data have been distributed to JIP members on a CD. Analyses of the data yielded calculations for deposition thickness as a function of location, time, inlet bulk oil temperature, inlet coolant temperature and Reynolds number. Deposition thickness was calculated based on both pressure drop and temperature measurements. HTGC analyses of deposits yielded new information for predicting trapped oil concentration in the deposits. Analyses of the data suggest that molecular diffusion cannot account for all of the deposition phenomena observed. Paraffin deposition is a very complex process that will require significant basic research to fully understand the many phenomena involved. Additional mechanisms that must be considered include: the role of viscosity of a colloidal dispersion in the boundary layer region; the relative roles of mass and thermal diffusion; the size of paraffin crystals being formed; the role of a gelled oil layer, including the affect of shear stress and yield strength in sloughing or creeping flow; and, the influence of growth or reorganization of paraffin crystals and the possible role of heat flux in accelerating the aging or hardening process.

Development of an initial multiphase flow deposition computer program is complete. The program combines the following: modern multiphase flow mechanistic models for wells and pipelines; a state-of-the-art solid-liquid-vapor equilibrium module (from Multiphase Solutions Inc.); a broad range of multiphase flow heat transfer options (from Oklahoma State University); and, multiphase flow deposition models based on engineering assumptions and analyses of the single-phase TU tests. A user-friendly GUI for the program is being developed by Multiphase Solutions Inc. Improved deposition models will be added later based on more extensive multiphase flow tests.

Construction of the multiphase flow deposition loop is complete. Single-phase oil tests with the multiphase flow loop were conducted in December 1998 and verified results obtained earlier with the single-phase flow loop. Two-phase flow testing began in January, 1999. Most systems in the multiphase flow facility functioned as designed, requiring only minor facility modifications. The testing program includes:

- developing flow pattern maps for horizontal, vertical and inclined flow in a non-deposition environment;
- refining operational procedures in a two-phase deposition environment;
- conducting two-phase horizontal deposition tests;
- conducting two-phase vertical deposition tests; and
- conducting two-phase uphill and downhill deposition tests.

The two-phase test conditions will utilize one inlet bulk oil temperature, one inlet coolant temperature, and

Separator, oil tank and water tank in multiphase wax deposition flow loop

flowing South Pelto crude oil with natural gas at pressures of 500 psia. The duration of the remaining test program will be approximately five months. The two-phase test program will consist of 16 to 22 tests in order to investigate all flow patterns. This includes 6 to 10 tests in a horizontal loop, 4 to 6 tests in a vertical loop, 3 tests in an uphill loop, and 3 tests in a downhill loop.

Optimization of Horizontal-Well Completion: Joint Industry Project (JIP)

The objectives of this JIP are to provide completion guidelines for horizontal wells and to develop software to be used in the design of optimum well completions. Completion optimization will provide members of the JIP with a low cost means of increasing the economic benefit expected from horizontal wells. Current members of the JIP are Amoco Production, DOE, MMS, Phillips Petroleum, and Unocal/Sprit 76. This JIP is a collaborative effort of reservoir and production disciplines of petroleum engineering, spearheaded by co-principal investigators Mohan Kelkar of The University of Tulsa, Erdal Ozkan of Colorado School of Mines and Cem Sarica of The Pennsylvania State University.

In a horizontal well, depending upon the completion method, fluid may enter the wellbore at various locations along the well length. The pressure distribution in a horizontal well can influence the well completion and well profile design, as well as having an impact on the production behavior of the well. Therefore, both the pressure-drop versus flow behavior along the well and the relationship between the pressure-drop along the well and the influx from the reservoir need to be understood.

Significant progress has been accomplished during the first year of the JIP. Modifications to an existing TUFFP experimental facility have been completed. Eight new test sections have been designed and manufactured. Data acquisition and analysis for two of the test sections have already been completed. The data analysis indicates that phasing of slots in slotted liners has a significant effect on the wellbore flow. Data acquisition and analysis for the remaining test sections will be completed by May 1999. New friction factor correlations will be developed to predict the effects of opening density and phasing on the wellbore hydraulics.

This JIP will be completed at the end of 1999. Although significant progress will have been made, there are many significant aspects of horizontal well completions yet to be investigated. Examples are pre-packed screens, damage caused by perforating horizontal wells, single phase flow of gases, multiphase flow of oil, gas, water, and sand through horizontal well completions, and completion optimization of slanted wells.

We are well positioned and have the momentum to continue with further horizontal well completion studies after the completion of this JIP and are currently enthusiastically working on formulating the next project. For further information, please contact any of us at:

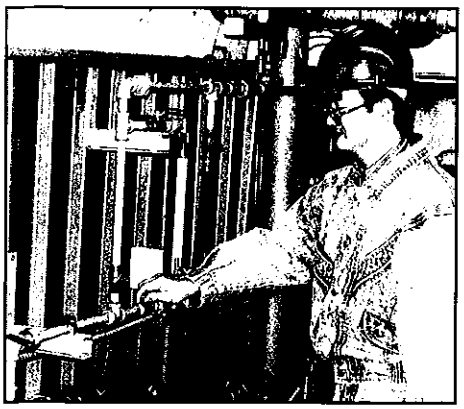
Dr. Erdal Ozkan
Petroleum Engineering
Colorado School of Mines
Golden, Colorado 80401
Phone: (303) 273-3188
Fax: (303) 273-3189
e-mail: eozkan@mines.edu

Dr. Cem Sarica
Petroleum & Natural Gas Engr.
The Penn State University
122 Hosler Building
University Park, PA 16802
Phone: (814) 863-6341
Fax: (814) 863-1875
e-mail: sarica@pnge.psu.edu

Dr. Mohan Kelkar
Petroleum Engineering
The University of Tulsa
600 South College Avenue
Tulsa, Oklahoma 74104
Phone: (918) 631-3036
Fax: (918) 631-2059
e-mail: mohan@utulsa.edu

Please send in your Request for Information form and make hotel reservations for the upcoming Advisory Board meetings as soon as possible.

Low Liquid Loading Two-Phase Flow In Near-Horizontal Pipelines



Weihong Meng

Gas-liquid two-phase flow with a small amount of liquid is frequently encountered in natural gas pipelines. Even when single-phase gas enters a pipeline, condensate traces can be formed by retrograde condensation. The presence of these liquid traces can lead to a significant increase in pressure loss over that for single-phase gas flow. Despite numerous theoretical and experimental investigations into gas-liquid pipeline flow, only a few studies on low liquid loading two-phase flow have appeared in the literature and the topic has not been adequately studied. Existing models do not predict the flow characteristics of gas-condensate mixtures in natural gas pipelines with sufficient accuracy.

The objective of this project is to investigate, experimentally and theoretically, low liquid loading two-phase flow in near-horizontal pipelines. Both stratified-wavy and annular flows, the most common flow patterns encountered in gas pipelines, are currently being studied.

Significant progress has been made since the last Advisory Board meeting on September 23, 1998. All designed tests have been completed. The data acquired include liquid flow rate, gas flow rate, pressure gradient and liquid film height and liquid film flow rate and droplet deposition rate from a liquid removal device. The superficial gas velocities ranged from 5 - 25 m/sec and superficial liquid velocities ranged from 0.001 - 0.053 m/sec. Correspondingly, the liquid loadings investigated are from approximately 40 - 10600 m^3/MM^3 (7 - 1888 BBL/MMSCF). At high superficial gas velocity, it was surprising to find that liquid film flow rate and liquid holdup decrease with an increase in liquid flow rate. Liquid droplets are entrained in the gas core after roll waves are generated. These droplet diameters are very small near the liquid entrainment onset point. Larger droplets exist when the gas velocity and liquid velocity are both high. Some of the tests were videotaped. Data processing has been completed and modeling studies are currently underway.

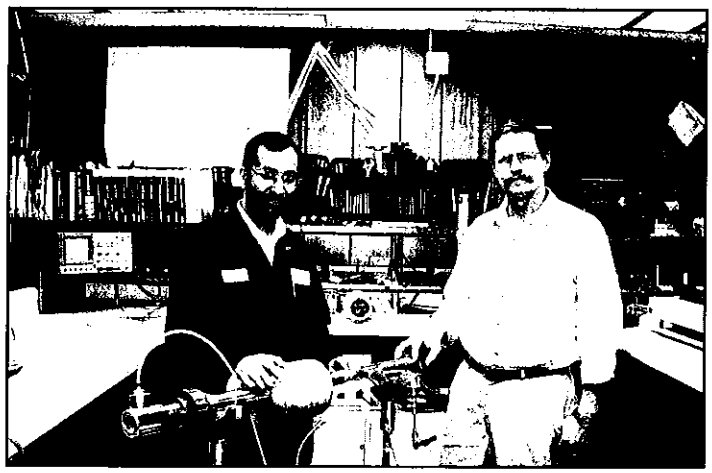
Two Phase Flow in Hilly Terrain Pipelines

Hilly terrain pipelines are inevitable in field operations. Both offshore seafloor and onshore land exhibit hilly terrain configurations. Prediction of flow behavior for hilly terrain pipelines is important to properly manage hydrocarbon recovery. Hydrodynamic slugs generated in uphill sections may or may not decay in following downhill sections, causing uncertainties in pressure behavior. Such configurations can also result in terrain induced slugs that are much longer than those normally encountered in horizontal pipelines. These long slugs often cause operational problems, flooding of downstream facilities, severe pipe corrosion, and structural instability of the pipeline, as well as production loss and poor reservoir management due to unpredictable wellhead pressures.

TUFFP's research initiative on two-phase flow in hilly terrain pipelines includes studies at both The University of Tulsa and Tel Aviv University. Progress on the slug tracking study subcontracted to Tel Aviv University is described elsewhere in this newsletter. The objectives of this study at The University of Tulsa are four fold:

- Investigate slug initiation and evolution in general.
- Determine slug length distributions at several locations along a 1370-ft long TUFFP pipeline.
- Develop a constitutive relationship for slug initiation at the bottom elbow of a pipeline.
- Generate data for various hill and valley configurations to evaluate the computer program to track slugs being developed at Tel Aviv University.

An existing 420-m (1370 ft) long, 77.9-mm (3.068 in.) diameter pipeline, will be modified significantly to conduct the experimental part of this study. A 2-in. diameter steel pipe will be used instead of the existing 3-in. diameter pipe due to the availability of 2-in. capacitance sensors to measure slug characteristics. The 2-in. pipe has been laid above the existing 3-in. pipe, except in the testing section, where the 2-



Eissa Al-Safran and Tony Butler working on capacitance sensors

in. pipe replaced the 3-in. pipe. The test section will be made of 2-in. diameter, transparent acrylic pipe, and will simulate a single hilly terrain unit with 70-ft long uphill (downhill) and 70-ft long downhill (uphill) sections (L/D=840). The inclination angles to be investigated are ± 0.5° and ± 2° from horizontal. Six measurement stations with all necessary instruments to measure the flow parameters will be installed along the flow loop. Four of the stations will be installed on the testing section, while the other two will be on the horizontal pipe upstream and downstream of the testing section. Thirteen capacitance sensors will be installed at different locations along the pipeline to measure flow characteristics.

Significant progress has been made since the last Advisory Board meeting in September 1998. A new liquid storage tank has been designed, built, and installed. An existing metering section has been refurbished and connected. A request for a donation of two gas and two liquid Micro Motion meters to replace the existing metering equipment is currently being evaluated. All existing Validyne absolute and differential pressure transducers and temperature transmitters are being replaced with Fisher-Rosemount devices purchased at a significant discount. These will improve measurement accuracy and simplify cabling requirements. Installation of the 2-in. pipe is nearing completion. In addition to the available capacitance sensors, new backup capacitance sensors have been built, and both the new and the old capacitance sensors are being tested statically in the laboratory.

Design of the test section, including the top and bottom elbows and the trapping section for dynamic calibration has been completed. The required materials have been ordered, and construction is underway. Safety and environmental concerns have been addressed. A system for the loop to prevent any oil spills has been designed and construction is underway. Near future tasks include completing the tasks now underway, assembling the test section, and mounting the measurement stations and instrumentation along the flow loop. A detailed progress report will be presented at the Advisory Board meeting in April 1999.

Oil - Water Flow Patterns in Slightly Inclined Pipelines

A systematic research program has been underway at TUFFP since 1992 to investigate oil-water flow in wellbores and pipelines. Trallero completed a study on oil-water flow patterns in horizontal pipes. He classified oil-water flow patterns based on both his experimental data taken at the TUFFP Oil-Water Flow Facility, and data from several other sources. A new mechanistic model was developed based on a rigorous two-fluid model and a force balance between gravity and turbulent fluctuations normal to the main flow. Comparisons of the model with data from both his research and from several other studies show that the Trallero flow pattern model performs very well for horizontal pipelines. In a recent study by Flores, oil-water flow has been investigated for an inclination angle range of 45° - 90°. Flow patterns for vertical and deviated flows were identified and models for vertical upward flow were developed.

Banu Alkaya

Although there are no perfectly horizontal pipelines, research on the flow of oil-water mixtures in slightly inclined pipelines is almost nonexistent. The objective of this project is to develop mechanistic models to predict oil-water flow pattern transitions for slightly inclined pipelines by using experimental data that will be obtained at various flow conditions and inclination angles using mineral oil and water.

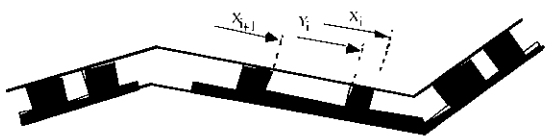
A comprehensive review of the literature has already been completed. Facility modifications and a new test section design are currently underway. A new three-phase separator has been ordered since the existing one was unable to provide adequate separation over the full range of planned experiments. Facility modifications and construction of the new test section will be completed by May 1, 1999. A detailed progress report will be presented at the Spring 1999 Advisory Board meeting.

Slug Tracking in Hilly Terrain Pipelines

In October 1998, TUFFP funded a research project at Tel Aviv University to investigate slug tracking as one part of a larger TUFFP initiative on two-phase flow in hilly terrain pipelines. Following is a progress report submitted by Yehuda Taitel, Dvora Barnea and Lev Shemer of the Department of Fluid Mechanics and Heat Transfer, Faculty of Engineering at Tel-Aviv University.

A hilly terrain pipeline consists of horizontal, uphill, and downhill sections. While slug flow is relatively well understood for any of the three configurations, there is a lack of understanding of how flow characteristics change when these configurations are interconnected, as in a hilly terrain pipeline.

The objective of this project is to develop a slug-tracking computer program that will be able to simulate slug flow behavior in hilly terrain pipelines. Every slug in the pipeline will be tracked by the variations of the position of its front X_i and its back Y_i with time. The calculation is based on quasi-steady state analysis. At each instant, the velocity of the liquid slugs and the liquid films behind the slugs are calculated using the same procedure as for steady slug flow. In addition, slug front and back velocities are calculated, allowing the prediction of the motion of the slug front, the slug back and their positions at the next time increment.



The simulator includes the effect of compressibility and is able to simulate the dissipation of slugs in the downhill sections, the generation of slugs at low elbows and the merging of short slugs into longer stable slugs. This method can handle the motion of hydrodynamic slugs (the term used for "steady" slug flow) as well as terrain induced slugs. When a long pipeline with downward shallow inclination is connected to a steep upward pipeline, a long terrain slug can be developed in the lower elbow. The front of the slug moves forward while the back of the slug moves backward, capturing a gas pocket behind the slug. The numerical method used is capable of predicting the unique behavior of terrain slugging.

The theory on which this simulator is based is relatively simple. It uses the hydrodynamics of steady slug flow and stratified flow combined with mass balances. However, the complication lies primarily in the programming scheme. The number of possible events that can take place is enormous. For example, slugs can move at different velocities and can be overtaken by slugs behind. Slugs may or may not dissipate in pipes with downward inclination, and can form a series of films which can move at different velocities and can merge to form a continuous long film. Usually, slug velocity is in the downstream direction. Yet, the analysis allows the development of special conditions in which slugs move temporarily backward, in the upstream direction.

Most of the progress until now was achieved prior to the commencement of the present project. Development of the program is in progress. At present, the program can handle compressible gas (without mass transfer), pipes with bottom and top elbows, that is when the pipe inclination changes from positive to negative and vise versa. Thus far, the program cannot handle a change of inclination from positive to positive or negative to negative angles. The program is still far from being user friendly and most operating conditions, geometry and fluid properties are simply written directly into the program listing.

Many test runs were conducted to test and debug the program and this process is still in progress. A typical test case that we have used consists of three sections, a 50 m shallow upward degree pipe, followed by 150 m shallow downward pipe that is followed by a 50 m upward pipe (see figure). Using this configuration and for different input rates and pipe inclinations, we successfully simulated the following cases:

1. Hydrodynamic slugs in all pipe sections;
2. Hydrodynamic slugs in the upward sections and film flow in the downward sections;
3. Hydrodynamic slug flow in the first shallow upward section, the development of stratified flow in the long downward section and the formation of terrain slugging in the elbow at the connection of the downward section with the last upward section. The simulation clearly shows that terrain slugging is developed only when the inclination angle of the last section is quite steep.

In addition, we have made some progress in the experimental study of slug initiation and development at the entrance region of a pipe. Our horizontal and inclinable two-phase flow loop is being modified to handle the current project. A Ph.D. student, Rene van Hout is in charge of this experimental program. Rene finished his undergraduate studies at Eindhoven University of Technology, the Netherlands and his Master's degree project in our department on the subject of slug length distribution and void fraction distribution within the liquid slug for vertical flows. After finishing his Master's Thesis, Rene returned to the Netherlands for about five years and then returned to our department for his Ph.D. degree. Rene is a very capable student with considerable experience in the area of two-phase flow.

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Two-Phase Flow Calendar

1999

February 1 – 3	ASME Energy Technology Conference and Exhibition (ETCE), Houston, Texas (nine sessions on multiphase flow and other topics as part of the Petroleum Production Technology Symposium)
February 22 – 23	Field Applications and New Technologies for Multiphase Metering, IBC UK Conference, Aberdeen Airport Thistle Hotel
March 4 – 5	IBC Flow Assurance Conference, Houston, Texas
March 14 – 18	AIChE Spring National meeting, Houston, Texas (symposium on wax thermodynamics and deposition)
March 28 – 31	SPE Mid Continent Operations Symposium, Oklahoma City, Oklahoma
April 20 – 21	Ohio University Erosion/Corrosion Advisory Board meeting, Athens, Ohio
April 28	TUFFP Advisory Board meeting, Tulsa, Oklahoma
April 29	Paraffin Deposition JIP Advisory Board meeting, Tulsa, Oklahoma
May 3 – 6	Offshore Technology Conference, Houston, Texas
May 10 – 14	TUFFP Short Course on "Two-Phase Flow in Pipes", Tulsa, Oklahoma
June 16 – 18	BHRG Multiphase '99 Conference, Cannes, France
August 15 – 17	33rd National Heat Transfer Conference, Albuquerque, New Mexico (session on Experimental Study of Multiphase Flow)
September 29	TUFFP Advisory Board meeting, Tulsa, Oklahoma
September 30	Possible Paraffin deposition JIP Advisory Board meeting, Tulsa, Oklahoma
October 3 – 6	SPE Annual Technical Conference and Exhibition, Houston, Texas

2001

May 27 – June 1	4th International Conference on Multiphase Flows, New Orleans, Louisiana

The University of Tulsa
Fluid Flow Projects
Department of Petroleum Engineering
600 South College Avenue
Tulsa, Oklahoma 74104-3189