THE UNIVERSITY of TULSA

TUFFP

TULSA UNIVERSITY FLUID FLOW PROJECTS NEWSLETTER

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Editorial by James P. Brill

These are indeed interesting, challenging, and exciting times in both the oil patch and at TUFFP. Many things are happening at TUFFP and the new Wax Consortium, TUPDP, that will be of interest to all of our friends and supporters.

First of all, I am sad to announce that Cliff Redus retired from TU after a year on our faculty and as Director of TUFFP. His decision was based solely on medical reasons. Cliff has left Tulsa and purchased a new house where he grew up in Divine, Texas near San Antonio. We wish Cliff a rapid return to good health and hope he again becomes active in this interesting business.

With Cliff's departure, I have agreed to return as interim Director of TUFFP and as Principal Investigator for TUPDP. A search for Cliff's successor is underway and we still anticipate having somebody on board by my scheduled retirement date of December 31, 2000. If viable candidates are not identified by mid September, alternative approaches to filling the position will be considered. This could involve hiring a full-time Director for the programs rather than a faculty member. Either way, I will remain part time in the programs to ensure a smooth transition and to continue my strong interest in the technical aspects of multiphase flow and flow assurance.

TUPDP officially began on June 1, 2000 as a focused consortium to continue our exciting research on paraffin deposition. At inception, we already had 20 members on board, and anticipate more companies joining in the future and also receiving major additional funding from DOE.

Our understanding of multiphase flow in pipes has matured dramatically over the past decade. New technologies in modeling, computing and experimentation have opened the door to even greater advances in the future. Activities underway in both TUFFP and TUPDP are taking advantage of these new tools. The result is mechanistic models that can be used with greater confidence when designing multiphase flow facilities in the field. Progress reports later in this Newsletter describe projects that could not have been attempted only a few years ago. Ryo Manabe has begun to generate exciting new high pressure, natural gas-crude oil experimental data that will improve our ability to predict multiphase flow local heat transfer phenomena for different flow patterns in wells and pipelines. Eissa Al-safran has completed taking data that will permit us to better predict slug formation and dissipation in hilly-terrain pipelines. Yehuda Taitel and his team at Tel-Aviv University are collaborating with us to develop a computer program for tracking slugs as they flow through hilly-terrain pipelines. Our efforts in attacking a major shortcoming in all commercial programs … prediction of flow behavior with small amounts of liquid present … is bearing fruit. Nicholas Olive has continued a previous project on low liquid loading to generate data with water rather than oil and has uncovered additional very interesting phenomena. He will soon begin to generate data at even lower liquid loading values. The donation of a 6-in. diameter flow loop by BP Amoco will permit us to investigate the low liquid two-phase flow problem for larger diameter pipes.

Simultaneously, significant efforts are underway to not only improve the ease of using our deliverables (data, computer programs, research reports) but also in improving the access of the deliverables via our Web Site. New material is being added to our Web Site (www.tuffp.utulsa.edu) on a daily basis and I urge all readers to visit this site. In addition, technology transfer is accomplished through the annual TUFFP short course and active participation at technical meetings. TUFFP research resulted in presentation of eight technical papers at conferences over the past year and publication of three papers in technical journals.

Finally, high level discussions are taking place within the University, with major oil companies, service companies and government agencies. These involve the possibility of enhancing the capabilities of the North Campus with one or more Centers of Learning. These Centers could incorporate existing Consortia, could establish new ones in areas like Flow Assurance, and would result in more efficient utilization of both our resources and those of our supporting companies. These concepts are not new, but certainly make sense in today's business environment.

I am personally grateful to the many TUFFP members that have so generously supported my research activities over the past 28 years. I am proud of the marvelous accomplishments that our students, faculty and staff have made in the area of multiphase flow. These have helped open the doors to develop even more meaningful technologies that will be vital as the industry pursues ventures in deeper and deeper water. We look forward to continued participation from our loyal members and addition of new companies in the future.

New Computer Resource Manager Hired

Dan Underwood

Dan Underwood joined TUFFP in May 2000, filling the role of Computer Resource Manager. Dan, a native Tulsan, received his B.S. in Computer Information Systems in May from TU and is currently working on his M.S. in Computer Science. He is responsible for keeping TUFFP's computer resources running smoothly as well as identifying new ways to leverage technology to better serve our needs. He has already begun this by replacing our older Apple MacIntosh computers with Windows NT/2000 machines and is currently upgrading our network infrastructure to better support transferring the large amounts of data we are collecting. Dan has previously worked for VEXIS Systems as a Network Administrator and Total Information Services Inc. as a programmer.

TUFFP Web Page Expands

The TUFFP Web page is located at www.tuffp.utulsa.edu. The Web page is maintained jointly by Linda Jones and Dan Underwood.

In the "Members Only" section, the following research reports have been added: TUFFP Core Software User's Manual Version 2.0; Ph.D. Dissertation by Weihong Meng entitled "Low Liquid Loading Gas-Liquid Two-Phase Flow in Near-Horizontal Pipes"; M.S. Thesis by Eissa Al-safran entitled "An Experimental Study of Two-Phase Flow in a Hilly-Terrain Pipeline"; and, M.S. Thesis by Banu Alkaya entitled "Oil-Water Flow Patterns and Pressure Gradients in Slightly Inclined Pipes". Each research report includes the document in pdf format and the Fortran source code in plain text format. The Fortran source code for the research report by JinJiang Xiao entitled "A Comprehensive Mechanistic Model for Two-Phase in Pipelines" has also been uploaded. More research reports, data and Fortran programs will be added in the future.

In the "Research Projects" section, lists of all completed research projects are given in both chronological and subject orders. The purpose of these lists is to give visitors of the TUFFP Web page a feel for what kind research has been conducted in TUFFP since 1973.

Brill Returns from Sabbatical Leave

As part of his retirement plans, Jim and Marilyn Brill moved temporarily to Golden, Colorado in January where Jim taught a graduate course to 22 students on Multiphase Flow in Pipes at the Colorado School of Mines. Since the course was taught one afternoon a week, there was ample time (13 days) to enjoy skiing in the Colorado Mountains. Unfortunately, ETCE2000, BHRG2000, ASME and SPE paper editing, e-mail, preparations for the new Paraffin Deposition Consortium, planning for the July 2000 SPE Forum on Flow Assurance in Deep Water and TUFFP duties interfered with sporting activities. Nevertheless, his sabbatical was relaxing and he strongly recommends going to a host institution for sabbatical leaves.

Cliff Redus Announces Retirement

After only 10 months on our faculty, Cliff Redus decided to resign for medical reasons. During his brief term as a faculty member, he had a significant impact on both the department and TUFFP. He helped pioneer the use of WEB CT at Tulsa University as an Internet approach to teaching, and utilized his industry experience to enhance our undergraduate and graduate production courses. His dynamic personality will be missed and we wish him all the best in his future endeavors.

Brill Named ASME Fellow

Jim Brill, Floyd M. Stevenson Endowed Presidential Chair in Petroleum Engineering, was named a Fellow of ASME International in February. Dr. Ed Rybicki, Chair of Mechanical Engineering, presented the award to Jim on the North Campus. Fellow is the highest recognition given by ASME and has been bestowed on about 2% of the 108,000 ASME members.

2000 Questionnaire

We will be distributing the 2000 TUFFP Questionnaire to the official Advisory Board Representative by email in the very near future to solicit feedback on our research program. We received a much better response from member companies by utilizing email last year. Please submit suggestions that you may have on ways we may improve our program. We will tabulate the results and present them to members at the upcoming Advisory Board meeting on November 16th.

Cost Cutting and Mergers Continue to Impact TUFFP Membership

Three companies have indicated that they will terminate their TUFFP membership for 2001: IFP, Mobil and Unocal. This represents a loss of 9 members since 1999 and 16 remaining members for 2001. A concerted effort is being made to communicate with past and possible new members in an effort to reverse this trend. Discussions are underway with the U.S. Department of Energy, Statoil, Petronas, Petrobras, Norsk Hydro, Schlumberger and Saudi Aramco. A sustained oil price of $25 per barrel will help.

TUFFP Reinforces Programming and Data Format Standards

In the late 1980s, TUFFP established rigid guidelines for naming of symbols, Fortran variables and structure of Fortran programs. These steps received strong support from member companies who found it much easier to use, modify and incorporate the software into their own in-house programs. Whenever possible, the guidelines followed those of SPE, but in the multiphase flow field, the SPE guidelines were incomplete. Over the years, we gradually violated our guidelines, not only in programs, but also in the use of symbols in technical papers.

Holden Zhang spearheaded an internal work group over the summer and the TUFFP guidelines have now been expanded and will be used in the future. These guidelines are available for downloading on the TUFFP Web site.

TUFFP has never adopted specific guidelines for reporting of experimental data. Emmanuel Delle Case has developed guidelines that will be used in the future. This will also permit TUFFP members to download and easily use experimental data generated from experimental research projects.

TUFFP Financial Status Stable

The aggressive cost cutting enforced by TUFFP during 1999 resulted in a year-end reserve fund balance of approximately $160,000 or about the same as for 1998. This was accomplished in spite of a loss of three members during 1999. Cost containment has continued throughout 2000 to partially offset income reduction from losing an additional six members. Essentially all of the losses were due to mergers and unprecedented reductions in all expenditures related to research.

For 2001 we anticipate losing an additional three members. As a result, we have no alternative but to increase our membership fees from $30,000 to $35,000.

Every attempt will be made to continue aggressive cost control during 2001 to improve this financial picture. In addition, efforts are underway to collect unpaid membership fees from two companies in 1999. All but four companies have now paid their 2000 membership fees. At this time we anticipate a reserve fund balance at the end of 2000 of $180,000.

Meetings and Conferences

ETCE 2000 and ETCE 2001, Past and Future

The final tally for the Petroleum Production Technology Symposium at the 2000 ASME Energy Technology Conference and Exhibition (ETCE) was fantastic. ETCE 2000 was held February 14-16, 2000 at the New Orleans Sheraton Hotel. 85 technical papers were scheduled in 28 technical sessions, with 3 concurrent sessions occurring throughout the Symposium. These included five multiphase flow sessions comprising 16 excellent papers and a keynote talk by Cliff Redus. Also included were: 4 papers on pumping, 5 papers on flow assurance, 9 papers on separation, 4 papers on IPR, 5 papers on formation damage, 3 papers on metering, 4 papers on optimization plus a keynote talk, 8 papers on horizontal wells, 9 papers on erosion, 6 papers on simulation, 4 papers on artificial lift plus a workshop, and 8 papers on pollution and environmental issues. Jim Brill chaired the Symposium, and key players included 21 Steering Committee members and 17 additional professionals that served as Session Chairs or Vice-Chairs.

The University of Tulsa was well represented and received several awards at ETCE 2000. Jim Brill received the Frank Walk Service Award in the Petroleum Production area and the Collier Service Award. The University of Tulsa also received the Jacobson Best Paper Award for the paper entitled “Investigation of Paraffin Deposition during Multiphase Flow in Pipelines and Wellbores - Part 1 - Experiments” by A. Matzain, M. Apte, H. Zhang, M. Volk, J. Brill and J. Creek.

Plans are rapidly progressing for ETCE 2001, which will be held at the Sheraton North Houston Hotel near George Bush Intercontinental Airport, February 5-7, 2001. It now appears that approximately 50 papers will be presented in the Production Technology Symposium, together with two or three workshops on gas lift and other topics that complement technical papers being presented. Stuart Scott of Texas A&M (a TUFFP alum) and Jim Brill serve as Symposium co-chairs. Luis Giusti, former CEO of PDVSA in Venezuela and Mike Wiley, new CEO of Baker Hughes will deliver keynote addresses. Both are Petroleum Engineering graduates from Tulsa University.

2000 TUFFP Membership

Arabian Oil Co., Ltd.

Baker Atlas

BG Technology

BP Amoco Exploration

Chevron Petroleum Technology Company

Conoco, Inc.

Ecopetrol/Instituto Colombiano Del Petroleo

Elf Exploration

ExxonMobil Upstream Research

Institut Francais du Petrole

Intevep

Japan National Oil Corporation

Marathon Oil Company

Minerals Management Service

Mobil Research and Development

Pemex Exploration y Produccion

Phillips Petroleum Company

Texaco

UNOCAL

Fall 2000 TUFFP Advisory Board Meeting

Final plans have now been made for the Fall 2000 TUFFP Advisory Board and related meetings. All meetings will be held at the Tulsa Marriott Southern Hills. The TUFFP Advisory Board meeting will begin at 8:30 a.m. on Thursday, November 16, 2000 and will adjourn at 5:00 p.m. A tour of test facilities will be held at 4:00 p.m. on Wednesday, November 15, 2000. Following the tour on Wednesday there will be a joint reception at the Tulsa Marriott Southern Hills from 6:00 - 9:00 p.m. TUFFP members will be joined by those attending the Paraffin Deposition Projects Advisory Board meeting that will be held earlier that day.

The Request for Information form and the Hotel Information form are included with this newsletter. All persons from your company that plan to attend the Advisory Board meetings should complete and return these forms as soon as possible to enable us to plan accordingly. Information on the Advisory Board meeting can also be found on our web site at www.tuffp.utulsa.edu/ABM/index.html. You can then follow the links for the Request for Information form and the Hotel Reservation form. The Request for Information form is an online form that can be submitted via the internet. The Hotel Reservation form is a word document for downloading and faxing to the hotel.

A summary of the dates for the Fall 2000 and the Spring 2001 Advisory Board activities are shown in the table below. The Spring 2001 Advisory Board meetings have been tentatively scheduled for the Adam's Mark Hotel.

TUFFP Advisory Board meeting brochures will be available for members at the meeting and a concerted effort will be made to have the brochure available for downloading from the TUFFP web site at www.tuffp.utulsa.edu shortly before the meeting. The brochure will contain sufficient information to help each attendee to actively participate in discussion on current and future research projects, financial matters, and operating procedures. The brochure will also contain slide copy for all presentations.

Future Advisory Board Meetings Schedule

November 15, 2000

Meeting	**TUPDP Advisory Board Meeting Tulsa Marriott Southern Hills**
Tour	**Tour of TUFFP Test Facilities University of Tulsa - North Campus**
Reception	**Joint TUFFP/TUPDP Cocktail Reception Tulsa Marriott Southern Hills**

November 16, 2000

Meeting	**TUFFP Advisory Board Meeting**

May 23, 2001 (Tentative Schedule)

Meeting	**TUPDP Advisory Board Meeting Adam's Mark Hotel**
Tour	**Tour of TUFFP/TUPDP Test Facilities University of Tulsa - North Campus**
Reception	**Joint TUFFP/TUPDP Cocktail Reception Adam's Mark Hotel**

May 24, 2001

Meeting	**TUFFP Advisory Board Meeting**

BHR Group Conference in Banff Springs a Resounding Success

Since 1991, TUFFP has participated as a co-sponsor of BHR Group conferences on Multiphase Production. In odd years, the June conference is held in Cannes, France. In 1998 and 2000, conferences were held in Banff Springs, Alberta, Canada. In addition to submitting technical papers, TUFFP personnel participate in reviewing papers, serving as session chairs, and advertising the conferences to our member companies. The 2000 conference this past June involved 26 technical papers (3 from TU) and was attended by 100 people from around the world.

TUFFP Short Course Another Success

For the first time, the TUFFP Short Course "Two-Phase Flow in Pipes – State of the Art" was held in Houston, Texas on May 8-12, 2000. The course was taught by Jim Brill and was attended by 13 engineers, including 8 from 4 TUFFP members and 5 from 4 non-member firms. The diversity of the attendees continues to amaze us with multiple persons having BS, MS and PhD degrees in Petroleum, Mechanical, Chemical, Civil and Electrical Engineering.

Paraffin Deposition Consortium History and Projects

With the conclusion of the 4-year, $4.6 million Paraffin Deposition JIP in December 1999, it was clear that the petroleum industry desired that this research be continued. A proposal was prepared for the formation of a focused Paraffin Deposition Prediction Research and Model Validation Consortium (TUPDP) and mailed to companies worldwide in July 1999. The proposal called for a minimum of 14 companies participating at $30,000 per year each and DOE funding of $400,000 per year.

Single-Phase Paraffin Deposition Flow Loop

TUPDP was officially started on June 1, 2000 with 20 paying member companies and three non-paying companies. DOE funds have not yet been secured, but member companies unanimously asked that TUPDP start to permit addressing some of their deep water flow assurance needs. Current members include: Alberta Research Council (in kind), Baker Petrolite, BG Technology, BHP Petroleum, BP Amoco, Champion Technologies, Chevron, Conoco, ExxonMobil, Halliburton, International Specialty Products, Marathon, MMS, MSI (in kind), Nalco/Exxon, ONGC, Pemex, PetroCanada (in kind), Phillips, Shell, Statoil, Texaco, and TotalFinaElf. Several additional member companies are anticipated.

Three operating committees will help guide all research activity. The Model Development Committee will help our research staff with reviewing existing single and multiphase deposition models, define deposition physics tasks, help identify key parameters affecting deposition, propose improvements to models, help develop experimental test matrices and participate in upgrading computer programs and graphical user interfaces. The Model Validation Committee will work closely with full time staff and students to plan test facility improvements and operating procedures, design new spool pieces for analysis of deposits, help select instrumentation and sampling techniques, guide us in analytical techniques and procedures, help establish criteria for data acquisition and processing, identify and arrange for transport of other oils, and help coordinate field studies to validate models. The Technology Transfer Committee will address publications, data distribution, Web site information and releases of new codes.

Significant efforts will be devoted during the next three years to modeling at both the macroscopic and microscopic levels. The entire area of deposition physics will be studied, including investigation of deposit aging and physical characteristics of deposits. A new generation of sensors will be pursued to permit monitoring of deposits in the field. Additional oils will be tested, as will the effect of water fraction on deposition.

Since June 1, several improvements have been made to the test facilities. The multiphase flow loop has been modified in preparation for some non-deposition heat transfer tests and precise flow pattern maps generation. Several temperature sensors have been added to yield more information such as pipe wall temperatures. These tests will allow us to determine the influence of pressure on flow pattern boundaries and to develop heat transfer correlations suitable for crude oil and natural gas at pressures up to 750 psia. These correlations will then be used for analyses of data from subsequent wax deposition tests and will be very useful for modeling and understanding of deposition phenomena. The flow pattern tests began in mid August 2000.

The multiphase flow loop data acquisition and control system has also been modified to incorporate a more robust safety algorithm and emergency shut-down procedure. Control algorithms have also been replaced to allow a more flexible operation strategy. Finally, minor modifications have been made to permit long-term deposition tests (up to 30 days).

The single-phase flow loop data acquisition and control system is being upgraded to Intellution FIX 32 and several control valves are being added to allow extensive testing and better control of the facility. The quality of data will improve from these modifications.

As part of the new Wax Consortium, new spool pieces are being designed to include additional measurements during the deposition tests. These spool pieces will be designed to yield information such as wall temperatures and heat flux as well as allowing on-line sampling. On-line sampling is necessary to assess the evolution of the wax properties with time and focus on the aging phenomenon.

Multiphase, High Pressure Paraffin Deposition Flow Loop

Oris Hernandez, an MS student, is currently implementing a new deposition model proposed by Phillips Petroleum Co. This new model is based on convective mass transfer instead of molecular diffusion to predict wax deposition rate. By Colburn analogy, the difference between both methods is a factor dependent on the Lewis number. Ms. Hernandez is now modifying the single-phase program developed during the WAX JIP and comparing the new model results with data from previous single-phase tests. Preliminary comparisons suggest significant improvement is obtained in prediction of wax deposition rate when using the new method. The same modifications will be made to the multiphase wax deposition prediction program along with implementation of new correlations for oil content in deposit and the shear stripping effect.

Rishi Adari, a new PhD student, will be the Research Assistant assigned to the multiphase flow experimental program.

Two-Phase Flow in Hilly-Terrain Pipelines

Eissa Al-safran

A hilly-terrain pipeline consists of interconnected horizontal, uphill, and downhill sections. Both offshore and onshore pipelines exhibit such configurations. The prediction of slug characteristics under these conditions is important. Slug generation often causes operational problems, flooding of downstream facilities, severe pipe corrosion, and structural instability of the pipeline, as well as production loss and poor reservoir management.

In this study, two-phase flow in hilly-terrain pipelines will be investigated experimentally and theoretically. The objectives of this project are to:

- investigate slug initiation at the bottom elbow and slug dissipation at the top elbow.
- develop closure relationships for slug tracking models.
- generate data to evaluate the developed models.
- develop a model to simulate two-phase flow in hilly-terrain pipelines.

Hilly-Terrain Pipeline Meter Runs

The experimental program is a major part of this project. The test facility used was a TUFFP flow loop located at the North Campus of The University of Tulsa. This test facility is a 420-m (1378-ft) long, 50.8-mm (2-in.) diameter, horizontal steel pipeline that was recently modified to conduct the experimental part (phase I) of this study.

A new test section made of 2-in. diameter transparent acrylic pipe simulates a single hilly-terrain unit of 70-ft uphill (downhill) and 70 ft downhill (uphill) sections. The inclination angles to be investigated are horizontal and ±1°, ±2° from horizontal, including valley and hill configurations. The test section contains four measurement stations to monitor the change in slug flow characteristics along the test section. A total of 115 tests were conducted with hill and valley configurations. The superficial liquid and gas velocities ranged from 0.2 to 4 ft/s and from 2 to 15 ft/s, respectively.

Hilly-Terrain Pipeline Test Section (Hill Configuration)

A two-phase flow mechanistic model to predict slug initiation at the bottom elbow, slug dissipation at the top elbow, and slug length distribution at the hilly-terrain pipeline entrance are the focused modeling tasks of this project. Furthermore, closure relationships will be developed to improve the prediction of slug dissipation and generation in the downhill section and uphill section, respectively. The film hydrodynamics will be investigated because of its crucial role in the above-mentioned mechanisms. These models and closure relationships will be integrated into the TUFFP slug-tracking model to improve its predictions.

Significant progress has been made since the last Advisory Board meeting in May 2000. The entire experimental part of this project was completed and data processing is underway. A detailed progress report will be presented at the next Advisory Board meeting in November 2000.

Mechanistic Heat Transfer Model and High Pressure Flow Pattern Validation for Inclined Two-Phase Flow

Ryo Manabe

Estimating heat transfer, including the prediction of convective heat transfer coefficients, for gas-liquid two-phase flow is a primary concern in modeling thermal behavior of petroleum multiphase systems. However, the petroleum industry has paid less attention to heat transfer in multiphase flow than to the hydrodynamics, such as flow pattern, pressure drop and liquid holdup. Thus, the heat transfer for natural gas-oil two-phase flow is not well understood, and a robust prediction method for all possible operating conditions in petroleum multiphase systems does not exist.

Flow pattern is a central issue in two-phase hydrodynamics. Clearly, two-phase heat transfer strongly depends on the existing flow pattern. Although existing flow pattern models have been well validated in low-pressure systems, the validity of these models under high-pressure conditions has not been adequately documented in the literature.

Capacitance Sensor

The objectives of this project are to:

- acquire experimental data on flow pattern transition boundaries and heat transfer for high-pressure, gas-liquid (natural gas-crude oil) two-phase flow in horizontal, vertical and inclined pipes.
- verify and extend the mechanistic flow pattern transition models to high-pressure conditions.
- develop a comprehensive mechanistic heat transfer model.
- validate the proposed model with experimental data.

A new spool piece with a high-pressure capacitance sensor and probe was installed with a new high-frequency data acquisition system. Manufacturing and calibrating this new spool piece took much longer than anticipated. Data acquisition began in mid August 2000 and will be completed at the end of October 2000. The results of the experimental study will be presented at the next Advisory Board meeting in November 2000.

Low Liquid Loading Gas-Liquid Flow in Near-Horizontal Pipes

Gas-liquid two-phase flow exists extensively in the transportation of hydrocarbon fluids. A more precise prediction of liquid holdup in near-horizontal, wet-gas pipelines is needed in order to better size downstream processing facilities. Stratified flow and annular flow are the two flow patterns observed most often in near-horizontal pipelines under low liquid loading conditions.

The objective of this study is to investigate, experimentally and theoretically, low liquid loading gas-liquid two-phase flow in near-horizontal pipes, and to develop improved design models for wet-gas pipelines.

Nicolas Olive by Liquid Film Removal Device

A 50.8-mm inner diameter, 19-m long test facility is being used for this study. The test loop can be inclined from –2° to +2° from the horizontal. The fluids used for this study are air and water. The measured parameters include gas flow rate, liquid flow rate, pressure, differential pressure, temperature, liquid holdup, liquid film flow rate, wave characteristics (frequency and amplitude), droplet entrainment fraction and droplet deposition rate. A new capacitance probe is being built which can be used to measure the wave frequency and amplitude.

A surprising phenomenon was observed by Meng (1999) with air-oil flow in a previous study using the same flow loop. At high gas velocities (annular flow), liquid film flow rate, liquid holdup and pressure gradient decreased as liquid velocity increased. However, this phenomenon could not be reproduced with air-water flow, possibly due to the differences in fluid properties. However, a new phenomenon was observed with air-water flow. At low superficial velocities and with a liquid loading larger than 600 m^3/MMm^3, the liquid holdup increased as gas superficial velocity increased.

This study was reoriented after the May 2000 TUFFP Advisory Board meeting. According to the comments and expectations from member companies, the liquid loading range was changed from 300-1800 m^3/MMm^3 to 50-900 m^3/MMm^3. A new turbine meter for water was installed in the flow loop. With this new flow meter, we can measure liquid loadings as low as 50 m^3/MMm^3 (about 10 bbl/MMscf).

A new model will be developed for prediction of liquid hold-up and pressure gradient in wet-gas transportation. The interfacial friction factor will be evaluated in terms of the interfacial wave structures. The characterizations of the waves will be correlated to the gas and liquid flow rates based on the experimental results. A correlation developed by Lopez (1994) will be used to calculate the friction factor from wave characteristics.

BP Amoco Flow Loop Donation

When BP Amoco decided to terminate future experimental research using a 6-in. diameter, 400-ft long pipeline located at their Sunbury Technology Center, they donated the flow loop to TUFFP. On behalf of the other TUFFP members and The University of Tulsa, we express our sincere gratitude to BP Amoco for this marvelous donation.

BP Amoco Flow Loop Facility

Site preparation work at the TU North Campus was completed in July and the flow loop arrived in Tulsa from the UK in August 1999. Unfortunately, all of the 6-in. pipe was damaged during shipment and efforts to salvage the pipe failed. BP Amoco is funding the purchase of new clear PVC pipe and fittings, a new 2,000-gallon liquid storage tank (separator), and a variable speed drive for the liquid pump. The target date to commission the flow loop is just before the November 15-16, 2000 TUFFP Advisory Board Meeting.

The new flow loop will be used as a research facility and also as a multiphase flow demonstration laboratory for petroleum engineering students and professionals. The initial research project that will be conducted will be an extension of the current low liquid loading project using air and water in a 2-in. flow loop. This will permit investigating the effect of pipe diameter on phenomena observed. Due to its large diameter, the 6-in. flow loop is also an ideal apparatus to study wave characteristics and interfacial shear stress in stratified flow.

Slug Tracking in Hilly-Terrain Pipelines

This project is being conducted for TUFFP at the Department of Fluid Mechanics and Heat Transfer at Tel-Aviv University under the direction of Professors Yehuda Taitel, Dvora Barnea and Lev Shemer.

EXPERIMENTAL

Measurements of the spatial evolution of the liquid slug length and the elongated bubble length distributions along the pipe were performed. The measuring module, which includes three fiber probes at a fixed distance of 2 cm between adjacent probes, can be located at various distances from the pipe inlet. Measurements are performed in two pipes, with internal diameters of 24 mm and 54 mm, for inclined and vertical upward slug flow and various gas and liquid flow rates.

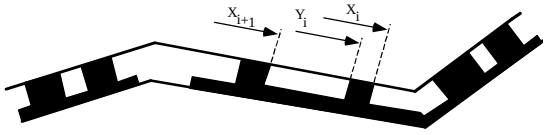
The fiber probes provide direct information on the time history of the passage of a gas-liquid interface. This information is sampled using a fast A/D converter and recorded for further processing. Instantaneous velocities of propagation of the gas-liquid interface are determined by comparing the time histories recorded by the adjacent probes. These velocities are then used to translate the directly measured time distribution at each measuring location into the length distributions of elongated bubbles and liquid slugs. Instantaneous and averaged propagation velocities of the elongated bubbles are determined

for various locations along the pipe. In addition, the bubble propagation velocities as a function of the liquid slug length ahead of the bubble are determined at different measurement locations. The dependence of the bubble translational velocity on the liquid slug length ahead of it is an essential input for the slug tracking model.

The experimental work is part of Rene van Hout's Ph.D. project entitled "Investigation of the hydrodynamic and kinematic parameters in gas liquid undeveloped slug flow" supervised by Prof. Shemer and Prof. Barnea. Considerable data have been accumulated and are now in the process of analysis. Target date for the submission of the Thesis is December 2000.

THEORETICAL

A working program was presented and submitted to TUFFP in May 2000. Detailed explanations of how to run the Code were given to Eissa Al-safran for use in the simulation of his experimental results. Based on his experimental data, some of the empirical inputs used in the Code can be improved.



The Code has the following major empirical inputs:

- slug length distribution at the entrance.
- the dependence of the bubble velocity on the slug length ahead of it.
- the slug length distribution generated at bottom elbows.
- the void fraction within the liquid slugs.

The experiments performed by van Hout and by Al-safran should improve the empirical correlations to be used with the slug tracking Code. The Code can now simulate many actual cases and is still in the process of being improved.

A Unified Comprehensive Mechanistic Model for Gas-Liquid Flow in Wells and Pipelines

Development of a unified comprehensive mechanistic model for predicting two-phase flow behavior in pipes at any inclination angle was one of the highest ranked projects by TUFFP members in the 1999 questionnaire. A comprehensive flow behavior (hydrodynamic) model is also the first essential step in the development of a mechanistic model for predicting multiphase heat transfer in wells and pipelines (another highly rated project in the 1999 questionnaire). These two projects are clearly interrelated.

An improved multiphase heat transfer model is needed to calculate different parameters for heat and mass transfer in the paraffin deposition process. Consequently, the high- pressure multiphase flow paraffin deposition flow loop was loaned to TUFFP by the new Paraffin Deposition Consortium to complete the experimental part of the project "Mechanistic Heat Transfer Model". This project is described elsewhere in the Newsletter.

It is now time to proceed with the development of a unified hydrodynamic model. TUFFP has developed different comprehensive mechanistic models in the past (Ansari model for upward vertical flow, Xiao model for near horizontal flow, and Kaya model for deviated wells). However, there are gaps between these models that must be filled to create a unified model. The major difficulty in development of the unified mechanistic model is the closure relationships for the momentum equations. These relationships must behave smoothly for inclination angles from –90° to 90°.

This new project was initiated in July 2000. Holden Zhang is currently selecting the best models and the required closure relationships from the literature. Existing relationships will be modified or new relationships will be developed if no satisfactory models are found for the different flow conditions. The new unified model will be verified with published data and with the TUFFP databanks. A progress report will be presented at the Advisory Board meeting in November 2000.

Two-Phase Flow Calendar

2000

October 1 - 4
SPE Annual Technical Conference and Exhibition - Dallas, Texas

November 15
Tulsa University Paraffin Deposition Projects (TUPDP) Advisory Board Meeting - Tulsa, Oklahoma

November 16
Tulsa University Fluid Flow Projects (TUFFP) Advisory Board Meeting - Tulsa, Oklahoma

2001

February 5 - 7
ETCE 2001 - Houston, Texas

March 14 - 16
First International Conference on Computational Methods in Multiphase Flow - Multiphase Flow 2001 - Orlando, Florida

March 24 - 27
SPE Production and Operations Symposium - Oklahoma City, Oklahoma

April 30 - May 3
OTC 2001 - Houston, Texas

May 23
Tulsa University Paraffin Deposition Projects (TUPDP) Advisory Board Meeting - Tulsa, Oklahoma

May 24
Tulsa University Fluid Flow Projects (TUFFP) Advisory Board Meeting - Tulsa, Oklahoma

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

June 13 - 15
BHRG Conference on Multiphase Production, Cannes, France