Multiphase flow

PhD program: Multiphase Transport

Dept. of Energy and Process Technology
NTNU

Report year 2006

November 2006
Ole Jørgen Nydal
The following is a report on 2006 activities in the PhD program on Multiphase Transport, and includes reporting on the student projects at the Multiphase flow laboratory at NTNU, Department of Energy and Process Technology. PhD activities are sponsored by a group of companies, and the project students and the laboratory are sponsored through a research agreement with Statoil.
STATUS

Participants in the PhD program in 2006 have been

- BP
- Chevron
- ENI
- Hydro
- Shell
- Total
- Scandpower SPT
- IFE

RESEARCHERS

The persons in Table 1 have been active in the multiphase flow group at NTNU in 2006.

Table 1 Researchers 2006

<table>
<thead>
<tr>
<th>Name</th>
<th>Position</th>
<th>Description</th>
<th>Affiliation</th>
<th>Finance</th>
<th>Complete</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ole Jørgen Nydal</td>
<td>Prof.</td>
<td>Supervisor</td>
<td>NTNU</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Roar Larsen</td>
<td>Prof. II.</td>
<td>Supervisor</td>
<td>NTNU/Sinte</td>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>Monika Johansen</td>
<td>PhD</td>
<td>Slug flow experiments, 3phase</td>
<td>NTNU</td>
<td>Program</td>
<td>2006</td>
</tr>
<tr>
<td>Angela de Leebeeck</td>
<td>PhD</td>
<td>Waves in a slug tracking scheme</td>
<td>NTNU</td>
<td>Total</td>
<td>2009</td>
</tr>
<tr>
<td>Xiaouju Du</td>
<td>PhD</td>
<td>Numerical methods gas liquid flows</td>
<td>NTNU</td>
<td>ENI</td>
<td>2009</td>
</tr>
<tr>
<td>M. M. Shabani</td>
<td>PhD</td>
<td>Hydrate particles in multiphase flow</td>
<td>NTNU</td>
<td>BP</td>
<td>2009</td>
</tr>
<tr>
<td>Jørn Kjølaas</td>
<td>PhD</td>
<td>Hydrate plug simulation</td>
<td>NTNU</td>
<td>Shell</td>
<td>2007</td>
</tr>
<tr>
<td>George Johnson</td>
<td>Post.Doc.</td>
<td>Instrumentation</td>
<td>NTNU/Sinte</td>
<td>Total/Hydro</td>
<td>2007</td>
</tr>
<tr>
<td>Kristian Holmås</td>
<td>PhD</td>
<td>Multiphase CFD</td>
<td>UiO</td>
<td>IFE</td>
<td>2007</td>
</tr>
<tr>
<td>Håvard Holmås</td>
<td>PhD</td>
<td>Numerics of stratified wavy flow</td>
<td>UiO</td>
<td>Scandpower</td>
<td>2008</td>
</tr>
</tbody>
</table>

Trygve Wangensteen started to work with Scandpower on November 1st 2005. Fabien Renault started to work with Banque de France, August 1st 2005. The PhD defenses for both are delayed until the spring 2007.

Monika Johansen defended her thesis on March 16th 2006. The defense was combined with a status meeting in the program.

Angela de Leebeeck, Xiaouju Du and M. M. Shabani started their PhD periods at NTNU after the summer 2006.

George Johnson started his PostDoc period working on instrumentation, in collaboration with SINTEF and IFE (two energy gamma densitometry). In mid 2006 he switched to numerical work.

PROJECT STUDENTS

Final year students participate in the research activities with a project in the fall and a MSc thesis in the spring. If the PhD’s see a need for extended support, we also invite students from European universities. Table 2 shows the student activities in 2006.
Table 2 Student projects at NTNU laboratory 2006

<table>
<thead>
<tr>
<th>2005</th>
<th>Student projects</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Spring</strong></td>
<td></td>
</tr>
<tr>
<td>Tellef Havig -</td>
<td>Netlab, lab control from web site. Moving camera.</td>
</tr>
<tr>
<td>Bård Dragsten Olsen</td>
<td>Flow visualization (video, time traces, flow regimes)</td>
</tr>
<tr>
<td>Andreas Skog</td>
<td>Oil-water: pipe flow and rheometers</td>
</tr>
<tr>
<td>Benjamin Pierre</td>
<td>Experiments. Downwards flow. Effect of inlet conditions</td>
</tr>
<tr>
<td>Jean-Marie Albanese</td>
<td>Downwards flow. Effect of inlet conditions. Simulations</td>
</tr>
<tr>
<td><strong>Fall</strong></td>
<td></td>
</tr>
<tr>
<td>Christine A Maren</td>
<td>Oil-water flow</td>
</tr>
</tbody>
</table>

**MEETINGS**

*Status meetings*
Progress reports are presented by the PhD’s at two yearly meetings. The winter meeting was hosted by Statoil in Trondheim, and was arranged together with the PhD defense of Monika Johansen. The summer meeting was arranged in Murmansk, Russia. The meeting was hosted by Murmansk Technical State University, and partly sponsored by Hydro.
RESEARCH ACTIVITIES

Laboratory
A short description of the multiphase flow laboratory is given in Appendix 1.

Among the laboratory staff, the following persons have participated in the activities in the multiphase flow laboratory:

<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erling Mikkelsen</td>
<td>Verksmester</td>
</tr>
<tr>
<td>Knut Glasø</td>
<td>Verksmester</td>
</tr>
<tr>
<td>Per Bjørnaas</td>
<td>Engineer</td>
</tr>
<tr>
<td>Helge Laukholm</td>
<td>Engineer</td>
</tr>
</tbody>
</table>

The laboratory activities in 2006 were mainly:

- Visualization: video, photo, pressure and holdup recordings
- Experiments with blow out of plug, single and two phase
- Moving camera
- Downwards flow: effect of inlet conditions
- Demonstrations in NTNU courses

Flow modeling
Flow modeling/simulation activities are made in the frameworks of:

- OLGA/Petra/Opus applications
- Special purpose flow modeling in Matlab
  - Matlab provides an efficient framework for prototyping of model concepts and for investigation of special problems (e.g. two-fluid model issues, point models, flow regime transitions, numerical schemes for front capturing). We also use Matlab extensively for analysis of experimental time traces
- C++
  - Plug tracking methods
    - The activity on modeling hydrate plug release during depressurization is made within a slug tracking model, and an object oriented implementation in C++.

Research Council projects
Petromaks
A proposal on gas hydrates (model particles) in multiphase flow was approved by NRC (Scandpower, NTNU, BP). The project is linked to the PhD (M.M. Shabani) sponsored by BP. The project provides funding for experimental costs.

Centre for Research based Innovation
NTNU (Multiphase laboratory and Ugelstad laboratory) participated in an application for the establishment of a CRI on Multiphase Flow Assurance (FACE) together with SINTEF and IFE. About 10 centers, each with a duration of 5-8 years, will be established in Norway during 2006.
FACE was approved and will start in January 2007. The focus of the collaboration is transport of complex mixtures. The annual budget is in the order of 25MNOK.

LIST OF ACTIVITIES
PhD

Title: Experiments on Bubble Propagation Velocity in Three-Phase Slug Flow

Monika Johansen

Supervisor: Ole Jørgen Nydal

Objective
The propagation behavior of large slug bubbles is an important closure model in both averaged slug flow models ("unit cell" models) and in slug tracking models. Experiments have been designed to quantify the bubble velocity for various flow conditions. Simple relations for the velocity shall be suggested on a form which can be implemented in flow simulators.

Activities
Some open questions on the bubble velocity in slug flow relate to transient flows, large diameter pipes, bubbly flows and oil-water flows. The experimental work in the NTNU laboratory has focused largely on the three phase flow problem, where single bubbles have been injected into flowing oil-water mixtures.

Bubble rise velocity in large diameter pipes
Some rise velocity experiments in an air-water system have been made in transparent 20 cm and 40 cm I.D. vertical pipes. The measurements of the Taylor bubble in stagnant liquid gave rise velocities in good agreement with prevailing relations.

Drift velocity in three phase flow
The bubble drift velocity has been measured for horizontal three phase flows with diameters of 5 and 3 cm and for two phase flow with diameters up to 20 cm. A relation suggested by Weber, taking the surface tension into account, corresponds well with the measurements.

Bubble propagation velocity in oil-water flows
Single bubble experiments have been made with both separated and mixed oil-water flows. For separated flows, a bubble propagation relating to the oil velocity is suggested. For mixed oil-water flows, the bubble appears to behave similar as for single phase flows.

Bubble turning process
The conditions for bubble turning in downwards three phase flow have been measured and compare well with a criterion based on neutral pressure drop at the point of transition. The transition is gradual.

Transient flows
Small scale experiments (16 mm I.D.) have been made, where a bubble push liquid out of a pipe in a transient. The bubble and liquid velocities are determined from videos of the bubble and liquid front propagation. The data show some scatter, but the steady flow relations for the bubble velocity compares quite well also for very fast transients.

Completion
Monika completed her work in 2005, and the PhD defense took place in March 2006
PhD

Title: Slug Initiation Methods for Slug Tracking Schemes

Name: Fabien RENAUlT
Supervisor: Ole Jørgen Nydal

Objective
Investigate slug initiation models, in order to improve the precisions of the slug tracking methods.

Background
As general purpose flow models need criteria for flow regime transitions, so do slug tracking codes need models and procedures for slug initiation. How, when and where to initiate the liquid slugs in the stratified flow pipe are the main questions.

Theoretical Investigations

Stability analysis
The work has covered stability analysis of stratified flows, as a method for generating flow regime transition boundaries. This method has weaknesses for high gas density flows, where the transition to slug flow often evolves from wave coalescence, and not from unstable smooth stratified flow.

Two fluid model
Solution of a two fluid model has been investigated, as a general method for slug initiation prediction. The evolution of waves into slugs can be simulated using a fine grid.

Hybrid two fluid and slug tracking model
A combined Lagrangian slug tracking model (slugs are followed) and slug capturing model (slugs are automatically initiated) has been formulated, implemented and tested. The screen-shot on the right shows slug initiation in a 2 cm diameter air/water horizontal 30 m long pipe (pipe holdup in black, pressure profile at the bottom and inlet pressure time series on top).

Experiments

Initiation in bends: Influence of the inclination angle and upstream volume on the length of the generated slugs. The experiments were carried out with the help of two students from ENSAM (France). This project was awarded the third best ENSAM project prize. The results compare well with predictions.

Initiation in an horizontal pipe: Observation of slug initiation mechanisms in a 3 cm pipe: videos, photos, and holdup traces were collected for comparisons with numerical simulations.

Completion
Fabien completed his work in 2005, and the PhD defense will take place in 2007.
Objective
Explore methods for transient multiphase flow simulations.

Background
Many multiphase flow phenomena can be formulated with an incompressible flow model. These models can be used as stand alone models to simulate problems like wavy flow and oil-water flow, or the models can be used as sub models in gas liquid-liquid flow to describe the liquid-liquid flow. To solve these models, numerical methods are needed. These methods differ in accuracy, and robustness and some methods are more applicable for some problems than other.

Activities
Unit cell modelling
Methods for implementing a unit cell slug flow model (or a general algebraic slip relation) on a transient two-fluid model have been investigated. The method in OLGA is based on deriving an interface friction factor from a slip relation. This method has some weaknesses, in particular for cases where the slip relation gives zero relative velocity, where correction schemes must be made. This problem has been solved by using the unit cell holdup instead of the unit cell slip as basis for deriving the interface closure relations.

Numerical methods
A variety of numerical methods based on the characteristics of the model’s Jacobian has been investigated: Godunov, ROE/FDS and different variations of second order accuracy. These methods work very well when the models have distinct eigenvalues, but they fail for singular problems, like transition to single phase flow. A new numerical method (Harmonic scheme) based on the slip velocity is developed. This method, compared with the Jacobian based schemes, is simpler and robust for flow phenomena where the Jacobian based schemes fail. For special flow problems, like wavy flow, the Harmonic scheme is less accurate than the Jacobian based schemes.

Completion
Trygve completed his work in 2005, and the PhD defense will take place in 2007.
PhD

Title: Gas hydrate plugs in multiphase flow lines

Name: Jørn Kjølaas

Supervisor: Ole-Jørgen Nydal

Background
The PhD work concerns prediction methods for the flow dynamics of a plug propagating in a two phase flow line. Single sided depressurization across a hydrate plug represents a potential hazardous operation, as the may release and propagate at high speeds through the pipeline.

Objective
The objective of the PhD work was then to establish a numerical model for the plug release problem, and compare predictions with available experimental data.

Activities and results
The original slug tracking scheme, which was based on uniform pressure in the bubble, was compared with the Statoil experiments, where a model plug (400 g) was inserted into a vertical pipe (7 m high) and subject to a high pressure difference (up to 30 bar) by the sudden opening of a valve. The Figure shows that including a steady state pressure drop term in the bubble lead to improved predictions.

However, when comparing the modified model with the deep star data, the compression wave had to be included in order to reach the measured high plug velocities. The scheme was therefore modified to include a full two fluid model in the bubble region, and the energy equation was implemented as well.

Experiments
Some small scale experiments were made, where foam plugs were subject to a differential pressure, resulting in a very rapid expulsion of the plug. This was made with and without initial liquid in a pipe bend. Comparisons between experiments and simulations show that the initial transient is well reproduced, but the further damping is too low in the computations.
Post Doc

Title: Instrumentation

Name: George Johnson

Responsible: Ole Jørgen Nydal

Background
The NTNU laboratory has largely been used for transient type of flow experiments, and mainly with two phase gas-liquid. Moving on to three phase flow dynamics, we have a need for instrumentation for dynamic phase fractions measurements of gas, oil and water.

There are ongoing development projects on tomographical methods at other places, covering both impedance methods (notably Univ. Rosendorf, Germany) and X-ray methods (notably Imperial College, UK). Both IFE and SINTEF have tested impedance based tomographs in their laboratories, and those instruments appear to give valuable results for phase distribution across the pipe cross section area. The methods are, however, limited to stationary flows and/or to two-phase flows.

Dual energy gamma densitometry has been developed at IFE and applied in research projects at SINTEF and IFE on measuring dynamic three phase flows in pipes. Both narrow beam and broad beam configurations have been applied, and significant efforts have been invested in optimizing the instruments. The experience with the instrument is that the accuracy of the gas fraction measurement is acceptable, whereas the measured oil and water fractions need improved accuracy.

The background for an activity on instrumentation for phase fraction measurements is then

• There is a need for improved phase fraction instrumentation at the multiphase flow laboratories
• IFE and SINTEF have particular experience in developing and applying gamma densitometers for two and three phase flows
• The multiphase laboratory at NTNU has been granted university funding for instrumentation

Objective
The objective of the work is to develop new instrumentation for measurements of multiphase flow in pipes. Dynamic phase fraction measurements are needed for three phase flows and for flows with particles.

Activities
The work will focus on two energy gamma densitometry, in collaboration with SINTEF Multiphase Flow Laboratory. The type of work will include

• Evaluation of the existing instruments at SINTEF
• Improving the electronics part
• Improving the response model in order to arrive at efficient calibration procedures
• Testing in the laboratories at SINTEF and NTNU
PhD

Title: Numerical Simulation of two-phase pipe flows

Name: Angela De Leebeeck

Responsible: Ole Jørgen Nydal

Background

The title of the PhD is quite general. The focus will be on numerical issues of transient two phase flow, in a continuation of previous work at EPT. A particular problem in slug tracking models is the phenomena of large waves. At the point of transition to slug flow, where slugs are formed from stratified flow or decay from slug flow, the waves may be on the same scale as slugs. The starting point of the PhD work of Angela is to consider methods for dealing with waves in a slug tracking scheme.

One approach is to capture the initiation and evolution of waves from the solution of a two fluid model. Fabien and Trygve have demonstrated that this is numerically possible, although the accuracy depends on the numerical scheme as well on the model formulation. The evolution of an unstable flow phenomenon is difficult to model, in particular for a 1 dimensional model.

The other approach is to extend the slug tracking thinking to waves as well. If we do not aim at capturing the evolution of waves into slugs from a two fluid model on a fine grid, then we need slug initiation models (transition criteria and initial conditions). In high pressure flows, the transition is most often from wavy flow to slug flow, not from smooth stratified flow to slug flow, as can be seen in low pressure systems. An initiation model could then be applied to wave initiation, instead of slug initiation. The further evolution of the waves could be attempted with an integral wave model and a tracking scheme.

Objective

The objective of this PhD work is to develop a numerical wave model for the multiphase flow where large waves are on the same scale as slugs. A

Activities

Literature review on large waves in pipe flows
Formulation of an integral wave model
Implementation and testing in a slug tracking scheme
PhD

Title: Numerical methods for two phase flows

Name: Xiaoju Du

Responsible: Ole Jorgen Nydal

Background
This PhD project will be part of an existing project “Multiphase Transport” at NTNU, EPT (O.J. Nydal) focusing on the transport of oil and gas mixtures in pipelines. Multiphase flow is a complex phenomenon which depends on the physical parameters of the flow, several different flow regimes may occur. Flow regimes are commonly divided into separated (stratified, annular) and mixed (bubbly, dispersed) flows.

Pipeline simulators are commercially available, and in extensive use by petroleum engineers worldwide (f.ex OLGA). Transient and dynamic flows are particular classes of flow problems where the numerical methods become important. The PhD work will target some specific numerical challenges, some of which are also weak points in the commercially available programs.

Objectives
The objectives of the work is to arrive at improved numerical methods for one dimensional transient simulation of multiphase pipe flows. This project will be related to novel methods (slug tracking, multiscale) and to modern implementation methods (object oriented). Efficient, accurate and robust numerical schemes are to be constructed and tested by many numerical experiments. Moreover, the design should encourage code re-use to avoid unnecessary duplication.

Scope
Some numerical issues of practical importance in transient two phase flows are: staggered versus non-staggered grid, iterative versus non-iterative, adaptive grid for gravity dominated flows, water in slug tracking scheme, transient flows with steady gas approximation, multilevel modeling, level gradient driven flows.

The research tasks will be prioritized in discussion with ENI.

The work will be mainly numerical. However, for certain flow problems, some experiments may be undertaken in the multiphase flow laboratory. This can be made by defining MSc projects, supervised by the PhD candidate.

Research methodology
The methodology will largely be numerical experiments. It is likely that many numerical schemes will be tested in this project. The schemes will be compared to each others, as well as to commercially available programs (whenever appropriate). Some problems will also be tested against available experimental observations.

The numerical experiments will, as far as possible, be made in the framework of C++ classes. This will provide for reuse of the generated code.
Background
Gas hydrate management is a very critical issue in the design and operation of multiphase pipelines. Classical hydrate management strategies aims at avoiding the formation of hydrates in the pipes. The “cold flow” methods take the opposite approach, by allowing controlled formation of hydrates which are transportable, and which do not agglomerate into plugs. If future pipelines may carry multiphase mixtures with gas hydrate, then the prediction tools must be extended accordingly. As part of such an activity, a PhD study will focus on liquid-particle flows.

Objective
The objective of the study is to perform flow experiments with hydrate-like particles, with emphasis on transient flow conditions (e.g. shut-down, start-up, settling/dispersion, slugging).

Activities
Particles
Model particles will be made in collaboration with SINTEF Materials and Chemistry, and the ongoing hydrate research at SINTEF Petroleum Research. The particles will, as far as possible, have similar characteristics as real hydrates (size distribution, shape, density and wettability).
Laboratory
Modifications to the NTNU multiphase laboratory (air-oil-water) will include: Inlet for particles, separation at the pipe outlet, conditioning of particles for recirculation, varying pipe geometries for transient experiments.
Instrumentation
Video-based observations will be made, as the test pipes are transparent. The aim is also to acquire a dual energy gamma densitometer, and to evaluate impedance ring probes for hydrate recordings. Pressure recordings is part of the standard instrumentation. A device for measuring the inlet particle rates must be established. It may also be possible to "mark" the model particles (e.g. fluourescently, radioactively, or in a similar manner) to allow specific measurements to be made.
Flow experiments
Experiments will primarily be made for transient liquid-particle flows (shut-in / restart / rate changes) in varying pipe geometries (e.g. bends). Three-phase experiments will be made as far as time allows.
Flow modeling
The experiments will be compared with available flow models: OLGA and research codes at NTNU.
Title: Modeling of gas-liquid two-phase flow using CFD

Name: Kristian Holmås, IFE

Supervisor: Jan Nossen IFE, Hans Petter Langtangen, UiO, Ruben Schulkes, UiO

The PhD project was started in February 2004. The candidate is testing and further developing various CFD techniques for simulation of two-phase flow. The objective is to extract 3-D effects (velocity profiles, interface structure etc.) from the results of the CFD simulations and use this information to improve the 1-D models.

The project can be divided in three parts:

Turbulence modeling. 2-D CFD simulations of stratified two-phase flow in a horizontal channel have been performed. The simulations revealed that interfacial relations and a modified k-ε turbulence model have to be developed. Special conditions for the turbulence at the interface have been developed, but they have not yet been implemented.

Numerical methods. A standard level-set multiphase flow method has been implemented in an in-house finite element solver. Simulations of some test cases (most important stratified flow) showed that this method has too much numerical smearing at the interface. Therefore, a sharp interface finite element method has been developed.

Improve the 1-D models. 2- and 3-D CFD simulations of two-phase stratified flow as single-phase channel/pipe flow influenced by a moving wall has been performed in order to validate and improve the 1-D stratified flow model of Dag Biberg.

Publications
Paper to the 12th Int. Conference on Multiphase Production Technology 2005: “Simulation of wavy stratified two-phase flow using Computational Fluid Dynamics (CFD)”.

Paper to the 4th Int. Conference on CFD in the Oil and Gas, Metallurgical & Process Industries 2005: “Simulation of two-phase fluid flow using both the level-set and the volume of fluid methods”.


**PhD**

**Title:** Transient Simulation of Waves in Pipeflow with an Incompressible Two-Fluid Model

**Name:** Håvard Holmås, Scandpower Petroleum Technology (SPT)

**Supervisors:** Hans Petter Langtangen, UiO, Ruben Schulkes, UiO, Magnus Nordsveen, SPT

**Objective**

Investigate new physical formulations and implement higher order numerical methods for resolving waves in multiphase flow pipelines.

**Performed work**

The PhD project was started in August 2005. The first ten months were spent on continuation of work performed by the PhD candidate in his Master project. Effects of adding a diffusion term to an incompressible two-fluid model were investigated. It was found that second order diffusive terms can remedy the ill-posedness of the model by stabilizing short wavelengths. Simulations confirmed the mathematical analysis by demonstrating convergent numerical solutions for flow conditions beyond the inviscid Kelvin Helmholtz line. The results have been reported in a paper that has been submitted to the International Journal of Multiphase Flow.

The next step in the PhD project has been to study and implement a pseudospectral numerical method for the same two-fluid model. The particular numerical method is well-known in other areas in physics (e.g. turbulence modeling, meteorology, oceanography). However, to the knowledge of the candidate, it has not previously been applied to the modeling of multiphase pipe flow. The motivation for using this method was a need for a numerical scheme that could combine a high degree of accuracy with flexibility in terms of handling different types of equations. Thus, the undesired numerical effects can be minimized, and the method can become a useful tool for investigating new stratified wavy flow models. The candidate is currently in the process of verifying the new code, and the preliminary results have been outlined in an abstract paper submitted to the International Conference on Multiphase Flow 2007.

**Courses**

The compulsory PhD courses have been completed. They include UNIK4600 Mathematical Modeling of Physical Systems, INF-MAT4350 Numerical Linear Algebra and MEK4320 Hydrodynamic Wave Theory. All courses were taken at the University of Oslo.
STUDENT PROJECTS

NETLAB
Tellef Havig (Dept. Cybernetics) Co-supervisor: OJ Nydal

NetLab is a system for on-line control of the laboratory through a web site. Tellef has resolved limitations due to firewalls. In his MSc work, Tellef considered the control of a moving camera based on on-line digital image analysis. The image analysis could also be used for estimation of the liquid level in stratified flows.

VISUALIZATION OF TWO PHASE FLOWS
Bård Olsen Supervisor: OJ Nydal

Bård performed a series of high speed videos, normal videos and pressure and holdup recordings for a range of flow regimes. The flow visualization is prepared on a cd, with html or power point front end.

HEAVY OIL – WATER MIXTURES: MEASUREMENTS IN PIPE FLOWS AND RHEOMETERS
Anders Skog Supervisor: OJ Nydal, B. Pettersen (Statoil)

Anders compared measurements in pipe flows and in rheometers of oil-water mixtures. The oil was a real oil, and the experiments were made at Statoil Research Centre. For suitable low rpm-s for the rheometer, the two measurements were qualitatively similar, showing same inversion behaviour.
SLUG DECAY IN DOWNWARDS PIPES
Jean Marie Albanese, Benjamin Pierre        Supervisor: George Johnson

The flow in a downwards oriented pipe was studied in a small scale system. The flow regime was strongly dependent on the inlet flow conditions (slug flow or stratified flow at the inlet).
Attachment to report 2006: Laboratory

MULTIPHASE FLOW LABORATORY

The main purpose of the loop is to provide a flow laboratory for students (projects, MSc, PhD.) and a demonstration facility which can be used in courses.

The main specifications are given in the table below.

<table>
<thead>
<tr>
<th>Test sections</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Straight Acrylic</td>
<td>6 cm ID and 3 cm ID, 16 m long, +/- 15° inclination</td>
</tr>
<tr>
<td>Straight Steel</td>
<td>6 cm ID, 16 m long, +/- 15° inclination, coated and non-coated</td>
</tr>
<tr>
<td>Flexible PVC</td>
<td>5 cm ID, 30 m long configurable, transparent</td>
</tr>
<tr>
<td>S-riser</td>
<td>Acrylic, 5 cm ID, 16 m long, 7 m high</td>
</tr>
<tr>
<td>L-riser</td>
<td>Acrylic, 5 cm, 16 m long, 7 m high, +/- 1 degree first part</td>
</tr>
<tr>
<td>Fluids</td>
<td>Air from central system, tap water, oil</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow rates</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>air</td>
<td>0.5 – 30 m/s (vortex meter and coriolis meter)</td>
</tr>
<tr>
<td>water</td>
<td>0.02 – 2 m/s (2 electromagnetic meters)</td>
</tr>
<tr>
<td>oil</td>
<td>0.02 – 2 m/s (2 coriolis meters)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Instrumentation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>dP</td>
<td>slow response</td>
</tr>
<tr>
<td>Absolute p</td>
<td>fast response</td>
</tr>
<tr>
<td>Impedance ring probes</td>
<td>Electronics for capacitance and conductance</td>
</tr>
<tr>
<td>Quick closing valves</td>
<td>Manually operated</td>
</tr>
<tr>
<td>Optical</td>
<td>Video, Cameras and optical box for refraction index matching. Arrangement for moving camera</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Pressure</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Process</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Liquid circulation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>Central supply, 7 bar</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Separation</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air ventilation system</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Buffer tank</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Air buffer tank on low pressure side, for variation of the frequencies of terrain slugging</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Data acquisition and control</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>System</td>
<td>Lab-view based interface, Separate HP logging, Fast DAQ cards in PC’s</td>
</tr>
<tr>
<td>Control</td>
<td>Field point modules, Control valves, pump frequency regulation</td>
</tr>
<tr>
<td>NetLab</td>
<td>Remote lab control through web site</td>
</tr>
</tbody>
</table>

The loop can be operated both manually and automated, also from a web site. Oil and water are circulated with centrifugal pumps and metered before mixing with air at the inlet of the test sections. The air is taken from the central supply at the university and the pressure is reduced to about 3-4 bar in a buffer tank.

The air and the liquid streams can be routed to the straight pipes (6 cm ID) mounted on an aluminum beam, or to a pipe configuration mounted on the wall (5 cm ID). The wall arrangements are flexible. With the available bends which have made in the workshop, we can have L-shaped and S-shaped geometries.

Impedance probes are used for holdup measurements, flush ring probes and external clamp-on probes.
Moving and stationary cameras, with optical boxes and light boxes.

**MINI-LOOP**

A small-scale, table-top, two phase flow loop has also been instrumented. The loop can be dismantled and transported in a tailor made case. This also makes it easy to bring the loop into lecture rooms.

The main use of the loop is for educational purposes. Typical two phase flow situations can be demonstrated and students can perform exercises using the loop. Typical cases are:

- Flow regimes (limited due to small diameter)
- Flow development in undulating geometries
- Terrain slugging
- Gas lift
- Gravity dominated flows in undulating pipelines

**Table 2: Specifications of mini-loop**

<table>
<thead>
<tr>
<th>Test sections</th>
<th>Flexible PVC</th>
<th>Configurable geometry. 16 mm ID, 1-3 m long</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fluids</td>
<td>Straight Acrylic</td>
<td>Several sections which can be joined in any desired geometry. 12 mm ID</td>
</tr>
<tr>
<td>Instrumentation</td>
<td>Air and colored water</td>
<td>Absolute pressure at inlet</td>
</tr>
<tr>
<td></td>
<td>Flow meter air</td>
<td>Flow meter water</td>
</tr>
<tr>
<td></td>
<td>Clamp-on light diodes for slug detection</td>
<td></td>
</tr>
<tr>
<td>Process</td>
<td>Air</td>
<td>Compressor</td>
</tr>
<tr>
<td></td>
<td>Water</td>
<td>Pump</td>
</tr>
<tr>
<td>Separators</td>
<td>Acrylic tanks</td>
<td>Buffer tank for adjusting compressibility for terrain slugging</td>
</tr>
<tr>
<td>Tanks</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Support</td>
<td>Aluminum mountings</td>
<td></td>
</tr>
</tbody>
</table>