FACE

Annual Status Report 2011

March 30, 2011

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Executive Summary

The Flow Assurance and Innovation Centre is a Centre for Research driven Innovation (CRI), and is a collaborative effort between the research partners NTNU, IFE and SINTEF. This report covers the period January-December 2011.

The funding partners in 2011 have been: The Research Council of Norway, Statoil ASA, VetcoGray Scandinavia AS, SPTgroup AS, FMC technologies, CD-adapco and Shell Technology Norway AS.

The biggest milestone in 2011 was the first series of multiphase flow measurements of viscous oils at SINTEFs multiphase flow laboratories at Tiller in Q3 and Q4, 2011. This campaign marks the first in a series of several that will expand our existing databases for viscous oils and eventually include effects of surfactants.

In this document selected details of the results from 2011 are presented along with a general status report on each sub-project. For more detailed progress reports, we refer to the presentations from the FACE status meeting in December 2011. The centre is currently working under the scientific plans laid out in the 2010-2012 FACE work plan document. All documents are available for download from the electronic project room, eRoom.

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1. Introduction

This is the annual report to the Research Council of Norway for FACE – the Flow Assurance and innovation centre. FACE is a collaborative effort between the research partners NTNU, IFE and SINTEF and this report covers the period January-December 2011, i.e. the fourth full year of operation.

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Additionally, significant effort was spent on improving the in-kind processes. Some changes were implemented to allow for improved integration of in-kind deliverables with existing work plans.

In this document, we describe briefly the main purpose of the centre and some headlines of the scientific work in 2011. The appendices outline the 2011 costs and the FACE staff that worked on the project during the year. For a more detailed progress report, we refer to presentations from our FACE workshops, and to the bi-annual progress reports. For more details on the scientific plans, we also refer to the current documents on the 2010-2012 FACE plans. All these documents are available for FACE partners in the electronic project room (eRoom).

2. Health, Safety and Environment (HSE)

Fortunately, 2011 was a year of no recorded HSE incidents or injuries of any kind. An EHS awareness day was held on June 1 which included invited talks on various aspects of HSE. In particular we chose to focus on the challenges that arise with virtual organization such as ours. HSE will continue to be a cornerstone of our operations in the years to come.

3. Project status

FACE Academy

2011 proved to be a year in transition for the FACE Academy following on from the highly productive year of 2010. A new PhD student, Srikanth Bojja, was hired at NTNU under the supervision of Professor Maria Fernandino. He will be working on extending the two-phase + surfactant Lattice-Boltzmann Model (LBM) to higher viscosity and

density ratios. The code will subsequently be used to study large scale instabilities in two phase flows under the presence of surfactants.

The LBM implementation was finalised in 2010 and was used extensively throughout 2011. This resulted in a high quality publication in the journal *Rheologica Acta* with reviewers' calling the work "innovative" and a "timely contribution". The editor in chief stated his personal interest and requested the authors to send more material of the same quality. This work is one of the first to our knowledge where it is possible to simulate the viscosity of a realistic emulsion in a realistic volume on a relatively affordable computer. An example result from the simulations is shown in Figure 1. The paper will appear in *Rheologica Acta* in 2012.

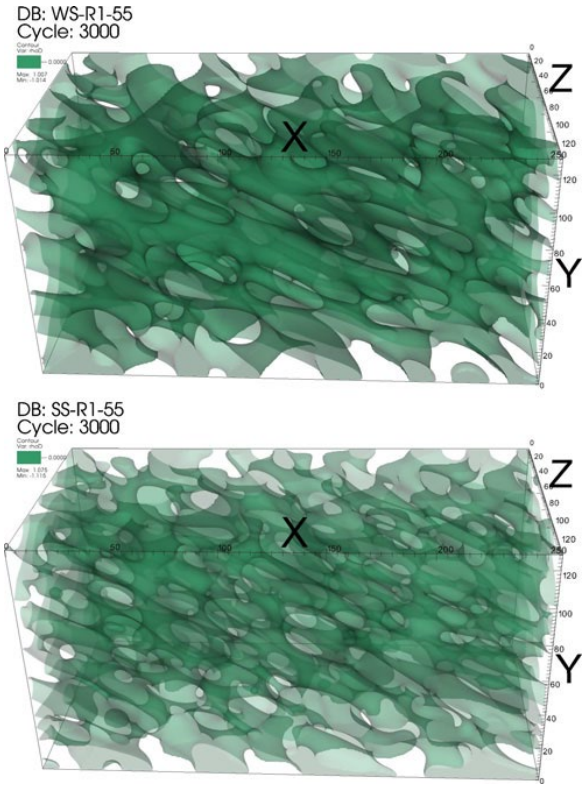

Figure 1 Emulsion morphology for 0.5/0.5 volume fraction at early times. Upper panel weak surfactant forces. Lower panel strong surfactant forces. The fluid domains are bi-continuous, and the characteristic scale of the morphology is smaller with stronger surfactant.

As part of their in-kind contribution, CD-adapco held an introductory course on CFD modelling with Star-CCM+ in Trondheim in May 2011. The course was held over 3 days with 8 attendees from FACE.

In 2011, the FACE academy employed the following PhD and Post-Doctoral researchers:

- Mehdi Benmekhbi (PhD student, Ugelstad lab, NTNU)
- Serkan Keleşoğlu (Post Doc, Ugelstad lab, NTNU), 50%
- Srikanth Bojja (PhD student, EPT, NTNU)

Separation

As planned, the separation project progressed in two different directions. The first objective was to develop a CFD framework capable of handling a satisfactory description of the Dense Packed Layer (DPL). Due to IPR restrictions and public information availability, this development was reverted from LEDA Q3D to Fluent. This added a new challenge in the sense that no large scale interface reconstruction is available in Fluent. The problem was overcome thanks to a new modeling concept coupling phase inversion over a diffuse interface with a control of downward water flux throughout the DPL. This was achieved by deriving new equations for the hindrance factor within the DPL to match the water release rate correlation from Hartland and Jeelani. Simulations proved to be stable and insensitive to grid size. This technique is versatile in that sense that new hindrance factors can be derived to match any correlation for the water release rate. This should enable implementation of results from the other part of the project, which deals with the description of coalescence mechanisms and kinetics in presence of asphaltenes. The objective was to understand how coalescence is impacted by surface properties and how those surface properties evolve depending upon adsorption conditions. It was demonstrated by droplet size measurements that (like all emulsion stabilizers) asphaltenes block coalescence when their relative surface coverage reaches a critical value (around 0.8-0.9), whatever are the adsorption conditions (in particular adsorption time). This results was confirmed by pendant droplet experiments showing that interfacial tension and interfacial modulus only depend on surface coverage and not on adsorption conditions (in particular not on adsorption time). An equation of state could be derived leading to an interfacial area for asphaltenes much lower than generally estimated. However this interfacial area proves compatible with the latest published results about the average molecular structure of asphaltenes and their conformation at the surface of water. Moreover the analysis of dynamic interfacial tension demonstrated that adsorption kinetics are first controlled by diffusion of molecular asphaltenes then slow down due to steric hindrance or potential barrier increase (similarly to random sequential adsorption of nanoparticles). Experiments performed on crude oil confirm all these features and prove that the only adsorbing species are the asphaltenes monomers not nanoaggregates. As expected the equation of state is the same for model solutions and crude oil. Those results open the way for a comprehensive modelling of emulsion stability by a simple coupling of thermodynamics (adsorption isotherm), hydrodynamics (mass transport of asphaltenes to interface) and physics (blockage criterion). This was confirmed by droplet size measurements after short turbulent emulsification (with simplified isotherm thanks to very aliphatic solvent). Effect of rotation speed, emulsification time, water cut and asphaltenes concentration could be completely rationalized by the coupling of an advective transport model with the blockage criterion.

Statoil’s in-kind contribution to FACE in 2011 came in the form of a report on experiments on separation in a horizontal liquid-liquid settler. Additionally, Statoil provided an introductory report on colloid chemistry written by Professor Ivanov (Univ. Sofia). Finally, the end result from one of Statoil’s 2010 in-kind contributions were finalized and delivered in 2011; the report was a statistical analysis of samples taken from the emulsion band in a producing separator. The report gave indications that increased emulsifier concentrations were found in the emulsion band.

CD-adapco provided in-kind work on CFD modelling of hindered settling in Oil-Water separation. Osmotic pressure and a correction to the drag-coefficient were implemented as field-functions in Star-CCM+ which means that the models are openly available to all FACE partners. The results will form the basis for the 2012 in-kind contribution from CD-adapco.

As part of their in-kind contribution, Shell provided experimental data from their lab in Amsterdam. This work will continue into 2012 in close collaboration with the FACE researchers.

The separation project employed the following PhD and Post-Doctoral researchers during 2011:

- Tirthankar Roy (Post Doc at NTNU/SINTEF)
- Jayant Rane (PhD student at CUNY, US)
- Nicolas Abi Chebel (Post Doc at ENSIACET, Toulouse, FR)

Suspensions

The main activities in the suspension project during 2011 consisted of the PhD students working at University of Oslo, University of Newcastle and University of Twente. In December, PhD student Andy Bragg defended his thesis entitled "*Development of the pdf kinetic approach for modelling inertial particle dispersion in turbulent boundary layers*". The quality of his work in FACE led to Andy being offered a Post-Doctoral position at Cornell University, with one of the strongest research groups in the world that work on particles and turbulence.

PhD student Dirk van Eijkeren at University of Twente is funded by FMC Technologies through their in-kind contribution. Dirk is working on modelling of forces on suspended particles or droplets and presented his work at two conferences in 2011.

GE Oil&Gas provided in-kind in the form of results from direct impact erosion experiments. The work focused on generating correlation data for small sand particles (smaller than 50μm) impacting two types of steel, UNS NO6625 and UNS S32750, better known as Inconel 625 (or similar) and SuperDuplex steel. These data are not readily and widely available in the existing literature.

The work on erosion in the Suspension project was supplemented by MSc student Akar Abdulla who entitled his thesis "*Estimating Erosion in Oil and Gas Pipe Line Due to Sand Presence*".

The suspension project employed the following PhD and Post-Doctoral researchers during 2011:

- Jostein Kolaas (PhD student at UiO, NO)
- Andrew Bragg (PhD student at University of Newcastle, UK)

- Dirk van Eijkeren (PhD student at University of Twente, NL)

Multiphase flow

In the Multiphase flow project the research focuses on improving our understanding of two-phase pipe flow of gas/oil and water/oil with particular emphasis on a) heavy, viscous oils and on b) the influence of surfactants on multiphase flows.

At NTNU (EPT lab) and at Statoils facility at Rotvoll experiments have been performed by PhD student Jose Placencia measuring the impact of pipe diameter scaling on pressure drops for oil/water flows. The work also involves characterisation of several real crudes and comparison of the reference fluid with corresponding real crude. Jose has performed a high number of experiments, drawing on the lab at Statoil (Rotvoll) and EPT (NTNU). He has particularly excelled in 2011 in his efforts to use FACE as a centre and a network that may add value to his work. For this reason Jose was awarded the FACE Scientific Achievement award for 2011. The price was shared with Post Doc Jun Huang.

Post-Doctoral researcher Jun Huang turned focus to evaluating the use of Smooth (aka Smoothed) Particle Hydrodynamics (SPH) for multiphase flow simulation. During 2011 he published 4 papers on various topics and was awarded the FACE Scientific Achievement award for 2011 for his outstanding production rate.

A highlight of 2011 was the gas/high viscosity oil experiment campaign at SINTEF which got underway in Q3 and Q4, and from which an example is shown in Figure 2. The campaign focused on two oils (100 cP and 35 cP) and two gas densities (24 and 48 kg/m^3). In total the campaign consisted of 333 two-phase experiments and 34 single phase experiments with a varying degree of instrumentation applied (density profiles, velocity measurements with LDA and wave measurements). A new Post-Doctoral researcher (Hatef Khaledi Alidoosti) was hired at NTNU/SINTEF in December 2011 and will be working with data processing from this campaign.

The experiments will be supplemented in 2012 with experiments performed at IFE with water and viscous oils. Additionally, Statoil will contribute with a large database on viscous oils in 2012, as part of their in-kind contribution. In total this should add extensive data for viscous oil transport which may be used for model closures in Multiphase Flow models such as OLGA and LedaFlow.

On the modelling side, a joint effort between SINTEF and IFE was initiated in 2010 and carried into 2011. The group has implemented a point model in Matlab which will be used to test closures and models. In 2011 the code was tested and a user interface was added.

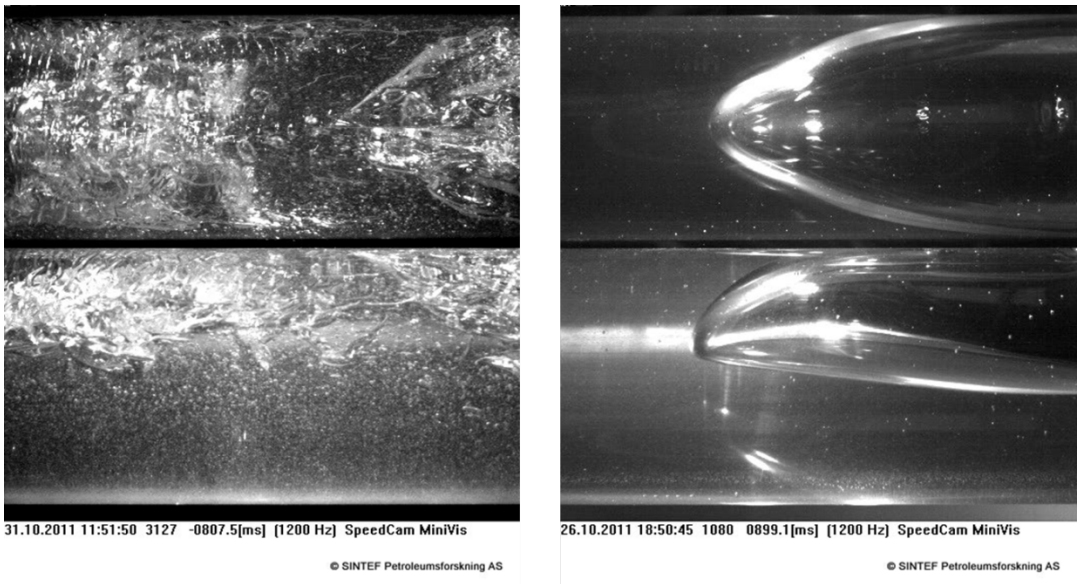

Figure 2 showing top view (upper row) and side view (lower row) respectively of two experiments with different Usg (0.75m/s to the left and 0.06m/s to the right). The experiments were conducted at Uso=0.4m/s, 8 bara, and a 100cP oil without surfactant.

The preliminary flow map from one of the experiment series is shown in Figure 3 for illustration.

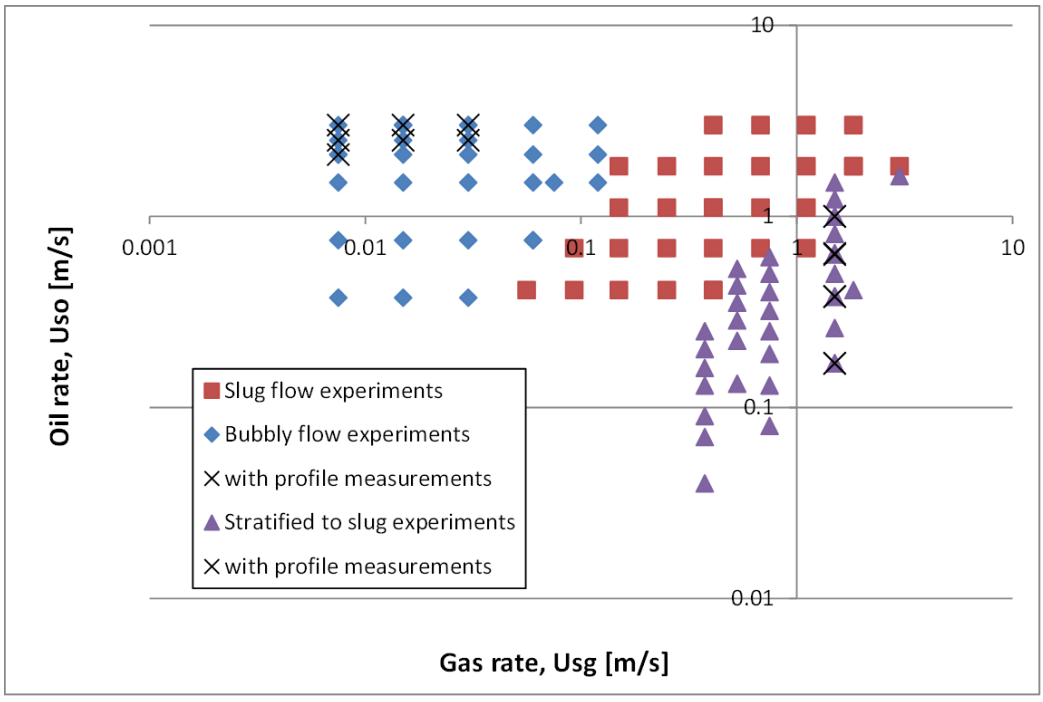

Figure 3 showing a preliminary flow map from the experiments with 100cP oil and 8 bara pressure.

The Multiphase flow project employed the following PhD and Post-Doctoral researchers in 2011:

- Jose Placencia (PhD student, EPT-lab, NTNU)
- Jun Huang (Post Doc, EPT-lab, NTNU)

- Hatef Khaledi Alidoosti (Post Doc, EPT/SINTEF), started Dec 2011

4. Key performance indicators

In large, FACE is currently running according to plan. There are no major hurdles or obstacles and our scientific production is showing great progression. The trend is clearly seen in Figure 4 where the total production of scientific reports is shown. Readers should note that the figure does not include software codes or MSc theses produced by FACE.

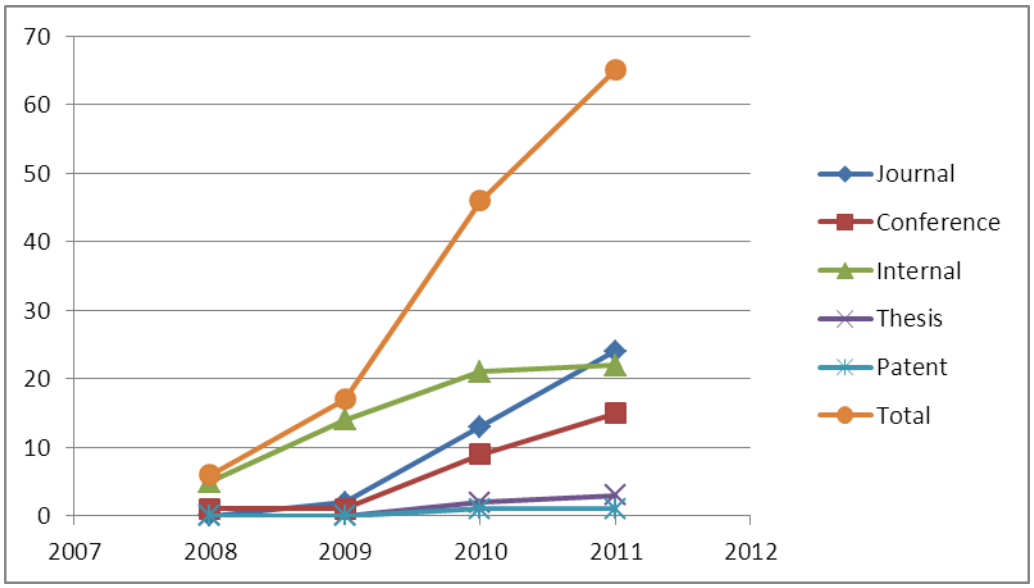

Figure 4 showing scientific production.

The centre management uses the following key performance indicators for evaluating the centre production:

KPI 1: Scientific results

To a large extent the first KPI also inherently contains many of the subsequent KPI's, such as journal and conference publications. Additionally, this KPI should cover results that are intended for internal use only, such as research results that the industry partners wish to keep from publication, for example new multiphase flow models that may be incorporated into software codes such as OLGA or LEDAflow. Internal, unpublished reports belong under this KPI and one such technical report was produced in 2011. In this category, new simulation models and computer codes also belong. In 2011, the first version of the point model for multiphase flow was finalized and was made available in the electronic project room.

KPI 2: PhDs, Masters, postdocs

The third PhD candidate from FACE, Andrew Bragg of University of Newcastle, defended his thesis in December 2011.

FACE additionally funded 11 other PhD and Post Doc researchers in 2011 and roughly 50% of the research funding was used on this activity.

Education of MSc candidates has been a shortcoming of FACE for several years, but 2011 saw two candidates come through under the FACE umbrella; Eirik Schaefer finished his MSc under the supervision of Prof O. J. Nydal working with pipe flow experiments with water-in-oil emulsions, supporting PhD student Jose Placensia. The second student to finish his MSc was Akar Abdulla who did his work at an external institution but supervised by Gustavo Zarruk of IFE and FACE. His thesis was entitled "Estimating Erosion in Oil and Gas Pipe Line Due to Sand Presence" and is available in the eRoom. Mr Abdulla was kindly granted a license of Star-CCM+ from CD-adapco which was used for his erosion prediction simulations.

KPI 3: Journal papers

During 2011, the number of submitted or published journal publications climbed from 15 to 25. A research program such as FACE should preferably publish 10-20 journal publications per year of operation and this will continue to be the FACE goal for the years to come. Additionally we will focus on finding a balance between publication and secrecy so as to ensure the industry partner's interests are protected.

KPI 4: Conference papers

FACE was represented with 6 conference presentations during 2011. Now that our journal publication rate is climbing, we should ensure that our results are also presented in relevant industry conferences in the coming years.

KPI 5: Number of Partners

10 partners are currently FACE members. The FACE management is continuously searching for new partners. In 2011 we approached PDVSA Intevep, Petrobras, Petronas and Chevron, but have not yet been successful in recruiting a new partner to our program.

KPI 6: IPR

The patent application for the reference fluid was submitted in 2010. This represents a milestone in FACE and will be a significant building block for our future activities. In 2011 work continued on Generation 2 of the reference fluid and the patent situation for this fluid is under assessment.

KPI 7: International cooperation

The international cooperation is one of the stronger sides of FACE. During 2010 direct collaborations took place with CUNY (US), Univ. of Twente (NL), Univ. of Newcastle (UK) and Univ of Toulouse (Fr). It should also be mentioned that the activity at University of Oslo enjoys a long standing collaboration with Univ. of Cambridge (UK) which indirectly becomes part of the FACE deliverable. Paul Meakin, Idaho Nat. Lab, is working closely with the FACE academy team on modelling of emulsion rheology. Additionally, Professor Luis Rojjas from University Simon Bolivar, Venezuela and Professor Antonio Bannwart from University of Campinas, Brazil were invited as

keynote lecturers at the June status meeting 2011. They presented talks on simulations of particle-liquid flows and Flow assurance for Heavy oils respectively.

KPI 8: Industrial partners' evaluation

All the industry partners were invited to hold bi-lateral talks with FACE in 2011 as part of our improvement process. The goals of these meetings are to communicate FACE results and listen to industry feedback. This included a re-assessment of the centre using the same assessment form that was used for the mid-term evaluation in 2010. The general trend was very positive.

KPI 9: Involvement of industrial partners

FACE staff has traditionally been in close cooperation and contact with the industry through the in-kind contributions. The main intention behind the in-kind funding was to let industry researcher's work alongside institute and academic researchers. These contributions make up for 25% of the research in FACE. Significant effort was spent in 2011 to improve the process for defining and approving the in-kind contributions from each company. In earlier years, each company was only required to define their in-kind contribution by end of year. This meant that integration with other FACE activities were somewhat challenging and that the use of cash-for-in-kind contributions were always transferred to the following year. The changes we implemented in 2011 means that in-kind contributions from each company should be defined by end of previous year and will be more closely integrated with the FACE work program.

KPI 10: Scientific cooperation across institute lines

Being a virtual organisation, scientific cooperation across institute lines is sometimes challenging, but often highly rewarding. 2011 provided several examples of excellent cooperation between the institute researchers. In the Multiphase flow project, researchers from IFE and SINTEF are working closely on modelling aspects. In the FACE academy, the Ugelstad laboratory and IFE collaboration is producing publications at a steady rate and at a consistently high quality on simulations of emulsions with surfactants and their rheology in shearing flows.

5. Recruitment

FACE will over the course of 8 years educate 15-16 PhD students and Post-Doctoral researchers. This number includes the PhD candidate delivered as in-kind contribution by FMC Technologies. In 2010 recruitment and education of MSc students was flagged as an area of priority and in 2011 two MSc candidates have written their thesis under the FACE umbrella. It is a goal for FACE to increase the number of MSc students that come through the program.

6. External presentations

FACE was represented at the TEKNA Heavy Oil Technology for Offshore Applications 2011 with a presentation providing an overview of the research in FACE.

7. Deviations

The FACE work in 2011 got off to a great start following on from the successful mid-term evaluation in late 2010 and the dramatic increase in scientific production towards the end of 2010 and early 2011.

Due to issues with hiring of a Post Doc in Trondheim, the Multiphase Transport project has been pushing unused funding from late 2010 and halfway through 2011. By November the large experiment campaign in SINTEFs Tiller flow loop got under way and consumed a large part of this funding. The campaign gathered data for gas and viscous oil flow which will be supplemented by data for water and viscous oil from experiments that will take place at IFE in 2012. The large push towards the end of the year was, however, not enough to catch up the accumulated funding in this project and 1.3MNOK will be carried over into 2012. The remaining projects finished the year on budget.

Totally, we have transferred 2.57MNOK from 2011 to 2012. These funds will be used along with some cash for in kind contributions to cover the planned budget deficit in 2012 and the remaining work in the Multiphase Transport project.

8. Publications

Bragg, Andrew. “Development of the PDF kinetic approach for modelling inertial particle dispersion in turbulent boundary layers.” Ph.D. dissertation, School of Mechanical \& Systems Engineering, University of Newcastle Upon Tyne, 2011.

Eijkeren, D.F. van, and H.W.M. Hoeijmakers. “History Force and Drag Correlation in a Lagrangian Method Applied to Oil-Water Separation.”, 2011.

Eijkeren, D.F. van, and H.W.M. Hoeijmakers. “Lagrangian Particle Tracking for Water De-Oiling.” *Lagrangian Particle Tracking for Water De-Oiling.* January 2011.

Foss, Martin, Attila Palencsár, and Johan Sjöblom. “Study of the effect of oil on CO2 corrosion inhibitor efficiency using electrochemical impedance (EIS).” *TBD* na (2011): na.

Huang, Jun. “Letter to the editor - comment on Balakin et al's model.” *AIChE* 57, no. 8 (2011): 2287.

Huang, Jun, and Ole Jørgen Nydal. “Coupling of discrete-element method and smoothed particle hydrodynamics for liquid-solid flows.” *Theoretical and Applied Mechanics Letters* na (2011): na.

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Huang, Jun, Angela De Leebeeck, and Ole Jørgen Nydal. “DEM Simulation of Particulate Flow Using Multi-scale Time Steps.” *Submitted to International Journal of Computational Methods* na (2011): na.

Kolaas, Jostein, and Atle Jensen. “Time-resolved Combined DPIV/PTV measurements of two-phase turbulent pipe flow.” 2011.

Kolaas, Jostein, Atle Jensen, and Michael Mielnik. “Visualization and measurement of flow in micro Y-channels with an expanded bifurcation.” *Submitted to Exp. Fluids*, 2011.

Nossen, Jan, and Chris Lawrence. “Pressure Drop in Laminar Slug Flow with Heavy Oil.” 2011.

Pauchard, V., and T. Roy. “Droplet size measurements for water in oil emulsion during stirred reactor experiments: effect of asphaltenes adsorption.” 2011.

Pauchard, Vincent, and David Arla. “Differences in separation kinetics between actual gravity separation and bottle tests: a complex synergistic effect of demulsifier addition and dynamic collisions.” unpublished, 2011.

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Zarruk, Gustavo A., Jaijus Pallippadan Johny, and Atle Jensen. “Accuracy of PIV and PTV Measurements in Dispersed Flows.” *Submitted to Flow Measurement and Technology* na (2011): na.