FACE

Annual Status Report 2012

April 6, 2012

http://www.sfiface.no

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 2012.

The funding partners in 2012 have been: The Research Council of Norway, Statoil ASA, GE Oil & Gas, SPT group AS, FMC Technologies, CD-adapco and Shell Technology Norway AS.

The biggest milestone in 2012 was the publication of the findings regarding asphaltene adsorption on interfaces from the separations project. The work has led to a publication in Langmuir by Jayant Rane et al. with the title; Interfacial rheology of asphaltenes at oil-water interfaces and interpretation of the equation of state. The results have already spurred a significant interest in the field of asphaltene chemistry.

In this document selected details of the results from 2012 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 2012. 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 2012, i.e. the fifth full year of operation.

The funding partners in 2012 were: The Research Council of Norway, Statoil ASA, GE Oil & Gas, SPT group AS, FMC technologies, CD-adapco and Shell Technology Norway AS.

The biggest milestone in 2012 was the publication of the findings regarding asphaltene adsorption on interfaces from the separations project. The work has led to a publication in Langmuir by Jayant Rane et al. with the title; Interfacial rheology of asphaltenes at oil-water interfaces and interpretation of the equation of state. The results have already spurred a significant interest in the field of asphaltene chemistry.

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. An effort was also made to integrate the in-kind deliverables into the activities of each of the projects and to utilize the added value of the in-kind delivered.

In this document, we describe briefly the main purpose of the centre and some headlines of the scientific work in 2012. The appendices outline the 2012 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)

No HSE incidents or injuries of any kind were reported in the centre in 2012. The HSE awareness is maintained by including updates on the status of the HSE work in each of the status meetings in the centre. Plans for laboratory inspections to assess all labs where PhDs and PDs work were also prepared in 2012. The initial inspections were held in December 2012 and all labs will be inspected by the end of 2013.

3. Project status

FACE Academy

In 2012 the FACE academy has continued the different fruitful activities in progress in 2011.

A new Post-Doctor, Galina Rodionova, was hired at Ugelstad Laboratory NTNU to work along with Serkan Keleşoğlu on the development of reference fluids. Those are fluids designed from non-expensive and easy to obtain chemicals which mimic the properties of crude oil emulsions (rheology, flow properties, stability). They have prepared new formulations of these fluids avoiding to use particles and allowing to mimic more viscous fluids. These formulations have a direct industrial interest.

PhD student Mehdi Benmekhbi has continued his PhD work on the study of properties of surfactants at interfaces. He is currently studying the coalescence of water droplet stabilized by the surfactant Span 80 with the drop-drop micromanipulator apparatus.

Modelling activities led by Roar Skartlien and Maria Fernandino have continued their progress. These activities use the method called Lattice-Boltzmann Model (LBM) to model the behaviour of surfactants and interfaces. In 2012 the activities have focused on the implementation of numeric in the LBM codes to study emulsions in turbulent flow. The modelling activities have resulted in the publication in 2012 of two articles in high impact factor journals: Rheologica Acta and The Journal of Chemical Physics. In the article published in The Journal of Chemical Physics Lattice Boltzmann simulations were used to study the coalescence kinetics in emulsions with amphiphilic surfactant, under neutrally buoyant conditions, and with a significant kinematic viscosity contrast between the phases (emulating water in oil emulsions). The main findings showed that increased surfactant contents slowed down the coalescence rate between droplets due to the Gibbs-Marangoni effect, and the coalescence was driven by a quasi-turbulent velocity field. **Figure 1** shows simulation results showing the effect of surfactants on the coalescence of a droplet and an interface.

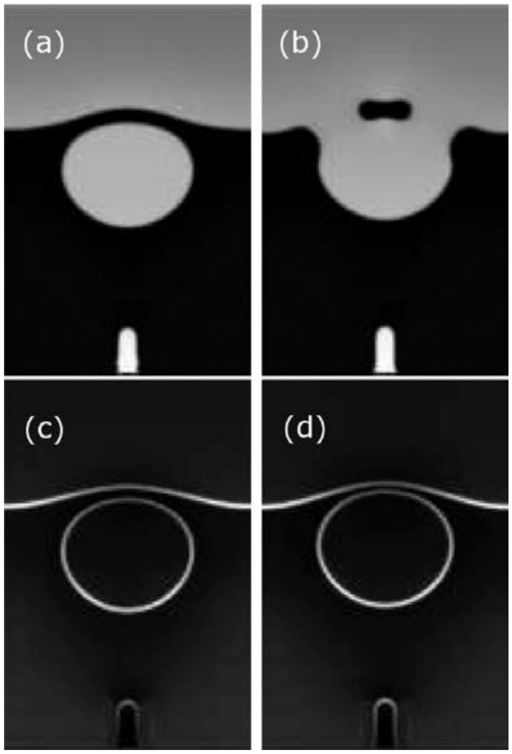

Figure 1. ***Delayed coalescence with the Marangoni effect. Upper panels [(a),(b)]: Coalescence between a buoyant droplet and an initially plane interface without surfactant forces for times t = 2000 (a) and t = 2500 (b). The time (t) refers to simulation time steps. The gray scale indicates the fluid density. Lower panels [(c),(d)]: Delayed coalescence with surfactant forces for t = 2000 (c) and t = 2500 (d). The surfactant density is indicated by the gray scale, and there is a slightly lower density at the droplet interface and the dimpled interface of the upper fluid, in the film region. The surfactant density gradient induces an inward Marangoni stress on the interfaces, which suppresses film drainage. (J. Chem. Phys. 37, 214701 (2012) © 2012 American Institute of Physics)***

Similarly to 2011, CD-adapco held an introductory course on CFD modelling with Star-CCM+ in Trondheim in October 2012 as part of their in-kind contribution.

A course on Flow Assurance Chemistry was lectured by associate professor II Martin Smedstad Foss for international clients at the Oilfield Chemistry symposium 2012 at Geilo. The course included areas suchs as wax, hydrates, scaling and asphaltenes.

In 2012, the FACE academy employed the following PhD and Post-Doctoral researchers:

- Galina Rodionova (Post Doc, Ugelstad laboratory, NTNU)
- Mehdi Benmekhbi (PhD student, Ugelstad laboratory, NTNU)
- Serkan Keleşoğlu (Post Doc, Ugelstad laboratory, NTNU), 20%
- Srikanth Bojja (PhD student, EPT, NTNU)

Separation

The first focus of the separation project has been to understand the adsorption at the water oil interface of emulsion stabilizers naturally present in most crude oils: asphaltenes. A significant progress was made leading to two publications in highly ranked journals and gaining the attention of renowned experts in the field. Properties such as interfacial tension or modulus could be related to the structure of the molecule by means of a classical equation of state (example in **Figure 2**). Those results proved robust enough to predict the data published worldwide in a wide variety of experimental conditions.

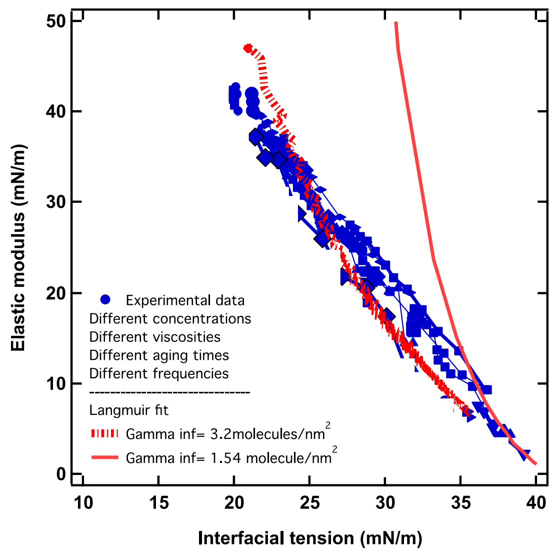

Figure 2: Parametric curve instantaneous elasticity vs. interfacial tension from Langmuir equation of state (previously identified Γ_{∞}=3.2 molecules/nm^2 and arbitrary Γ_{∞}=1.54 molecules/nm^2 to show sensitivity) and comparison with experimental results.

This baseline enabled to rationalize and understand the effect of asphaltenes on droplet coalescence. By selecting experimental conditions that lead to complete adsorption of asphaltenes on water droplets, a simple mass balance showed that coalescence is blocked when the surface coverage reaches a value close to maximum packing (as exemplified **Figure 3** by the linear relationship between equilibrium droplet size and the ratio between masses of water and asphaltenes). Again this result could be verified against data found in the literature.

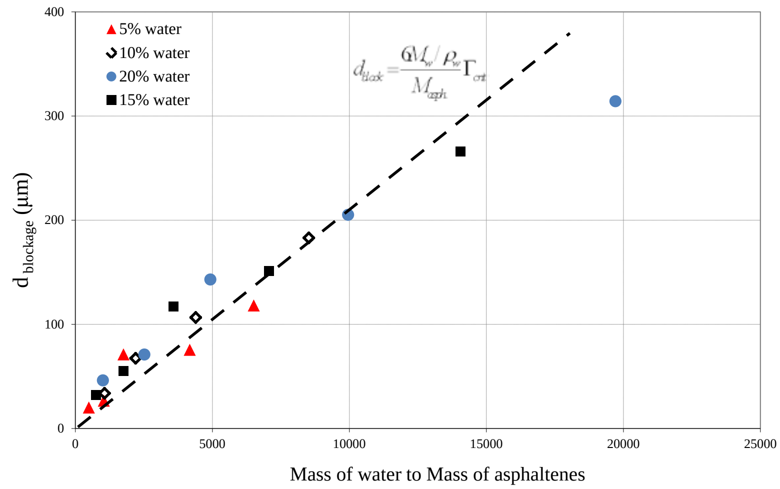

Figure 3: Dependency of blockage diameter over mass of water/mass of asphaltenes.

Furthermore similar behaviour had been previously reported for other types of emulsion stabilizers. It was then decided to develop CFD simulation methods accounting for surfactants in actual separation process. This requires modelling:

- Blockage of coalescence above a critical surface coverage.
- Partitioning of surfactant between bulk and interface.
- Mass transport of surfactant throughout the organic phase.

This effort was successful and enabled to reproduce the experimental results displayed in **Figure 3.**

Another working direction on the CFD side has been to account for the complex behaviour of the packed layer of water droplets forming in gravity separator (in which most of the coalescence process occurs). This was made by a combination of well verified phenomenological models and classical CFD. It was possible to reproduce experimental results with minimal parameter tuning (**Figure 4**).

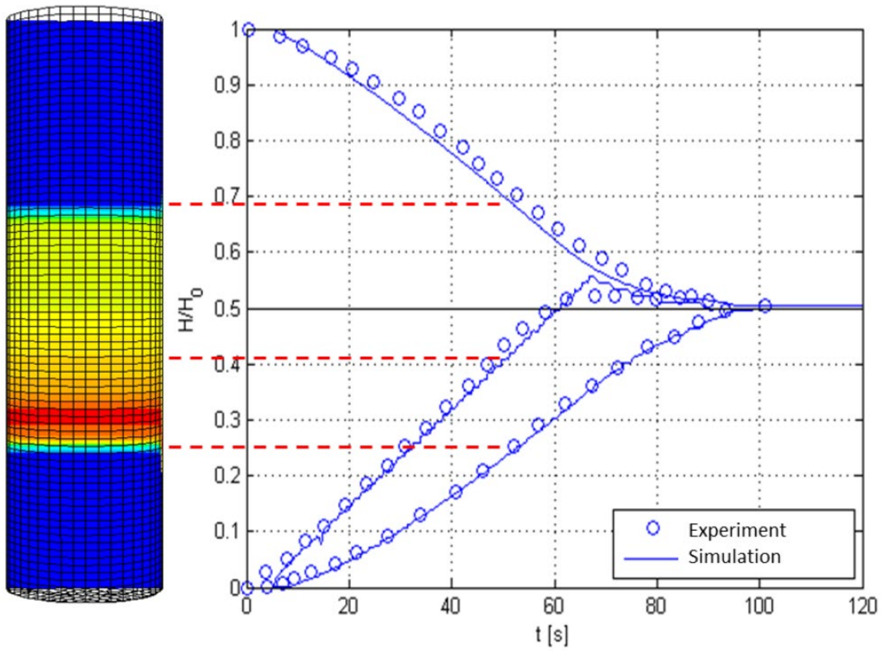

Figure 4: Validation of DPL simulations in Fluent against experimental data.

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 were included in 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 2013 in close collaboration with the FACE researchers.

The project also arranged a course on “Flow assurance and liquid-liquid separation in oil recovery processes” in 2012. The course was held at the Natural History Museum of Toulouse in France and was open to all FACE partners.

The separation project employed the following PhD and Post-Doctoral researchers during 2012:

- 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 suspensions project was scheduled to finish in 2012 and the activities were therefore reduced compared to other activities. The main activities in the project during 2012 consisted of the PhD students working at University of Oslo and at University of Twente. 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 one conference in 2012.

GE Oil&Gas provided in-kind in the form of results from direct impact erosion experiments. The results were presented at the mid-year status meeting and the report was shared with all partners through the e-room. 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 suspension project employed the following PhD and Post-Doctoral researchers during 2012:

- Jostein Kolaas (PhD student at UiO)
- Anis Ayati (PhD student at UiO)
- 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.

The multiphase transport project moved into its third year in 2012. Some of the scientific tasks that were introduced in 2010 have therefore reached their conclusion in 2012. The academic production in the project in 2012 was good and includes publication of four papers in international journals and two conference publications. Several other papers are accepted/submitted and will be published later. In addition to the publications courses was lectured by scientist connected to the project both at NTNU for students and at an international conference dealing with the topic of oilfield chemistry.

One of the main activities in the flow assurance innovation centre is education of PhDs and Post Docs. In the multiphase transport project the first PhD belonging to the project finished in 2012. The area of research was related to dispersed oil-water flow and was done at the department of energy and process technology at NTNU. Some of the main findings included a study of the effect of pipe diameter on effective viscosity of a dispersed oil-water stream. As seen in **Figure 5** below the study revealed that the relative viscosity of an emulsified fluid varies significantly with pipe diameter at high water cuts. It was concluded that the effect could be attributed to a combination of both emulsion size and shear thinning. The results are being published in an international journal and as part of the thesis.

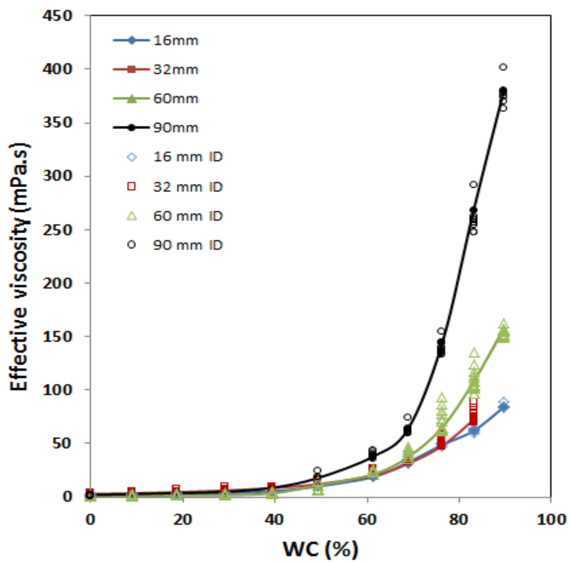

Figure 5 Effective viscosity as a function of pipe diameter [Copyrigh by Jose Plasencia, NTNU].

One PhD, one Post Doctor and one Professor II finished their involvement in the project in 2012 as planned after contributing both in the fields of lecturing and research. The PhD was hired by one of the industry partners involved in the centre thus exemplifying how the centre is used by the industry partners as a recruitment base for highly skilled personnel. Two new PhDs and one Post Doctor were also hired in 2012 to keep the scientific production at a high level. Both of the new PhDs are connected to the energy and process technology laboratory at NTNU and are being supervised by Ole Jørgen Nydal.

In addition to the academic work the multiphase flow project released the final version of a point model developed for flow of viscous oil and gas in 2012. The model is written in MATLAB to enable open use by all partners in the project. The development is part of the viscous oil focus in FACE and has produced a simple model that can be used in both testing of multiphase models and correlations and the planning of loop experiments using viscous oils. A publication on the model will be presented at the 2013 BHRG conference. **Figure 6** shows a comparison of the point model results with experimental data. It can be seen that the performance of the model is as good as or better at predicting holdup for viscous oil-gas flow than typical commercial software.

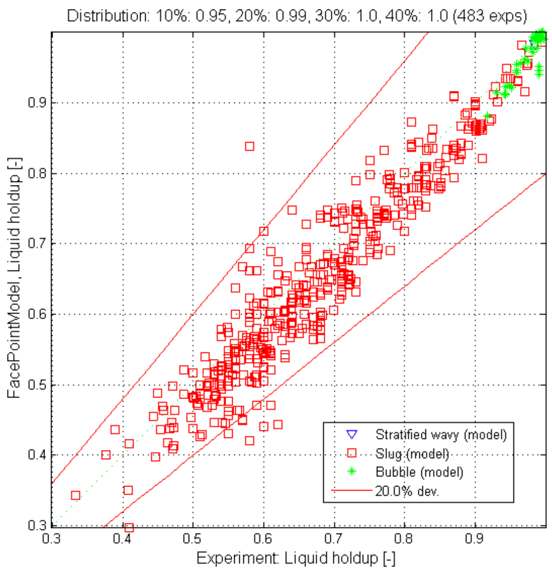

Figure 6. The figure shows the correlation between holdup in slug flow for the point model developed in FACE and several data sets available in the literature [Copyright by Jan Nossen, IFE].

A significant effort has also been put into processing of experimental data produced ever since the beginning of the project in 2010. This work aims at extracting new and important information form the experiments that are being conducted in the project. A database for use by the partners containing data from numerous experimental campaigns is thus being generated. Evaluation of the data sets on oil-gas produced in the project in 2011 continued in 2012 and the in-kind work contribution from SPT group and Shell were connected to the data produced in the centre.

The Multiphase flow project employed the following PhD and Post-Doctoral researchers in 2012:

- Jose Placencia (PhD student, EPT-lab, NTNU), Finished 2012
- Jun Huang (Post Doc, EPT-lab, NTNU), Finished 2012
- Hatef Khaledi Alidoosti (Post Doc, EPT/SINTEF)
- Heiner Shumann (PhD EPT, NTNU)
- Andreas Akselsen (In-Kind PhD EPT, NTNU)

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 continued progression. The trend is clearly seen in Figure 4 where the total production of scientific reports is shown. Readers should note that the figure only contains publications and not experimental data sets and software code produced in the centre.

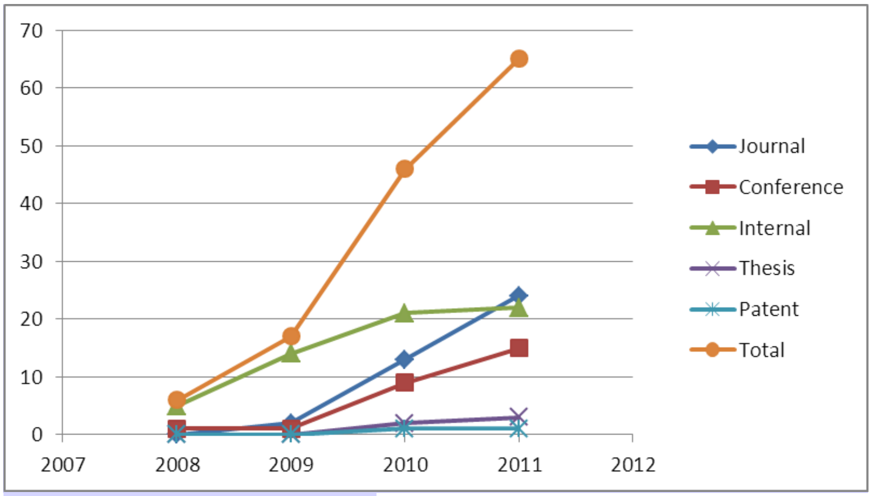

Figure 7 showing scientific production.

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

Comment [MF1]: Need update

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 and new simulation models and computer codes belong under this KPI. In 2012, the final version of the point model for multiphase flow was made available in the electronic project room. This marks an important milestone in the modelling work in FACE.

KPI 2: PhDs, Masters, postdocs

In 2012 two masters student delivered work into FACE. Their contribution supports the work of the PhDs and PDs and also makes recruitment from the university groups possible for FACE.

FACE additionally funded 15 PhD and Post Doc researchers in 2012 and roughly 50% of the research funding was used on this activity. The project is in a phase where a lot of the PhD students and Post-Doctoral researchers has finished in 2012 or will finish in 2013.

KPI 3: Journal papers

The production of papers was quite good in 2012 A total number of 14 journal publications were published. It is noted that as of 2012 the only publications included in the publication list are publish papers and not accepted or submitted work. A research program such as FACE should preferably publish more than 10 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 2012. This shows that the good trend from 2011 continues into 2012 and a steady presence from the centre in the major conferences on multiphase flow and flow assurance is seen. The focus on conferences is important to the centre since conferences is the primary meeting point between the international oil industry and the academic groups working on multiphase flow and flow assurance around the world.

KPI 5: Number of Partners

10 partners are currently FACE members. No new partners entered or left the centre in 2012. The program is nearing completion in 2014 and the focus of the centre is therefore to produce data needed by the current partners. The FACE management is, as before, continuously searching for new partners.

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 2012 work continued on Generation 2 of the reference fluid and the patent situation for this fluid is still under assessment.

KPI 7: International cooperation

The international cooperation is one of the stronger sides of FACE. Early collaborations took place with CUNY (US), Univ. of Twente (NL), Univ. of Newcastle (UK) and Univ of Toulouse (Fr). In 2012 the cooperation with CUNY and University of Twente continues and new collaborations with University of Leuven were initiated. 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 the international partners were asked to host both status meetings in 2012. The mid-year meeting was held in Rijswijk, Netherlands and the end of year meeting was held in Tolouse, France. This was done to allow more personnel from the international partner an opportunity to attend the meetings.

KPI 8: Industrial partners' evaluation

The partner's involvement and evaluation of the centre were the focus in two reference group meetings. Through open discussions valuable input to the centre management were received. Overall the partners are satisfied with the progress and have started using data produced in the centre directly in their in-kind contributions.

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. After a significant effort was spent in 2011 to improve the process for defining and approving the in-kind contributions the in-kind in 2012 was more closely related to the work in the centre. This was exemplified in that the data produced in FACE was used by the partners directly and data given as in-kind was used directly in the on-going work in the centre. The in-kind delivered by the partners were also spread out into al of the separate sub-projects in FACE, showing the relevance of the tasks to the industry partners.

In addition to the cooperation the benefit of the centre to the industry can be exemplified by looking at recruitment from the centre. Currently three of the PhD/PD finishing as part of the project have been hired by the member companies.

KPI 10: Scientific cooperation across institute lines

Being a virtual organisation, scientific cooperation across institute lines is sometimes challenging, but often highly rewarding. 2012 provided several examples of excellent cooperation between the institute researchers. In the Multiphase flow project, researchers from IFE and SINTEF continued 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. In the separations project the cooperation between CUNY and SINTEF is proving valuable through the production of high quality data for publication.

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. Two new PhD candidates have started working under FACE. In addition to the PhDs it is a goal for FACE to increase the number of MSc students that come through the program. In 2012 two master's students were working as part of the FACE program.

6. External presentations

FACE was represented at the following venues; Oilfield chemistry Symposium at Geilo 2012, BHR 2012, Petrophase 8, Ninth International Conference on CFD in the Minerals and Process Industries , IQPC – Flow Assurance and Integrated Production Technology in Abu Dhabi and the Transatlantic Science Week. By attending global events the centre is able to promote the expertise of Norwegian flow assurance as exemplified through FACE. .

7. Deviations

New plans have been made for FACE in the period 2013-2014 since the current plans end in 2012. This meant that a lot of the activities in 2012 consisted in wrapping up activities that would not continue in 2013. The suspensions project was therefore terminated at the end of 2012.

In 2010 and 2011 the centre experienced some delays in the hiring of PD and PhD candidates. This lead to a delay in spending for these activities. In addition to this there has been a significant increase in the PhD and PD cost. This means that a larger portion of the funding than originally planned was allocated to PhD and PD programs in 2012.

8. Publications

1. Amiri A., Nuland S., Øye G. and Sjöblom J., Use of a cross-sectional model for determining rheology in settling slurries: Effect of solvent, particle size, and density. Journal of Dispersion Science and Technology 2012; Volume 33, pp. 1336-1345.

2. Kelesoglu, S.; Pettersen, B. H.; Sjöblom, J. Characterization of Water-in-North Sea Acidic Crude Oil Emulsions by Means of Rheology, Droplet Size, and Laminar Flow in Pipeline. Journal of Dispersion Science and Technology 2012; Volume 33, pp. 536-548

3. Kelesoglu, S., Pettersen, B. H., Sjöblom, J. Flow Properties of Water-in-North Sea Heavy Crude Oil emulsions Journal of Petroleum Science & Engineering 2012; Volume 100, pp. 14-23

4. Kelesoglu, Serkan; Volden, Sondre; Kes, Murside; Sjöblom, Johan. Adsorption of Naphthenic Acids onto Mineral Surfaces Studied by Quartz Crystal Microbalance with Dissipation Monitoring (QCM-D). Energy & Fuels 2012; Volume 26, pp. 5060-5068

5. Skartlien, R.; Grimes B.; Meakin, P; Sjöblom, J; Sollum, E. Coalescence kinetics in surfactant stabilized emulsions: evolution equations from direct numerical simulations, The Journal of Chemical Physics 2012: Volume 137, 214701

6. Skartlien, R.; Sollum, E.; Akselsen, A.; Meakin, P.; Direct numerical simulation of surfactant stabilized emulsions - Morphology and shear viscosity in starting shear flow, Rheologica Acta 2012; Volume 51, pp 649-673

7. Huang, Y.J., Nydal, O.J. & Y. Wang, Body fitted link-cell algorithm for particulate flow simulation in curved pipeline, accepted by Journal of Applied Mathematics Modelling, DOI: 10.1016/j.apm.2012.08.001

8. Huang, Y.J., Jalali, P., & Hyäppanen T., Numerical simulation of the formation of granular shock wave over cylindrical objects. Journal of Particle & Particle System Characterization, 29, (2), 129–138, 2012 (SCI, IF: 0.44)

9. Huang, Y.J. & Nydal, O.J., Coupling of discrete-element method and smoothed particle hydrodynamics for solid-liquid problems, Theor. & Appl. Mech. Lett., 2, 0212002 (1-4), 2012

10. Huang, J.， De Leebeeck A. & Nydal, O.J., Simulation of particulate flow using multi-scale time steps, Int. J. Computational Methods, 09, 1240010 (1-10), 2012. (SCI, IF: 1.168)

11. Chan, K.T., Wang, X.Q., So, R.M.S. & Huang, J., Revolving superposed standing waves in spinning Timoshenko beams, Journal of Sound and Vibration, 2012, 331,(4), 815-832 (SCI, IF: 1.336)

12. Pauchard V., Tirthankar R., Droplet Size Measurements for Water in Oil Emulsion During Stirred Reactor Experiments: Effect of Asphaltenes Adsorption, Oilfield Chemistry Symposium, 18 – 21 March 2012, Geilo, Norway

13. Rane R., Adsorption Kineticks of Asphaltenes at the Oil-Water Interface and Nano-Aggregation in the Bulk, Petrophase 8, June 10-14 2012, Florida, USA

14. Huang, Y.J. & Nydal, O.J., Coupling of DEM and SPH for simulations of solid-liquid flows in pipeline, Proc. 8th KSME-JSME Thermal and Fluids Engineering Conference, March, 2012, Korea

15. Rane, J.P., Harbottle, D., Pauchard, V. & Banerjee, A.C.S., Adsorption kinetics of asphaltenes at the oil-water interface and nano-aggregation in the bulk, *Langmuir*, 2012, 28 (26), pp 9986–9995 DOI: 10.1021/la301423c

16. Van Eijkeren et. Al., History Force and Inertia Effects Applied to Swirling Flow Produced Water Treatment, Ninth International Conference on CFD in the

Minerals and Process Industries, CSIRO Melbourne, Australia, 10-12 December 2012.

17. Bragg A., Swailes D. C. and R. Skartlien, Particle transport in a turbulent boundary layer: Non-local closures for particle dispersion tensors accounting for particle-wall interactions, Phys. Fluids **24**, 103304 (2012)

18. Bragg A., Swailes D. C. and R. Skartlien, Drift-free kinetic equations for turbulent dispersion, Physical Review E, Vol. 86(5), pp. 12

19. Nossen J. and Lawrence C., Pressure Drop in Laminar Slug Flow with Heavy Oil, BHR Group 2012

20. Schaefer E., Plasencia J. and Nydal O. J., Pipe Flow of Water in Oil Emulsion in Different Pipe Diamaters, BHR Group 2012.