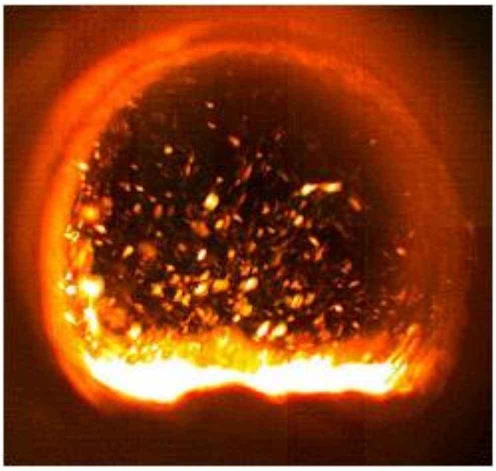
Consortium on Transient and Complex Multiphase Flows and Flow Assurance

TMF

PROSPECTUS ADDENDUM

2016-17



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In this addendum to the TMF prospectus, definitions of the various TMF sponsors are provided in addition to details of the membership costs associated with each level of sponsorship. A list of the current sponsors is also provided together with a concise description of the on-going projects within the TMF Consortium.

1. Definition of levels of sponsorship

- **Full Sponsor:** An organisation that is funding one or more projects (e.g. an operating company).
- **Associate Sponsor:** An organisation that is paying a reduced fee (e.g. a company providing services to operating companies, for instance, design-houses).
- **In-kind Sponsor:** An organisation that is not paying fees but offering in-kind contributions (e.g. an organisation developing and supplying design programs to the oil and natural gas industry). The level of contribution of "in-kind" sponsors should be commensurate with the fee paid by oil and natural gas companies. This value to be assessed and agreed by the members of the steering committee and in particular the Chairman of the Steering Committee or his nominated representative.

2. Fees

The details of TMF participation fees are detailed below. These fees are normally updated every 3 years. Existing projects would not be affected by updated fees.

- Full Sponsors:

  The unit cost is **£52k per annum for a 3-year period**. This fee will cover the cost of a European Union Ph.D. student working for 3 years and also includes funding for TMF management and organisation. These unit costs could alternatively be used to support a more senior researcher, e.g. a postdoctoral research associate, for a shorter period.

  The unit cost above is the minimum fee and this should be increased to cover the costs for any associated experiments, etc.

- Associate Sponsors

  The unit cost is **£17k per annum for a 3-year period**.

- Any category of sponsor who did not participate in TMF4 or TMF5 will be charged a one-off **buy-in fee of £9k** for access to previous TMF deliverables.

A standard contract has been set up through the Imperial College Research Contracts Office, which can be readily renewed and/or extended for a further project or researcher thus minimising the administrative effort involved in participation.

3. List of current participants

- Full Sponsors: BP, Schlumberger-Cameron Flow Control Technology, Chevron, Petrobras, Shell, Statoil, Total
- Associate Sponsors: FORSYS, Schlumberger Information Solutions,
- In-kind Sponsors: ASCOMP, CD-Adapco, FEESA (KBC Advanced Technologies), IFE, Kongsberg Oil & Gas Technologies, SINTEF, Wood Group Kenny

4. On-going projects

The following are the current TMF Consortium projects:

- BP: Oil water hold-up for shallow inclined elevations (Imperial College, Supervisors: Omar Matar and Christos Markides).

- Cameron: Analysing and modelling of power mixers liquid-liquid homogenisation and subsequently separation (Imperial College, Supervisors: Omar Matar and Christos Markides).

- Chevron: Experimental investigations of turbulence in concentrated dispersions (Nottingham University, Supervisor: David Hann).

- Chevron: Advanced measurements of developing multiphase flows (Imperial College London, Supervisors: Omar Matar and Christos Markides).

- Petrobras (collaborative project with TOTAL): One-dimensional modelling of intermittent flow (Imperial College, Supervisor: Raad Issa).

- Shell: The effect of surfactants on transition and flooding in two-phase flows (Imperial College, Supervisors: Omar Matar, Valeria Garbin, and Ronny Pini).

- SINTEF: Flow patterns and structures for industrially-relevant pipe diameters, gas densities, and liquid viscosities (Nottingham University, Supervisors: Barry Azzopardi and Buddhi Hewakandamby).

- Statoil: Experimental programme on gas lift of viscous liquids (Nottingham University, Supervisors: Barry Azzopardi and Buddhi Hewakandamby).

- TOTAL (collaborative project with Petrobras): Large diameter systems (Nottingham University, Supervisors: Barry Azzopardi and Buddhi Hewakandamby).

- TOTAL: Near-wall and interface studies of gas-liquid horizontal stratified flows (Imperial College London, Supervisors: Omar Matar and Christos Markides).

The scope of each project is as follows:

Project Title: Hold-up in horizontal and inclined oil-water two-phase flows

Sponsor (industrial contact): BP

Supervisors: Prof. Omar K. Matar (Imperial), Dr Christos Markides (Imperial)

Due to the limited processing capability of offshore facilities, export oil pipelines typically have a residual water content of < 5 % vol. At higher velocities, water is largely carried through with oil as droplets, and then possibly as a film brought about by droplet coalescence. As oil flow-rates are reduced, the residence time increases and water droplets have time to coalesce further with the water film and build a significant equilibrium water hold-up. As a result, water slugging in oil-water pipelines has been observed. A mechanical solution of this problem is sometimes used but operators are reluctant to continue to use this since the volume of water is unknown.

The project will focus on an investigation of oil-water hold-up in two-phase flows as a function of inclination angle, pipe diameter, and phase velocity; additional parameters, e.g. pressure drop, are also of importance. Advanced flow visualization and diagnostics techniques will be used in order to provide qualitative and quantitative data that can be used to elucidate the mechanisms underlying potential flow regime transitions resulting from the variation of the abovementioned parameters. The data will also be used for the verification of CFD predictions, which will also be part of this project. The novelty of the work lies in examining the possibility of inducing a flow regime transition, from stratified to slug-flow, for instance, following transient variation of the phase velocities.

Project Title: Analysing and modelling of a power mixer's liquid-liquid homogenisation and subsequent separation at low to medium superficial velocities

Sponsor (industrial contact): Cameron

Supervisors: Prof. Omar K. Matar (Imperial) and Dr Christos Markides (Imperial)

A representative sample of a crude oil batch is obtained through using automatic flow proportional sampling systems. The completed samples are then analysed to establish various batch properties including the water content with an uncertainty of ± 0.05 % v/v. Power mixing systems are frequently used to homogenise the fluids in the main pipeline prior to the sample extraction point. Given the costs associated with the separation of water from crude it is not desirable to mix the fluid to the point where it becomes a stabilised emulsion, meanwhile the water residence length has to be sufficient for a representative sample to be taken. It is therefore critical to understand the incoming verses outgoing fluid dispersion when designing mixing technology.

Currently the majority of operators use the BS EN ISO 3171:1999 Annex A analytical model. This was developed during the 1980's to estimate the water distribution and dispersion for a narrow band of process conditions and mixer variants used within sampling systems. Today's vast array of different types of crude oils and process requirements have pushed this analytical model beyond its original design range, thus leading to concerns about validity. These concerns and a need for greater predictive accuracy are driving industry to investigate CFD techniques.

The usability range of the ISO 3171:1988 Annex A analytical model stated in API standard 8.2 is: 27 – 34 API, 6 – 25 cSt, 16 – 52" pipe diameter, <5% water concentration. As opposed to relatively simpler single phase flow models, more recent attempts in designing two phase oil and water CFD models have often failed to produce realistic results due to their inherent complexity. As a result multiphase CFD models can produce visually stunning and believable results but these can be quite different to what is observed during field experiments.

The purpose of the project is therefore to experimentally investigate the behaviour of scaled down power mixing design over a wide range of flowing conditions potentially using Particle Tracking Velocimetry (PTV), Particle Image Velocimetry (µPIV) and Laser Induced Florescence (LIF). This detailed investigation will help to build improved CFD models that could eventually replace the current analytical models and will lead to a better understanding of energy requirements and the physical layout of the mixing systems.

Project Title: Multi-scale modelling of non-dilute, density-matched, liquid-solid dispersions

Sponsor (industrial contact): Chevron

Supervisors: Prof. David Hann (University of Nottingham)

This is a 3 year project to perform experimental investigations of turbulence in concentrated dispersions. This work is to be performed by David Hann's team at University of Nottingham under the umbrella of the Managing Institution's contract for TMF (Transient Multiphase Flows). The experimental apparatus will be set up to perform PIV measurements in vertical pipe flow of concentrated dispersions (greater than 10% volume fraction) using refractive indexed matched materials. The objective is to obtain high quality PIV measurements of both the continuous and dispersed phase motions. The deliverables will be a set of PIV data for turbulent flow with concentrated dispersions and that data will have been corrected for bias and systematic errors.

Project Title: The effect of surfactant on vertical two-phase flows

Sponsor (industrial contact): Shell

Supervisors: Prof. Omar K. Matar, Valeria Garbin, and Ronny Pini (Imperial)

In this project, the dynamics of gas-liquid flows in vertical tubes will be considered focusing on the effect of surfactant additives on flow regime transitions. Starting from counter-current configurations, the conditions under which flooding occurs will be investigated paying particular attention to the role of surfactant in the flooding transition. The study will also include how the presence of surfactant affects the transition to churn, and then annular flow. This project will involve the use of axial- and radial-view photography of the flow in order to elucidate the effect of surfactant on the flow structures, e.g. mean film thickness, interfacial waves (their shape, frequency, and celerity), droplet entrainment and re-deposition, as well as global parameters such as the pressure gradient. Particle Image Velocimetry (PIV) and Laser Induced Fluorescence (LIF) will also be used in order to provide detailed information of the interfacial structure and of the velocity distribution in the liquid phase. The combination of the above will be used to provide details of the transition to flooding.

The Imperial team have the capability as well as the experience and expertise of performing experiments involving surfactants, as well as multi-scale modelling to elucidate the mechanisms underlying the surfactant effects; this is part of an on-going project sponsored by the Engineering and Physical Sciences Research Council, UK, which will be leveraged in this project. Use will be made of the Statistical Associating Fluid Theory to estimate the intermolecular potentials between the carrier fluid and the surfactant particles using a top-down coarse-grained approach. Based on these interactions, MD simulations can be performed by taking into account the molecular architecture of surfactants which permit the calculation of the effect of concentration on the interfacial tension that plays a key role in the interfacial dynamics. This approach also permits optimisation of the architecture of the surfactant molecules to engineer the desired response in the vertical two-phase flows of interest to Shell.

Finally, the important question of scale-up will be addressed and the Imperial team will assess to what extent the mechanisms elucidated as part of their work, derived by studying the flows in lab and pilot-scale rigs, can be extended to provide scale-up rules applicable to Shell's field-scale operations.

Project Title: Experimental programme on gas lift of viscous liquids

Sponsor (industrial contact): Statoil

Supervisors: Barry Azzopardi and Buddhi Hewakandamby, Nottingham University

The study of the effect of gas lift in viscous liquids and the effect of the gas injector is studied on an existing vertical 127 mm internal diameter rig. It will essentially be of U configuration with a 300 mm diameter downcomer. It will be 10 m tall. The arrangement of instrumentation will be as per the figure below.

We propose to employ 4 ECT probes for void fraction measurement along the pipe. These will be validated in situ by level swell tests. Note, two will be mounted close together to obtain velocity information. We will use a WMS probe for spatial distribution of void fraction and bubble size measurements. Three pressure transducers will be mounted along the riser. A hot film probe will also be mounted for wall shear stress measurement. The circulation rate of the liquid and the injection rate of the gas will be metered by appropriate instruments.

A silicone oil of 0.5 Pa·s will be used at the liquid. This will give a Reynolds number of 229 for a liquid superficial velocity of 1 m/s. Liquid properties – density ~900 kg/m3, viscosity 0.5 Pa·s, surface tension ~0.02 N/m.

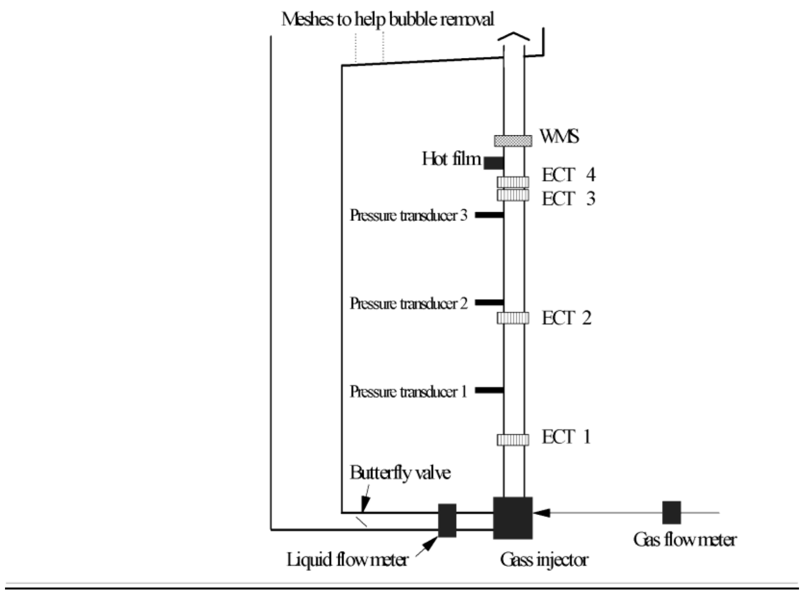
The facility will be constructed with a gas injector section that is interchangeable.

The experiments will provide:

- Time/space variation of bubble sizes;

- Axial void fraction and pressure profiles;
- Time varying directionally resolved wall shear stress;
- Videos of the flow

From these, pressure gradient and the liquid lift rate/gas injection rate relationship will be determined.



Schematic of facility showing instrumentation

Project Title: There are two associated projects:

- *Large diameter systems*
- *One-dimensional modelling of intermittent flow*

Sponsor (industrial contact): TOTAL and Petrobras

Supervisors: Barry Azzopardi, Buddhi Hewakandamby (Nottingham University), Raad Issa (Imperial)

The aim of these combined projects, where the lead is taken by Petrobras and Total, is to develop one-dimensional models for gas/liquid flows in vertical pipes. In these the flow patterns will emerge from the calculations rather than be imposed externally. It is intended that there will be soft boundaries to the flow pattern transitions, i.e., the flow will have the characteristics of one flow pattern but when it enters the transition region it will have the characteristics of both the dominance of one dropping and the other rising until we are fully in the new flow pattern.

To carry out the entirety of the modelling work will require several man years of effort. This project will tackle the first three man years.

The modelling effort at Imperial College will be focused on extending the capability of the transient, one-dimensional two-fluid model to predict intermittent (slug and churn) flow in vertical pipes. A main area of interest is application to large diameter risers. The work entails development of suitable closure models to be formulated with the aid of (i) the experimental investigations already, and to be, carried out at Nottingham University and (ii) multi-dimensional CFD calculations. In particular, the role of models for interfacial forces will be investigated and suitable correlations for those will be the target for development and implementation. Validation will be made against available experimental data, again mainly those obtained at Nottingham University. The work can be parcelled into the following tasks:

1. Review previous PhD work on the simulation of vertical slug and churn flow in vertical pipes; review correlations for interfacial forces in slug and churn flow and examine alternative ones.
2. Carry out multi-dimensional CFD calculations for intermittent flow in vertical pipes; assess local behaviour of wall friction and interfacial forces from calculations. Carry out similar exercise in large diameter pipes.
3. Analyse experimental data obtained at Nottingham to determine magnitudes of interfacial and friction forces.
4. Formulate new correlations for wall friction and interfacial forces based on both CFD calculations and experiment; implement in the one-dimensional TRIOMPH research code.
5. Validate models against available experimental data.
6. Write theses.

The modelling work will be supported by experimental work at Nottingham which will inform and validate the modelling. Experiments will be carried out with silicone oil with a surface tension similar to most oils and viscosity of 5 mPa s. Initially an experiment will be carried out to repeat some of the previous work but with a different gas liquid mixer. This will help in the modelling to ascertain the effects of inlet conditions on the model. The bulk of the experimental work will then be carried out on the Large Double Closed Loop Rig at Nottingham. The first tranche of work will be using air and silicone oil. Later work will employ sulphur hexafluoride as the gas. The vertical riser test section with be instrumented with pressure transducers, Wire Mesh Sensor, Electrical Capacitance Tomography Sensors (x4), multiple film probe sensors etc. As many of these as possible will be samples simultaneously. Though it is anticipated that the preliminary experiments and the air/silicone oil experiments on the large rig will be completed within the three man years of the project, it is expected the only a start will have been made on the sulphur hexafluoride experiments.

Project title: Near-wall and interface studies of gas-liquid horizontal stratified flows

Sponsor: TOTAL

Supervisors: Omar Matar and Christos Markides, Imperial College London

The overall aims of this project are to generate quantitative high-resolution data concerning: (1) the spatiotemporal distribution of the two phases with planar laser-induced fluorescence (PLIF), (2) the full velocity field in both phases (in the liquid phase in the first instance, and if time permits since this is more risky, also in the gas phase) with stereoscopic particle image velocimetry (PIV), (3) the circumferential distribution of wall shear-stresses (both azimuthal and axial components) from the data in (2), and (4) the interfacial stresses also from the data in (2). The PIV data in (2) and (3) will be validated against data obtained from overall pressure drop information (with pressure transducers) as well as shear-stress probes (subject to the cost of purchasing this system being within the available project budget).

Project title: Advanced measurements of developing multiphase flows

Sponsor: Chevron

Supervisors: Omar Matar and Christos Markides, Imperial College London

This effort is part of a broader activity in the Department of Chemical Engineering that involves the development and application of advanced laser-based measurement techniques for the generation of highly detailed, previously unavailable information in complex interfacial and multiphase flows. It involves fundamental research into dispersed oil-water horizontal flows with a focus on flow development, while also addressing an industrial need to develop an understanding of the underlying interfacial-instability and transport mechanisms in dispersed oil-water multiphase flows, as well as how these affect flow development in the presence of hydrate formation. The ultimate aims are to propose data-driven predictive relations of global flow-behaviour (e.g., pressure drop, hold up) and to provide highly detailed information in support of the development and validation of advanced modelling tools for these flows.