Fluid Mixing 7…. A preview ……
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Fluid Mixing 7 continues the tradition of a triennial UK Conference on mixing which started in 1981. The meeting is organised by the IChemE Subject Group on Fluid Mixing and will be held in Bradford on $10^{th}/11^{th}$ July 2002. Some 20 papers will be presented over the two days on many different aspect of mixing, with a number of papers applying computational fluid dynamics (CFD). The papers are briefly previewed here. For full details of the program and to register, contact the Proceedings Editor, Hadj Benkeira on 01274 2333721 or email him on h.benkeira@bradford.ac.uk.

The first day of the Conference has thirteen presentations, which are reviewed here under the headings of novel devices (two papers), phenomena (four papers), computational fluid dynamics (six papers), and characterisation (one paper).

Novel devices: Most fluid mixing takes place in stirred vessels which bear a geometrical resemblance to the lab beaker. Two papers could be said to depart from this orthodoxy. A contribution from Loughborough University (Conway et al) presents new results on gas-liquid-solid mixing using the so-called vortex ingesting reactor. This combines a helical-screw with a concentric draft-tube which entrains and internally recirculates gas as bubbles from the vessel head space. This mode avoids difficulties with conventional gas sparging at the vessel base. Although the study is at lab scale, it is shown that the rate of gas aeration barely affects the power draw, so that solid suspension is not adversely affected by the prescence of the gas.

The other contribution under this heading is from UMIST and concerns the use of a spinning cone (Cooke and Heggs). These when installed on the agitator shaft close to the fluid surface can be effective in controlling liquid level and reducing gas voidage in the prescence of surfactants giving rise to foaming. The effectiveness of such spinning cones as defoamers appears to scale at equal tip speed, suggesting that shear rate is the dominant issue.

Mixing phenomenologies: Four papers are categorised under this heading, which refers to basic research to quantify fundamental understanding of those complex phenomena routinely arising in fluid mixing. These four examples are for mixing with more than just one phase.

Fir liquid-liquid mixing, a full understanding of behaviour at all scales of scrutiny is still a long way off. A contribution from Bradford University (Reeve and Godfrey) describes lab studies on the vexed question of phase inversion, a crucial stability issue for anyone mixing immiscible fluids. The applications described are relevant to metals extraction on mixer-settlers of square cross section (a geometry special to the mining industries) equipped with retreat blade impellers fitted with single and double shrouds. Limiting conditions for stable operation are identified.

A second liquid-liquid study by BHRGroup (Clark and Ozcan-Taskin) focuses on the fundamentals of drop break-up in stirred vessel environments. Earlier work has been mostly confined to Coutte flows and roll mill devices. High speed video is combined with an on line video probe, which allows capture of both drop breakage and associated pre- and post-deformations as well as drop sizes. Patient elucidation of these fundamentals is essential for building better computational fluid dynamic (CFD) predictions. Even so, the work highlights some key practical issues like how to choose addition points away from poorly mixed regions.

A further phenomenological paper deals with three phase gas-liquid-solid mixing in stirred vessels. The existence of two dispersed phases in a third continuum phase gives orders of magnitude increases in mixing complexity. But as with the simpler two-liquid systems, it is still necessary to seek out the fundamentals. In a contribution from Birmingham University (Nienow and Bujakski) more details have been assembled resolving some uncertainties and complexities.. A particular issue always is the effect of gas flow on the extent and uniformity of any suspended solid. A series of impellers have been compared, in which some conventional designs like the Rushton turbine are compared with hollow blade radial flow impellers and hydrofoils like the Lightnin' A315.

Boiling gas-liquid reactors, which remove the heat of reaction by refluxing, are widely used in industry. They present severe problems in the fluid mechanical fundamentals of the gas(vapour)-liquid mixing. Surprisingly, earlier studies showed lower gas hold-up than the voaour flow would suggest. In a new study from Surrey and Twente Universities (Schaper), earlier differences in ambient and boiling behaviour have been attributed to low levels of contamination in the fluid. Although this has a big effect at low temperatures, there is negligible effect at high temperature. Gas density also has an effect and this has been evaluated using helium.

Computational fluid mixing (CFD): Multi-phase mixing presents some of the most profound challenges to CFD modelling. In a contribution from AEA Technology Engineering Software (Gobby et al), recent developments using coupled solvers are described. These can be applied via unstructured and adaptive meshes in CFX-5 software. Two practical two-phase cases are illustrated for gas mixing in bubble columns and particle suspension, for which detailed validation is available. Some results are shown in Figure 1.

In another two-phase analysis from Birmingham University (Jaworski and Pianko-Oprych) for liquid-liquid mixing in a Kenic's static mixer (Figure 2), Fluent (version 5.4.8) has been used to simulate the pressure drops across sets of inserts, local velocities and phase volume fractions. In order to track fluid drops a Lagrangian analysis is superimposed on the conventional Eulerian framework, with particle history being available as residence time distributions.

The four remaining papers on CFD are for the simpler single phase case. The first of these on jet mixing in a pipe from Chalmers University in Sweden (Mortensen et al) check the simulations against planar laser-induced fluorescence. Mixing and flows in relation to the hazardous release of flammable materials from chemical plants has been researched by Leeds University's Dept of chemical engineering (Alvani and Fairweather). They use a probability density approach (pdf) to simulate both jet and wake flows. They conclude that pdf methods are likely to be able to predict ignition risks in practical cases. For the radial jet flow from a pitched blade turbine, Jaworski and Zakrzewski from Birmingham University explore the impact of particular turbulence models. They conclude that the k-epsilon model is best, giving close velocity field predictions in the wall region, but underestimating the local energy dissipation rates. The final CFD paper is from Cambridge University (Chow et al) and deals with effluent mixing in the sea from coastal outflows. Although there is no detailed validation, both bouoyancy and turbulent dispersion are predicted to affect temperature, aalt and pollutant concentrations as less salty and colder wastewater form a pollutant surface cloud" on an unstratified stagnant sea.

Micromixing characterisation: Micromixing can be characterised and quantified by measuring the product distribution from a known fast reaction pair. Previous test reactions are unsuitable for boiling or nearly boiling reactors. In a paper from Surrey University (Zhao et al) a new reaction is proposed siutable for gas sparged systems up to 100 C. The quantitative characterisation sheds light on the effect of temperature, hence vapour pressure, on the operation of gas-liquid reactors.

The second day of fluid mixing 7 has 9 papers covering mixing time, mixing effects, CFD and instrumentation.

Mixing time: Mixing time provides the most basic measure of agitator performance in a stirred vessel. The shorter this is, the better the mixing. A joint paper from Mexico and Canada (Espinoza-Solares et al) examines a so-called hybrid combination, which has a twin configuration of a turbine and helical ribbon (see Figure 3). Order of magnitude differences in mixing time were observed for highly shear-thinning fluids when using Smith and Rushton impellers. Xanthan gum solutions formed model fluids exhibiting rheology evolution with gassing. The results are relevant to improving bioreactor/fermenter mixing whenever the fluid thickens and becomes viscous as batch reaction proceeds.

Mixing effects: Quantifying mixing in batch reactors suffers from the lack of a methodology equivalent to residence time distribution (RTD) testing in continuous flow reactors. Exactly as for mixing in flow reactors, the use of inert tracers provides no information for other than 1^{st} order reactions. In a paper from UMIST (Wabo and Mann), it is shown how the mixing of reactive tracers based on dilute acid-alkali solutions can be easily visualised by a suitable indicator. The fast acid-base reaction is inevitably much faster than the mixing, so the visualisation compactly captures the associated macro-mixing and quantifies macro-segregation. The visualisation results can be interpreted by networks-of-zones modelling via AVS imaging in 3D. Results from the 2 cubic metre vessel are useful for checking scale-up and CFD computations.

Understanding the safe quenching of a runaway polymerisation reaction in a stirred autoclave requires mixing theory to go far beyond one-dimensional scalar quantities like mixing time. This is because the process involves complex interactions of mixing and chemical reactions in 3D. The reactions typically involve initiation and propagation steps. At runaway, these reactions should be quickly suppressed by some suddenly injected stopper chemical. Often these reactions also have complex kinetics. In a theoretical paper from UMIST (Hristo and Mann), it is shown how the fast changes in 3D can be simulated by networks-of zones which can evaluate the reaction effects in a simplified fluid mechanical framework. By observing dynamic thermocouple responses at several spaced-out positions inside the vessel, it is shown how whether a safe quench will be achieved can be assessed if the kinetics are known.

Interactions of mixing and reaction may often provoke radical changes in chemical yield for multiple reactions, an aspect which is crucial to process profitability. For very fast reactions, the yield is linked to local rates of energy dissipation around a feed point. New results are put forward from Birmingham University (Assirelli et al) on the effect of feed point on the yield of the iodide-iodate test pair of reactions. Extensive lab results are reported for different impeller speeds and four injection locations (chosen to cover energy dissipation levels well above and below the average value). Choice of position can improve the by-product waste level from 20% to only 5%. In a surprising result, it is also shown that the yield from a conventional Rushton turbine can exceed that from some apparently intensive mixing devices.

Computational fluid dynamics (CFD): The second day has two papers on CFD application to stirred vessels, an area with surprisingly many unresolved issues, even in an era when computations can be done on a PC. In another contribution from Birmingham University (Bujalski et al), CFD has been used to explore how the predicted mixing time depends upon tracer input position. Their work was stimulated by the observation that CFD often fails to agree with well-established empirical correlations in the literature. The authors show a possible reason for this for the Rushton turbine. This is connected with the meshing structure, which accounts for movement of the impeller relative to stationary baffles. Apparently, if injection is away from the meshing boundary (closer to the vessel walls), predicted mixing is too slow. This finding thus raises serious questions about the validity of this type of protocol, since in this case the erroneous prediction is an artefact of the algorithm rather than the underlying fluid mechanics. A second paper also from Birmingham University (Nayan) examines Power No and velocity profiles sensitivity to the thickness of metal used to fabricate impellers, as it has been often observed that these minor geometrical parameters can radically change behaviour.

Instrumentation: Good instrumentation for fluid mixing is rare and many mixing applications in industry seem to be carried out without any. In the 2nd day's programme there are three papers on instrumentation.

In a joint paper between UMIST and ITS (Stanley et al), some new developments are described for the UMIST 1.45m stirred vessel using electrical resistance tomography (ERT) to monitor mixing during semi-batch operation. The ERT technique can reconstruct the vessel spatial concentration field in 3-dimensions as a brine solution is fed in from a feed reservoir over several minutes, mimicking semi-batch chemical manufacture. This reveals both how the reagent plume shape develops as well as the accumulation of the feed material in the fluid bulk. By using colour and opacity, an augmented-reality visualisation of the batch contents evolving in time is achieved. A typical visualisation is shown in Figure 4. The size and shape of the reagent plume can influence the chemical yield, so ERT offers the prospect of controlling chemical reaction rates in space and time. This work is also important for understanding the more complex case where reaction leads to formation of a precipitate.

In a 2nd instrumentation paper, this ERT technique has been developed for a simpler linear sensor, a sort of intelligent dip-stick. The paper is an industrial contribution from ITS in Manchester (Bolton et al). The probe has been integrated into a glass-lined vessel by inbuilding into a baffle. Thus, it can be deployed in hostile chemical environments. The probe detects phases from changes in electrical conductivity and can measure the distribution of solids content within a stirred fluid.

In the 3rd instrumentation paper between UCL and the University of Palermo (Micale et al), Prof. Brucato's group show how the pressure detected on the base of a stirred vessel can reveal the extent to which solid is in (desirable) suspension rather than undesirably sitting on the vessel base. This provides a measure of the extent of solid suspension as well as locating the just suspended condition. Of particular practical relevance is that visual access is not required. So the technique is ideal for the murky solid-liquid mixtures often encountered in industry.

Concluding remarks: If you currently need to know more about your fluid mixing, or if you have little idea what happens inside your mixing process, you ought to go to fluid mixing 7. The subject of fluid mixing is one of the areas of UK Chemical Engineering research where we can be said to be amongst the world leaders. Members of the fluid mixing subject group are regular contributors to the North American Mixing Forum (NAMF) biennial meetings in the USA and UK expertise is widely acknowledged.

The Bradford meeting will include the UK research student competition in fluid mixing for which the winner receives an all expenses paid trip to an international conference.

If, in your organisation, your young engineers need to improve their mixing know-how, send them under your training budget to fluid mixing 7. It is really good value!

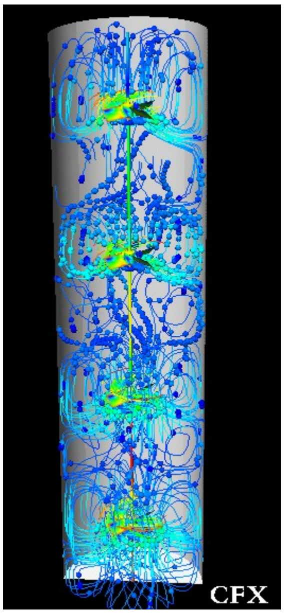

Figure 1a: Streamlines in the mixing tank

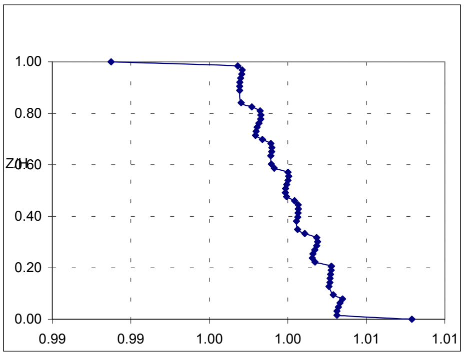

Figure 1b: Dimensionless Solids Concentration as a function of height.

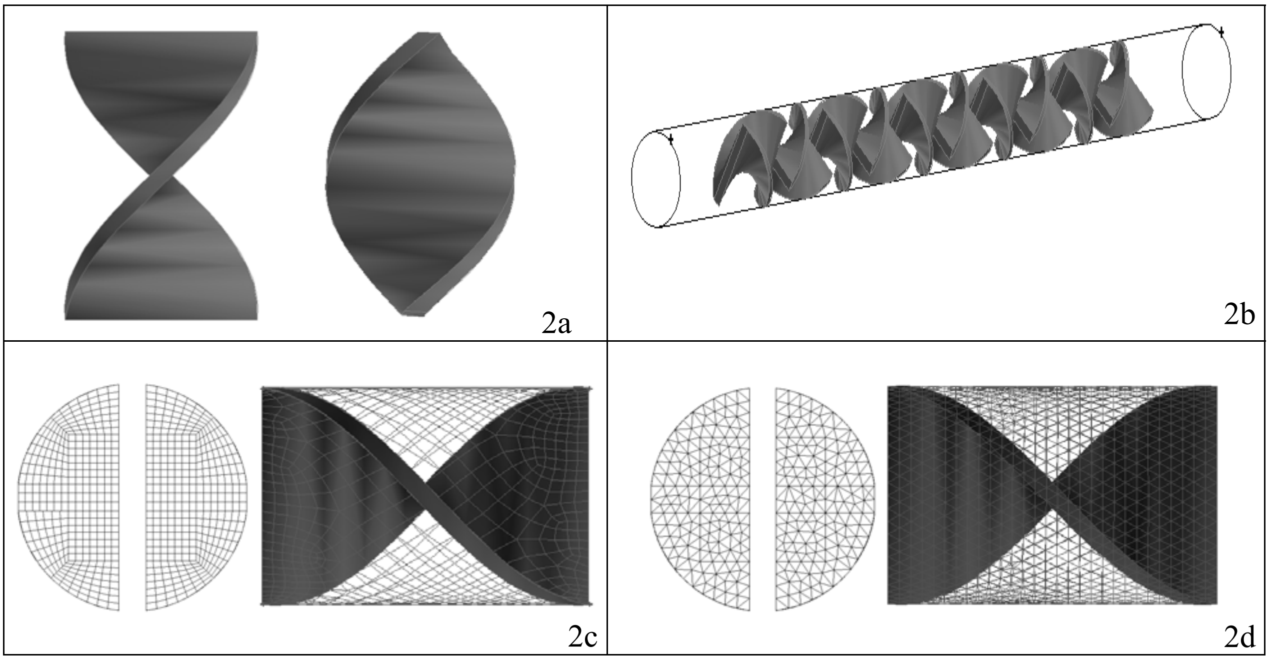

Figure 2: Kenics Static Mixer Meshed for CFD

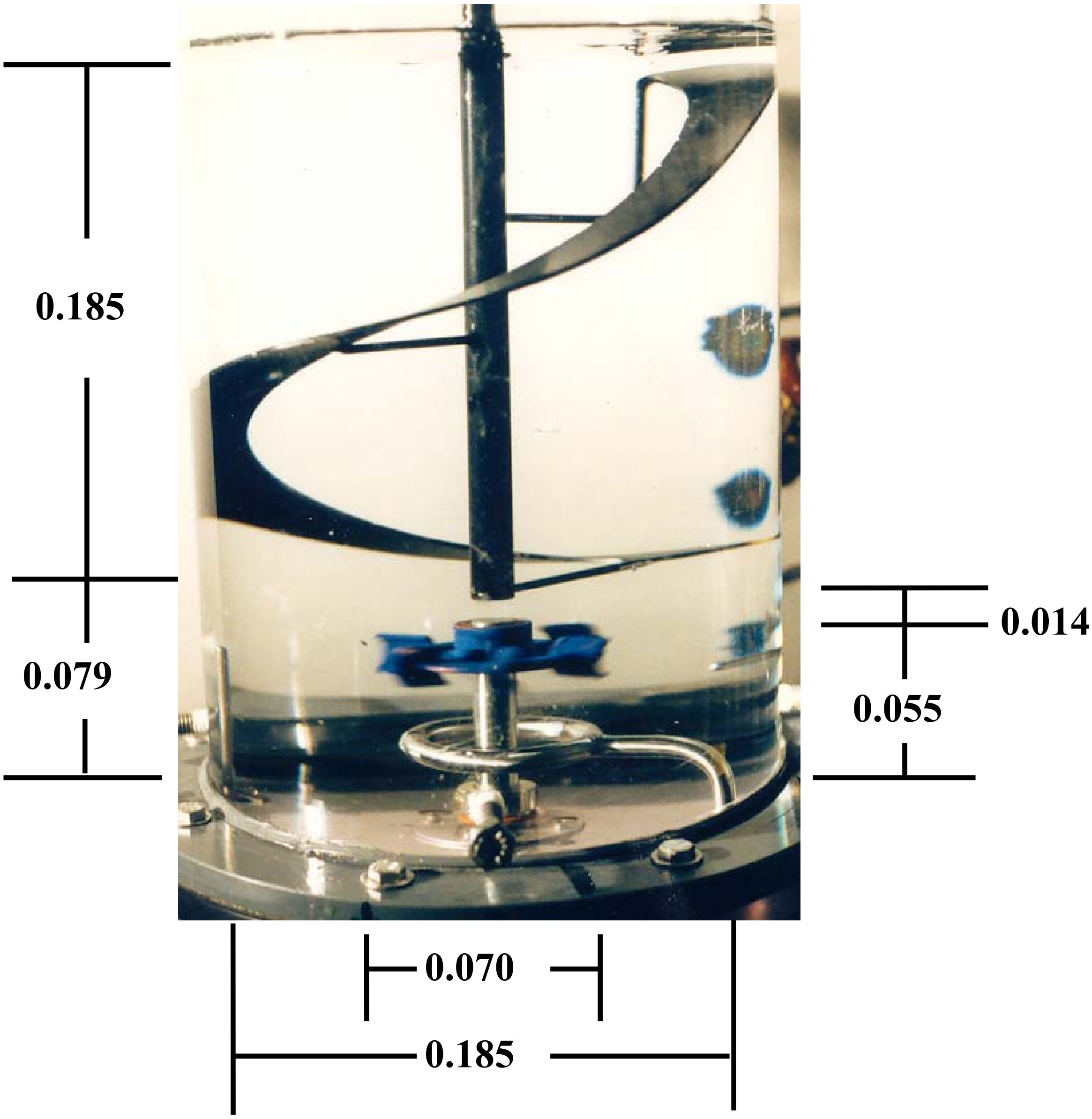

Figure 3: Hybrid Combination Impeller

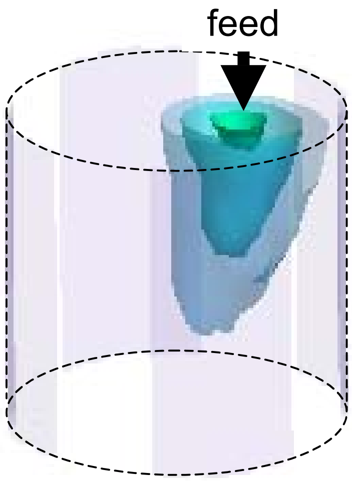

Figure 4: Tomographic Image of Semi-Batch Reagent Plume