Bridging the Gap – Coupling Fluid Chemistry with Fluid Dynamics

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Introduction

The development of the NCS could not have been possible without the cost savings and design standards provided by the implementation of the multiphase flow technology. As the core of this technology, flow simulators have been extensively used by the industry, to evaluate the feasibility of new development solutions with high credibility. However, the need for reducing investment and operational costs, in line with significantly reduced oil price, increases the demand for more accurate models. Predictability and a proper management of flow assurance problems is a prerequisite for more optimal design margins, gaining both costs, safety and environmental issues.

Flow assurance includes predicting and controlling gas hydrates, waxes, asphaltenes deposition and corrosion and includes the addition of chemicals to the production stream. While used as a remedy, these chemicals together with natural compounds occurring in crude oils (often surface active components) lead to stabilized oil-water dispersions, referred to as emulsions. These emulsions may have to be transported and handled in the processing facilities.

Oil-water dispersions play an important role in the oil and gas production system as they have a direct effect on the pressure drop in the transport lines. Reliable pressure drop predictions will lead to higher energy efficiency and cost reductions, potentially lower investment costs and facilitate the development of longer transport lines and tiebacks.

Water handling costs are high and in 2000 were estimated to be $40 billion/yr on a global scale. A considerable amount of these costs can be ascribed to flow assurance and emulsion treatment. Improved understanding of the formation, stability and rheological properties of emulsions is needed for better subsea processing design (e.g. boosting and separation) and for optimizing separation in the processing facilities. Improving measurement and predication capabilities for multiphase flows with dispersions may lead to huge cost savings during investment and operation.

Transport of produced oil and water

Upon increasing the velocity for a given fluid system the flow will eventually turn from a stratified to a more turbulent regime and ultimately to a dispersed flow where water is broken into droplets and dispersed in the oil or vice versa. In addition, in real production systems, dispersions can already be present in the reservoir or be produced by high shear in pumps and valves. Disregarding the pipe wall material and dimension, the main factors governing pressure drop are the density and viscosity of the fluid, the superficial velocities and which phase being continuous (i.e. oil, water or gas). Depending on these factors, oil-water mixtures can be arranged in different flow configurations (flow patterns) as shown in Figure 1. The left figure (a) shows different flow regimes and types of oil-in-water and water-in-oil dispersions. To the right (b), a typical flow map indicating qualitatively the flow regimes depending on the water cut and the mixture velocity. Such a flow map is very difficult to predict quantitatively and experiments must often be performed on the specific fluid system.

The state of the oil-water mixture can evolve along the transport line. As shown in Figure 2 the flow can develop from being dispersed to stratified (i.e: downstream of a valve or a pump) by separating along the transport line. This development will be highly influenced by the dispersion (droplet-droplet) stability and its rheology. Current models for oil-water flows do neither consider most of the possible oil-water flow patterns, as indicated in Figure 1, nor flow development or artificial mixing. As part of a strategic institute project at SINTEF the uncertainty of not predicting the correct oil-water flow pattern was estimated to be up to 1.7 MW with regard to pumping power. This indicates some of the cost-saving and optimization potential that this research area can contribute with.

The method

Experimental methods for studying dispersions in pipe flow experiments are quite known and tested at SINTEF and other laboratories. However, capturing the evolution of dispersion formation or dissolution during pipe flow would need flow loops in the range of tenths of kilometers. Traditional pipe flow loops are not suitable for studying transients of dispersions, lacking both the distance and (for most loops) the ability of working with real fluids and realistic conditions of pressure and temperature. To solve this challenge, SINTEF is researching on an additional alternative methodology using a wheel shaped flow loop", often referred to as "the wheel" Figure 3.

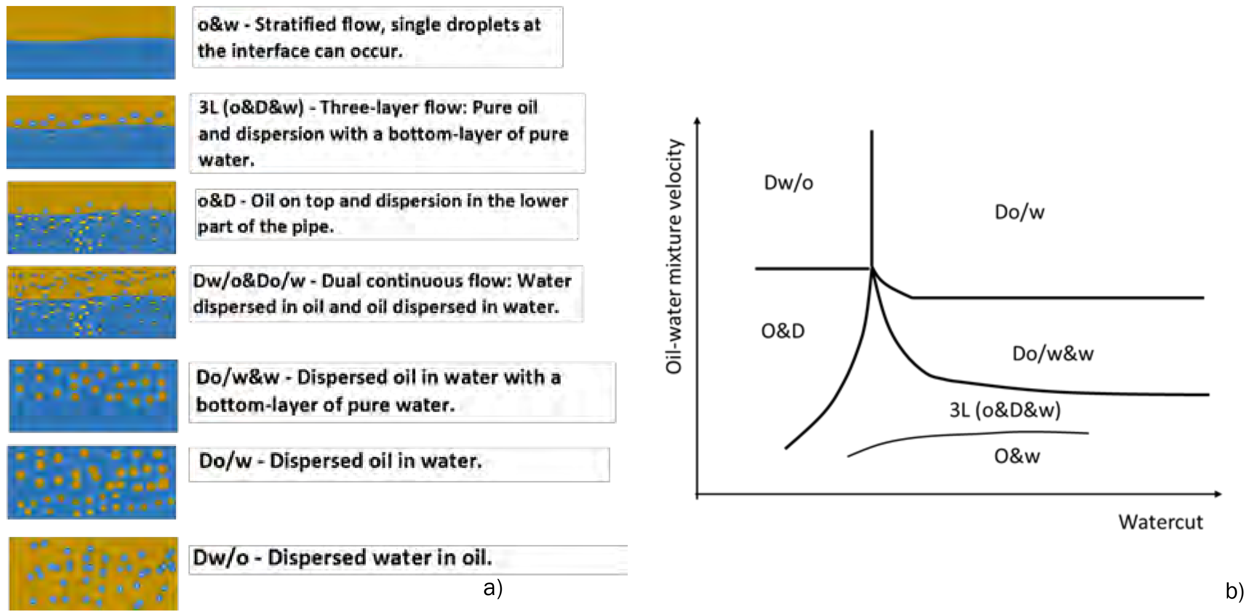

Figure 1. Oil-water flow patterns (a) and flow pattern map (b) in horizontal pipes[1]

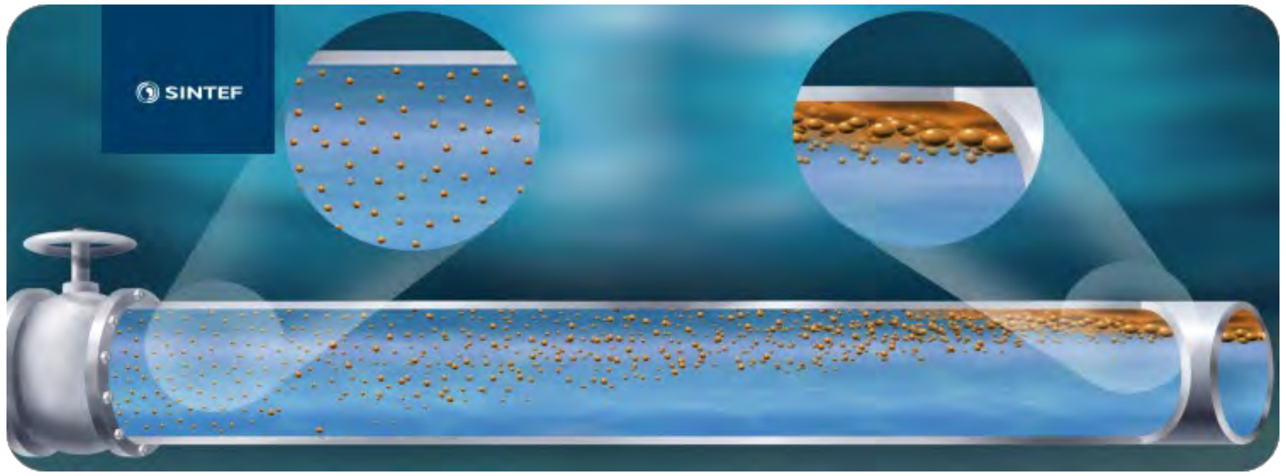

Figure 2. Example of an oil-water development process along the pipeline downstream a choke valve. The length scale for this development can be several kilometres and cannot be predicted by current commercial multiphase flow simulators.

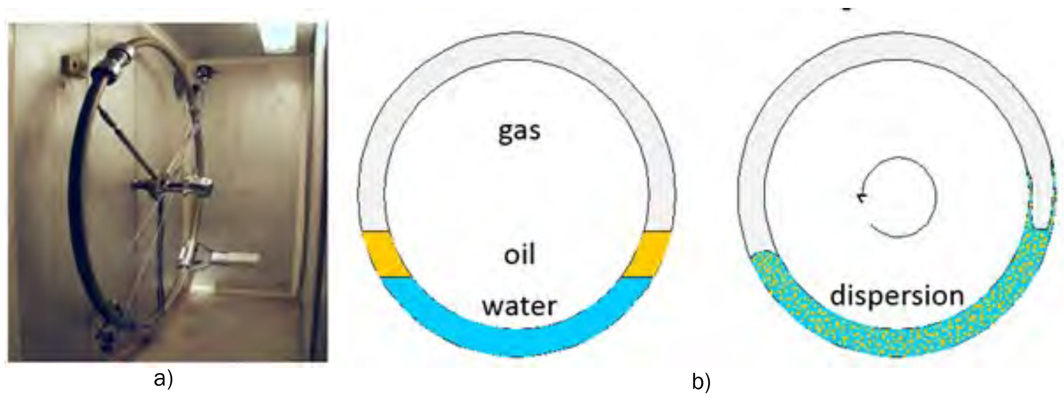

Figure 3. The wheel flow loop at SINTEF has traditionally been used to study formation and flow properties of gas hydrates. Typically, oil companies provide a crude oil of which they want to determine the potential for their system to form gas hydrates that may plug their pipe line. Moreover, the upcoming challenges caused by different production chemicals can evaluated in the wheel in a reliable and low cost way (e.g: LDHI, thermodynamic inhibitors, emulsifiers, etc). (a) The wheel flow loop placed in a climate chamber. (b) Schematic drawing of the wheel filled with a three phase system. Left: At rest and low velocities, the phases are separated. Right: When rotating at sufficiently high velocity, the flow becomes fully dispersed. A liquid tail is drawn up the pipe walls.

[1] Heiner Schümann, Murat Tutkun, Zhilin Yang, Ole Jørgen Nydal, (2016) Experimental study of dispersed oil-water flow in a horizontal pipe with enhanced inlet mixing, Part 1: Flow patterns, phase distributions and pressure gradients, Journal of Petroleum Science and Engineering, Volume 145, Pages 742-752.

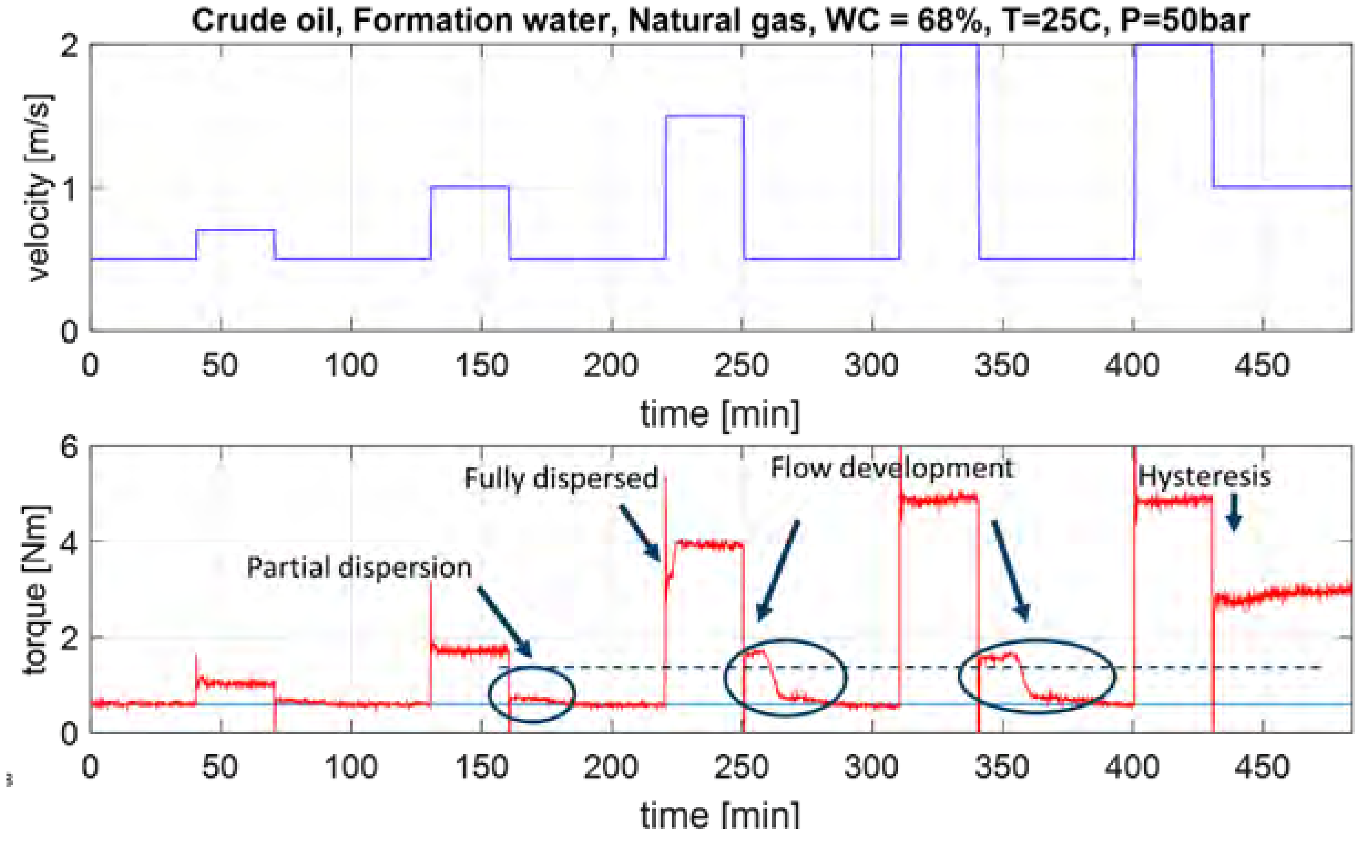

Figure 4. Example of a wheel experiment using a real crude system is shown. A velocity profile with predefined step changes was tested. Long time intervals between velocity changes allowed for flow development. The measured torque profile indicates dispersion formation as well as inflow-separation. When dispersion forms (e.g. after 220 sec), the torque gradually increases until steady state flow conditions are reached. When the mixing velocity is abruptly reduced again, the torque is gradually decreasing (e.g. after 250 sec and 390 sec), which indicates in-flow separation of the phases. The length of the separation time is a measure of dispersion stability under flowing conditions. For some conditions, flow will not separate again and shows a clear hysteresis (e.g. Torque at 450 sec exceeds the torque at 150 sec, even if mixing velocities are identical. At 150 sec phases were initially separated before the velocity was changed, while the flow was initially dispersed at 450 sec).

With the wheel it is possible to study both formation, and stability of dispersions at realistic conditions and in a simple and fast way. Furthermore, the method provides an indication of the viscosity increment when dispersions form. The system is design to run with real fluids at high pressures using hydrocarbon gas phase, brine and production chemicals. When the wheel starts rotating, the phases in the gravity driven flow will start to disperse at sufficiently high velocities. Such behavior can be confirmed with the help of a camera mounted on a window. A torque sensor has proven to be an effective instrument for indirectly measuring the increasing viscosity, sensitive enough to register even small changes in the amount of dispersion. Critical velocities required for dispersion formation can be identified for each fluid system. Testing predefined velocity profiles, a dispersion development timescale can be obtained for different input shear rates (Figure 4). This timescale might give an idea of physical flow development scales along the transport lines. Furthermore, upscaling and transformation to pressure drop in a flow line could be performed, when proper scaling rules are applied.

For oil-water systems modelling and prediction of the occurrence and kinetics of formation and breaking of dispersions is difficult. Nevertheless, it will be of huge value for the industry to be able to accurately predict transients in dispersion flow during production and in separation processes. Ongoing and future activities include finding methods for upscaling of results to be applied to large diameter pipes, characterizing different fluid systems including production chemicals, investigating effects of pressure and temperature, as well as model development considering dispersion stability properties and transient behavior.

The topics discussed in this article are based on ongoing research and development work (at SINTEF). The ideas have been presented in applications for funding to the Petromaks 2 programme by the Research Council of Norway.