Quantifying mixing efficiency in Automatic Pipeline Sampling

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Abstract

In custody transfer applications, crude oil is mostly transported as an oil-water mixture and the economic importance of quantifying the water-cut accurately has become increasingly significant. We have experimentally investigated the oil-water flow while also characterising the oil-water mixing efficiency of a prototype mixing device with a Jet In Cross Flow (JICF) configuration. As reported in a previous NSFMW (Lakshmanan et al 2015), such characterisation was achieved by commissioning a small multiphase flow loop (SMPFL) with 2.5” nominal pipe diameter at the University of Cambridge Magnetic Resonance Research Centre (MRRC) and by developing a Magnetic Resonance Imaging (MRI) pulse sequence and data acquisition methods. The data was also used to validate our CFD models, which are in turn utilised as a design tool to upscale the SMPFL to a large multiphase flow loop (LMPFL) with 10” nominal pipe diameter. For the industrial scale LMPFL, we developed a novel mixing product (SmartMix®). The SmartMix® is further tested and characterised according to ISO 3171 and API 8.2 by using a novel multipoint probe profiling (MPP) proving device The MPP enabled us to achieve true isokinetic condition as well as to capture the homogeneity of mixing and sampling more accurately. In particular, the MPP allowed the withdrawal of samples via its probes across the whole pipe diameter while also quantifying the composition (density) measurement through each channel of the MPP by a highly accurate Coriolis meter. The density profiles and hence calculated water cut are then compared with corresponding samples analysed using volumetric method.

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1. Introduction

Multiphase flows are complex and occur both in nature and in industry in the form of gas-liquid, gas-solid, liquid-liquid, liquid-solid or a combination of gas-liquid-solid flows. As such, there is significant interest to understand multiphase flows due to their scientific interest but more so due to their engineering and economic importance. For example, in the oil and gas industry, the accurate measurement of the water quantity during custody transfer from up-stream producers to mid-stream operators has significant economic importance. Accurate quantification of the water content in the pipeline is required both for the correct transaction as well as to determine taxation by governments.

In practice, this custody transfer quality measurement requires the extraction of samples from the main pipeline where, ideally, the fluid composition is homogeneously distributed across the diameter of the pipe. However, this homogeneous distribution must be achieved through an efficient mixing method, which has proved challenging. To that end, various types of mixing systems are used to produce varying degree of homogeneity and operational performance. Static mixers are commonly used in the industry with relatively narrow range of operating conditions. However the pressure drop across the mixing system is large and not desirable. Other common alternative configurations are jet mixers and power mixers [5] .

One of our primary interests in this investigation is to characterise the mixing efficiency of the SmartMix® mixing system developed by our partners in compliance with ISO 3171 and API 8.2, here after called the Automatic Pipe-line Sampling (APS) standards. This novel product uses twin-stream mixing nozzles based on a liquid jet in cross flow (LJICF) configuration [7]. Since the accurate mixing and sampling of oil-water flows in a pipeline in compliance with the APS standards [9] has significant commercial importance in custody transfer applications, we presented its five key stages in Figure 1 to demonstrate the significant challenges and the chain of uncertainties in this application.

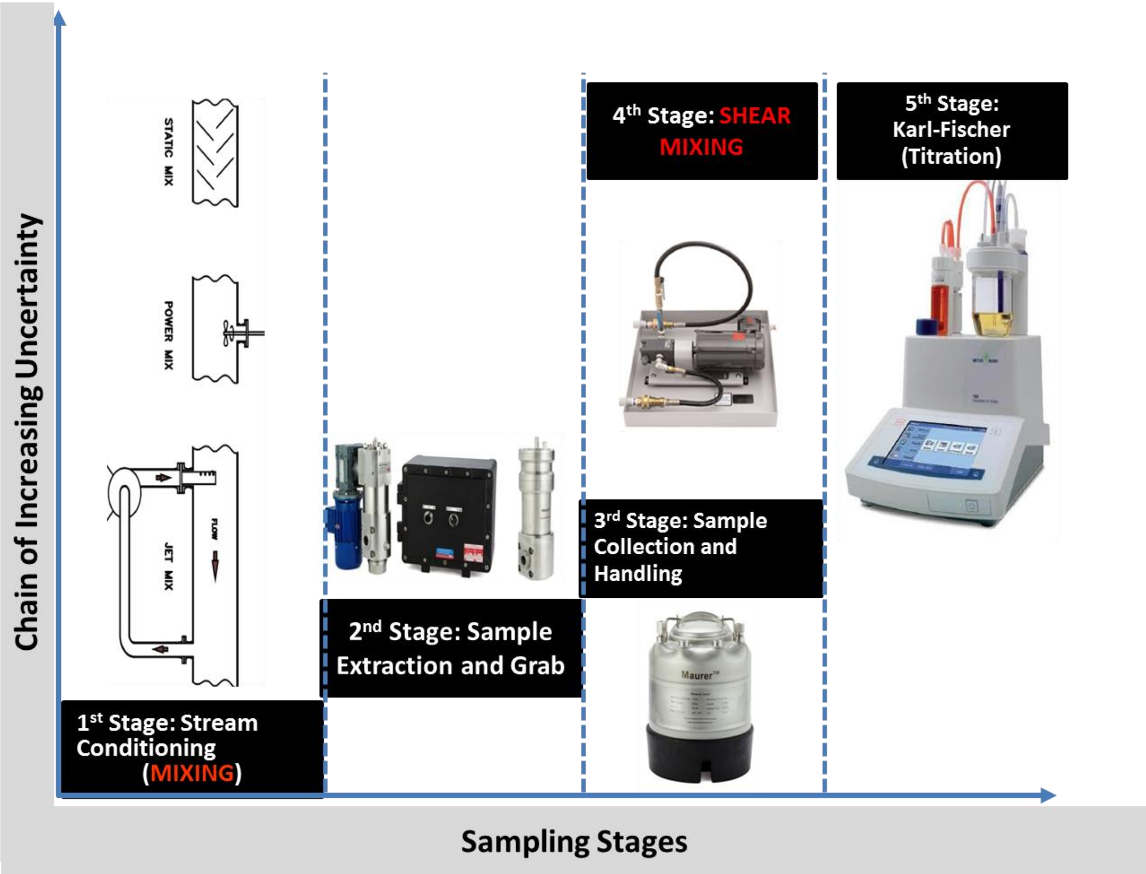


Figure 1 Automatic pipeline sampling according to the APS Standards

2. Methods of liquid-liquid flow quantification

Various techniques have been used to study the dynamics and compositional configurations of liquid-liquid (particularly oil-water) flows. These include visual observations, impedance probes, conductivity probes, particle imaging velocimetry (PIV), γ-ray Computer Tomography (CT), x-ray CT, wire mesh sensors etc. A brief review on these techniques were provided by Lakshmanan et al [7]. More recently, Magnetic Resonance (MR) imaging is proving a very useful tool for characterising single- and two-phase flows in pipes [10-12]. MR has several advantages over the other techniques mentioned above as it is completely non-invasive, can image optically opaque systems and can measure parameters including concentration, velocity, and diffusion. In liquid-liquid flows, MR is usually applied using chemical shift selective (CHESS) imaging to resolve the signal from each phase independently [13&14].

As reported by Lakshmanan et al (2015), CHESS was used to characterise the mixing efficiency of a prototype device in a 2.5” SMPFL that was designed and installed at the University of Cambridge’s Magnetic Resonance Research Centre. Those highly resolved MR images provided a very accurate distribution of the water droplets in oil across the pipeline diameter.

Unfortunately, the MR technique is unsuitable for industrial (or large) size pipes where automatic pipeline sampling for custody transfer is normally used. Therefore, we instead used the MR data to validate CFD models and in turn used the CFD models as design tools to upscale the SMPFL to the 10” LMPFL. This was possible due to the Integrated Flow Testing and Calibration Laboratory (IFTCL) depicted by Figure 2 and described by Lakshmanan et al (2015).

The IFTCL is consists of the liquid Flow Meter Calibration Loop (FMCL), SMPFL, LMPFL and the high performance computing (HPC) facilities. In brief, the LMPFL is a 4-times scaled up version of the SMPFL both geometrically and dynamically, which are both used for oil-water flow testing – including mixing. The LMPFL has a nominal diameter of 10” pipe. The liquid Flow Meter Calibration Loop (FMCL) has a nominal diameter of 12” and is designed and built specifically to calibrate flow meters. The SMPFL, LMPFL and FMCL will be under the calibration and verification audit of the network of facilities through ISO 17025 [15] accreditation by UKAS [16]. On the other hand, the HPC facility is the CFD platform to conduct advanced fluid simulations that are validated against physical experimental data for any flow of interest. More importantly, the CFD models are used to optimise and validate various multiphase technologies.

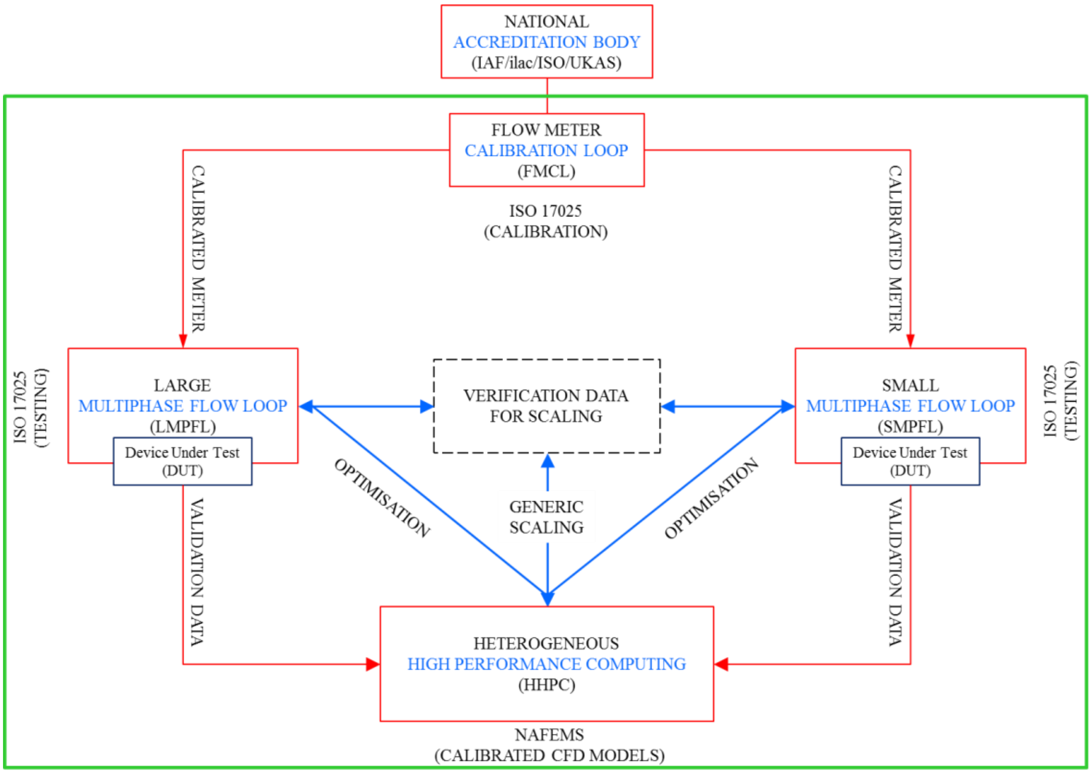


Figure 2 : OGM's integrated flow testing and calibration laboratory (IFTCL) [17]

In addition to the LMPFL, we also further investigated the prototype mixing device that was reported in Lakshmanan et al (2015) and up-scaled developed it in to a novel SmartMix® product that uses LJICF configuration to efficiently homogenise the oil-water flow in pipelines. To prove the efficient homogenisation of the SmartMix®, we developed a multiport probe profiling (MPP) according to ISO 3171, which is one of our main focus in this paper.

3.0 The Large Multiphase Flow Loop

This section will describe the construction and operation of the LMPFL while also emphasising its similarity with the SMPFL, which was described in detail by Lakshmanan et al (2015).

The Large Multiphase Flow Loop (LMPFL) with nominal diameter of 10" pipe diameter is designed and constructed to mimic most industrial mixing and sampling applications. The LMPFL is depicted by Figure 3 and organised in a modular manner as that of the SMPFL. A key aspect in its design is to accommodate both internal R&D programmes and to respond to demanding customer requirements. As such, we now describe the oil-water LMPFL that consists of four modules – also with a special focus on the multi-port profiling (MPP) unit.

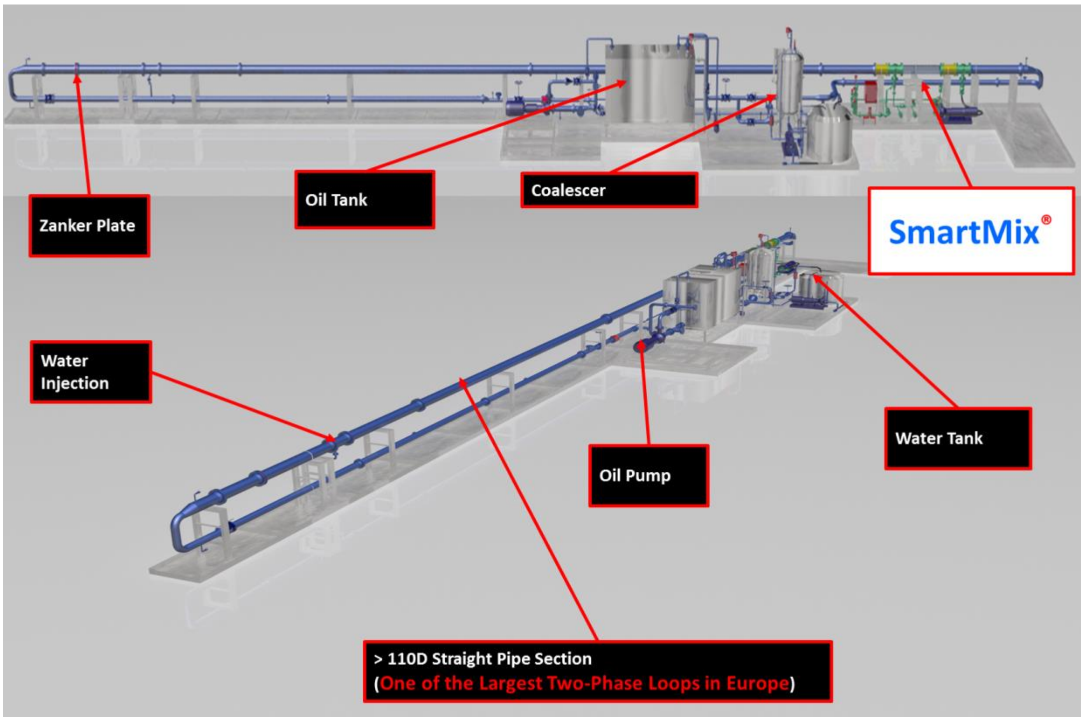


Figure3: The Large Multi-Phase Flow Loop (LMPFL) shown in front view (top) and in side view (bottom).

3.1 Equipment and Thermal Management

This module consists of major equipment such as the respective Oil- and Water-Storage Tanks; the Electric Thermal Management Unit (ETMU), the Coalescer unit as well as the respective Oil- and Water-pumps. The oil storage tank has a capacity of 10 m^3 while the water has a capacity of 2 m^3. The Oil tank is equipped with baffles to control the level of turbulence produced by the return flow. EDM-250 dielectric oil and de-ionised water are used as the two fluids for the experiment. Heaters and chillers are fitted into these tanks to allow the fluids to be operated at the desired temperature. The coalescer unit takes the oil-water mixture and separates it to the respective (oil or water) fluids and discharge it into their respective tanks. The coalescer has a separation efficiency of 50 ppm or less with equal level of impurities in both water-in-oil and oil-in-water phases. The equipment and instruments are controlled with a PLC panel and a Human-Machine Interface (HMI) unit, which allows to conduct experiments safely.

3.2 Flow Conditioning and Water Injection

In operation, oil is fed to the loop via the oil pump in a 4” pipeline where the flow rate is measured using a Helical Turbine Meter (HTM) from M&T-SAS. The maximum flow capacity of this HTM is 300m^3/hr with a turndown of 10:1; linearity of ±0.3% and repeatability of ±0.05%. The HTM is calibrated as a master meter. The flow passes progressively from the 4” to the 6” line and then to the 10” CS pipe. Similarly, water is pumped by the water pump through the 1 1/2”line and measured by a Turbine flow meter with calibrated flow range between 0.5 and 5 m^3/hr, having linearity and repeatability of ±0.37% and ±0.017%, respectively. A Zanker plate designed according to ISO 5167 to eliminate any swirling flow and turbulent fluctuations is fitted just 10D after the transition of 6” to 10” pipe size and 15D upstream of the water injection point. Water is injected at 23^0 angle in-line with the flow direction. The reason why the Zanker plate is placed upstream of the water injection is to avoid the introduction of mixing effect via the Zanker plate. To avoid further mixing at the water injection, a baffle with aerodynamically swept deign inside the pipe is used to limit the turbulence generated due to injection. To gauge the effect of the water injection on the flow, a 1m Perspex pipe was placed just after the water injection spool. For all ranges of the loop operating conditions, the water injection was shown to have very little effect – only producing stratified and wavy stratified flow. Although the loop has a capacity to deliver ~10% water cut, for separation efficiency and to accommodate the high oil flow, only water cut up to 5% was used during experiments.

3.3 Dynamically Equilibrating Flow (Straight Pipe) Module

This module consists of a long (~110D) straight pipe of 10” diameter, where the flow is expected to be affected by nothing other than the pipe wall. The flanges are prover grade flanges making the transition for the flow very smooth. At 10D downstream from the inlet of the module (i.e. 10D downstream of the water injection point), the loop is fitted with a 32-beam DFX ultrasonic flow meter from M&T-SAS. Although the main purpose of the DFX is as a check for the oil- and water-flow meters, investigation is also being carried out to quantify slip velocities between the stratified oil-water flow in order to correlate with the water cut and hold up. Furthermore, turbulent fluctuations and swirl data can be readily acquired based on the individual transit time measurements from each of the 32 beams.

Although this module has more than 110D straight pipe, this length is short compared to what is usually cited in the literature, which recommend 300D-600D (Nydal et al [20]). But, we argue that those studies were done on a 53mm and 90mm internal diameter pipes and were more focused to study slug frequency at elevated velocities. Therefore, for industrial scale flow loops such as the LMPFL, our observation through the optional 8D Perspex pipe just at the downstream end of this module indicates that the two-phase flow is fully equilibrated dynamically. This indicates that the effect of the water injection 110D upstream didn't propagate to the test section area. It is argued that only natural mixing due to the level of stream velocity and its interaction with the pipe wall could be attributed.

3.3 Fast Loop Test Rig (FLTR)

This module is positioned at the downstream end of the ~110D Straight Pipe section, where the SmartMix® device is shown in Figure 3. The FLTR consists of a 10" line with an electrical capacitance tomography (ECT) from ITS Ltd, the Nozzle spool, the MPP unit, the Scoop Spool, a second ECT unit that forms a dual-plane tomography – all arranged linearly. After the FLTR, the 10" pipeline then further continues and reducing to a 6" pipe to form the loop return flow. In particular, the FLTR has a fast loop that takes off fluid from the scoop and passes it through a pump, where the outlet is further split in to two lines feeding the Nozzle's internal and external inlets. The injection of fluid through the twin-nozzle into the 10" main is used to create the required homogenisation to extract representative sample through the scoop. The flow extracted via the scoop is measured by a turbine meter. The flow downstream of the pump with the branch traversing to the internal nozzle is also measured. This allows the control of the percentage flow in each stream of the nozzle. The internal nozzle branch is equipped with a microwave based water cut meter (AE048) from GODSEND Ltd while the external branch has a low frequency capacitance based water cut meter (AE047) from Agar Corp; a Maurer Sampler from Maurer Instruments Ltd and an advanced water cut meter from M-Flow Ltd, both connected in series. These four instruments allow a broader means of capturing the mixing efficiency of the SmartMix® device.

3.3.1 MPP Development

This section will focus on the development and utilisation of the MPP device that will allow us to quantify mixing homogeneity via physical sample measurement across the diameter of the 10" LMPFL. As was demonstrated in the SMPFL, although MRI is an advanced and accurate technique to characterise the homogeneity of mixing processes, it however has limitations to use it in industrial scale flows. Therefore, the MPP is the closest device for the LMPFL to capture the mixing homogeneity and distribution across the pipe diameter. The MPP and its internals are depicted by Figure 4. There are six port holes each with 8mm diameter. While one probe is placed at the base of the pipe wall, the other two are positioned 20 mm away from the bottom and top of the pipe wall. One is placed at the central axis of the pipe while those adjacent to it are positioned symmetric to each other according to ISO 3171. The port holes are connected with flexible tubes of equal length, which in turn are connected to Mini Coriolis flow meters from Bronkhorst Ltd. The Mini Coriolis meters each have a density and temperature measurement functionality that allows to measure the mixture property (density). This will be used to calculate the ratio of the water at symmetric probe location. . In addition, isokinetic sampling through the MPP is achieved by a control valve that is actuated based on the combined flow rate of oil and water. It worth pointing out that the (opening) position of the sample extraction scoop is below the centre line of the pipe axis and only two of the port holes of the MPP are in the same elevation, although 2D downstream.

A typical experimental cycle of proving by water injection (PWI) consists of 10 seconds of sampling to divert the fluid to the six Maurer Receivers connected the MPP flexible tubes with 5 minute intervals of continuous flow through to an intermediate bulk container (IBC). Each experiment at least has got 9-cycles, for each port, taking a total of 46.5 minutes for a single test. The 5 minutes intervals ensure the flushing of samples through the tubes. Mass flow rate, temperature, pressure and density are measured during the sample extraction via the Coriolis flow meters. The samples withdrawn through those MPP probes are analysed for its water content either using volumetric methods or coulometric Karl-Fischer titration. Once the experiment is complete, the fluid in the (IBC) is pumped to the coalescer.

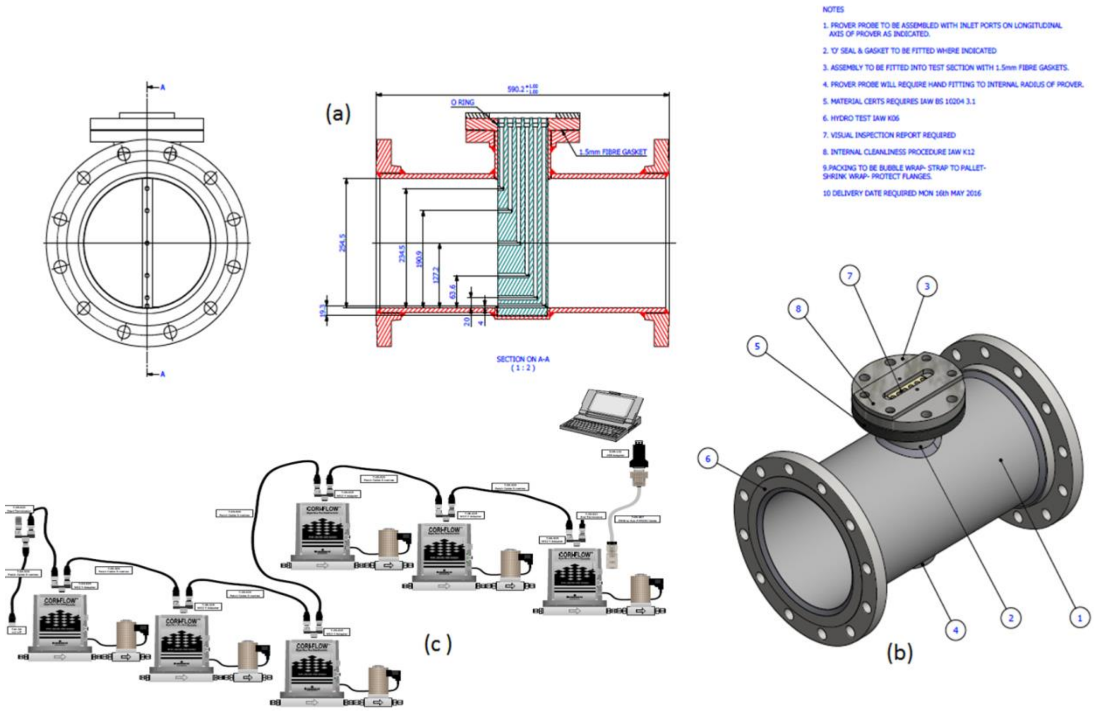


Figure 4 (a) MPP Structure (b) MPP spool where the MPP is inserted across the spool (c) Coriolis meters (M55, from Bronkhorst UK Limited) through flexible tube connection where the sampling and density profiling is done

4. Results and Discussion

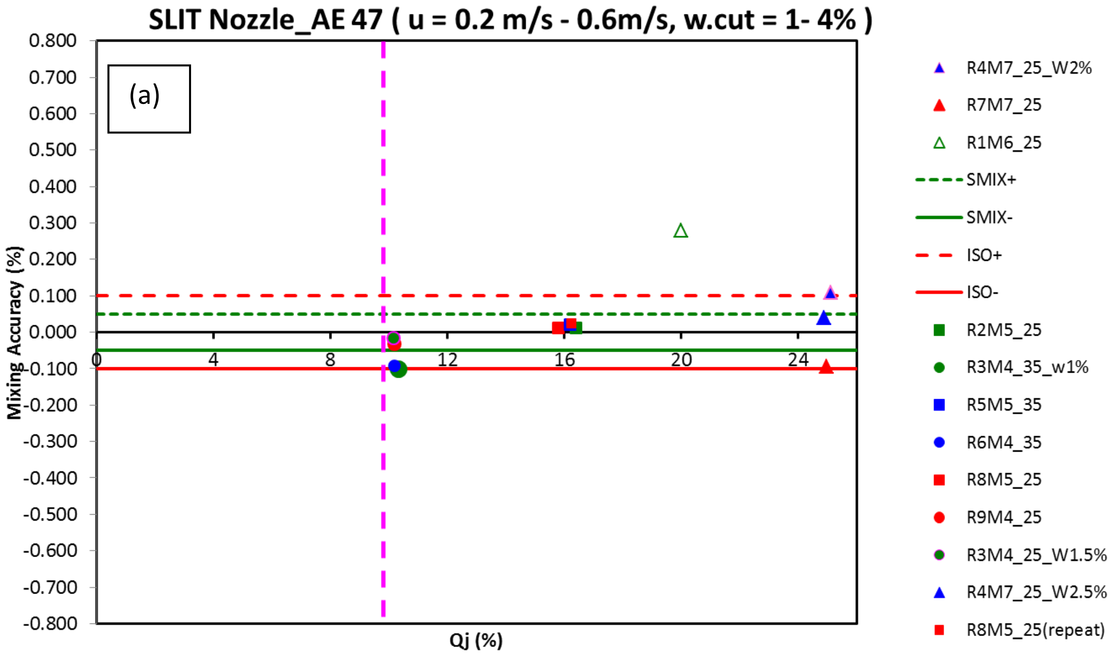
4.1 Mixing Experiments

The LMPFL experiments were conducted with velocity range from 0.2 -0.6 m/s with mean water cut of 1-4 %. . The designation letters for the experiments are in the form RxMy, where M indicates the entrainment ratio to generate the mixing jets.

Table 1. Design of Experiments

	R1	R2	R3	R4	R5	R6	R7	R8	R9
U(m/s)	0.2	0.4	0.6	0.2	0.4	0.6	0.2	0.4	0.6
WC(%)	1	1	1	2	2	2	4	4	4

The effect of entrainment ratio on mixing efficiency is discussed in this section. The entrainment ratio is typically the ratio of the flow rate through the nozzle to that of the flow through the pipe. Figure 5a and Figure 5b show the mixing accuracy (or degree of homogeneity) of the oil-water flow as a function of the entrainment ratio Qj against the base water cut of the LMPFL and the measured water cuts of AE47 and AE48, respectively.



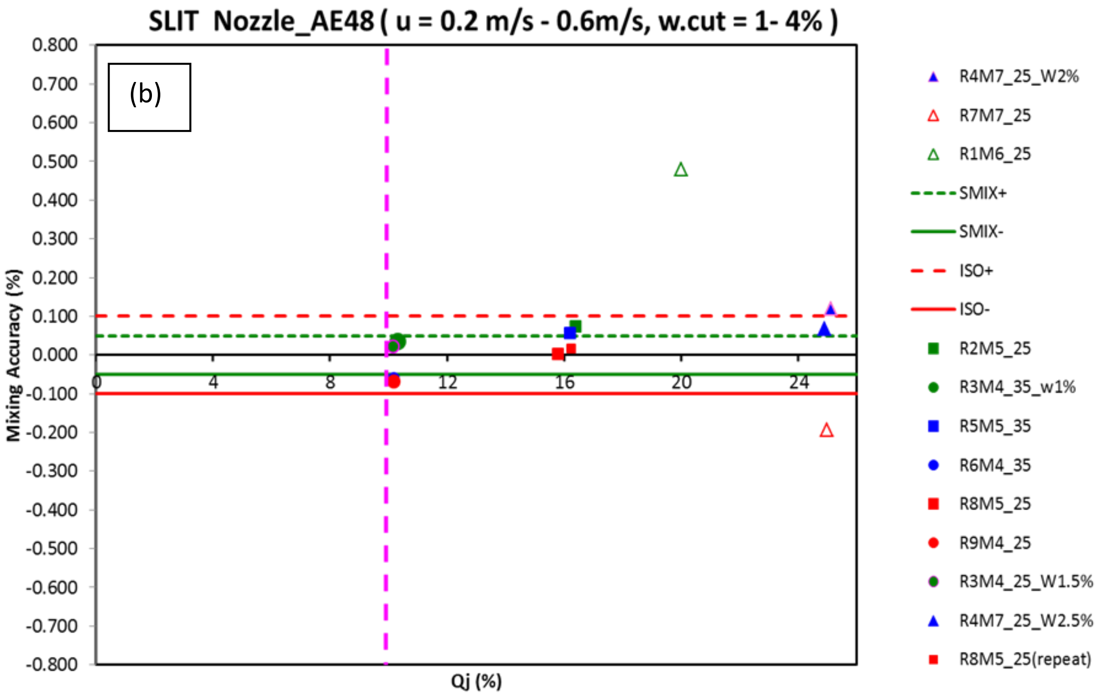


Figure 5(a) &(b): Mixing accuracy versus injection rate showing the degree of homogeneity at stream velocity (0.2 m/s to 0.6 m/s) as a function of water cut values of 1% (green symbols), 2%(blue symbols) and 4% (red symbols) as measured by the two water cut meters AE47 and AE48

From the above figure, the ±10% mixing accuracy or the better than 90% degree of homogeneity, delimited by the red lines is the minimum requirement that must be met for a mixing device to be compliant with the APS Standards, particularly ISO 3171. On the other hand, the ±5% mixing accuracy or the better than 95% degree of homogeneity, delimited by the green lines, is the minimum requirement set for the SmartMix® device. The pink dashed line indicates the minimum entrainment ratio required by the SmartMix® device to achieve homogeneous mixing. . Note that the entrainment ratio that is required to achieve an acceptable homogeneity is ~20%, ~16% and ~10% of the total flow rate corresponding to the mixture stream velocities of 0.2 m/s, 0.4 m/s, and 0.6 m/s, respectively. But, it is the distribution of the flows and the interaction between the internal nozzle (strong jet) and external nozzle (weak jet) that determines the degree of homogeneity. The "strong jet" and "weak jet" are indicators of the momentum flux ratio between the injected flow and the stream flow. However, measuring mixing homogeneity based on profile testing as recommended by the APS standards via the recovery of the injected water is at best sensitivity study as the base water cut may not be known in the field. To elucidate, we looked at water composition measurements using various water cut meters.

4.2. Composition measurement using MPP and Water-Cut Meters

While water cut meters such as AE47 and AE48 are well established in providing good approximations on the extracted fluid via the scoop, our earlier investigation [7] using MRI shows the instantaneous mixing to be asymmetric at times due to vortices created by turbulent jets. This was a key driver on the development of the MPP so that either vertical- or horizontal-profiling across the pipe diameter is possible. The MPP method, as recommended by the APS standards, allows the extraction of physical samples through each port. However, we further extend this technique to capture the real-time measurement of the flow rate and composition of the fluid.

In the following, a proving water injection (PWI) experiment was conducted at 0.2 m/s and 4% water cut. The water cut profiles from both AE47 and AE48 water cut meters are shown in Figure 6. The density, temperature profiles are shown in Figure7. Figures 6 and 7 show an investigation that highlighted what is usually masked in traditional methods that are based on water cut meters alone. It will also provide a perspective how the injection flow rate alone is not a sufficient condition for homogeneous mixing.

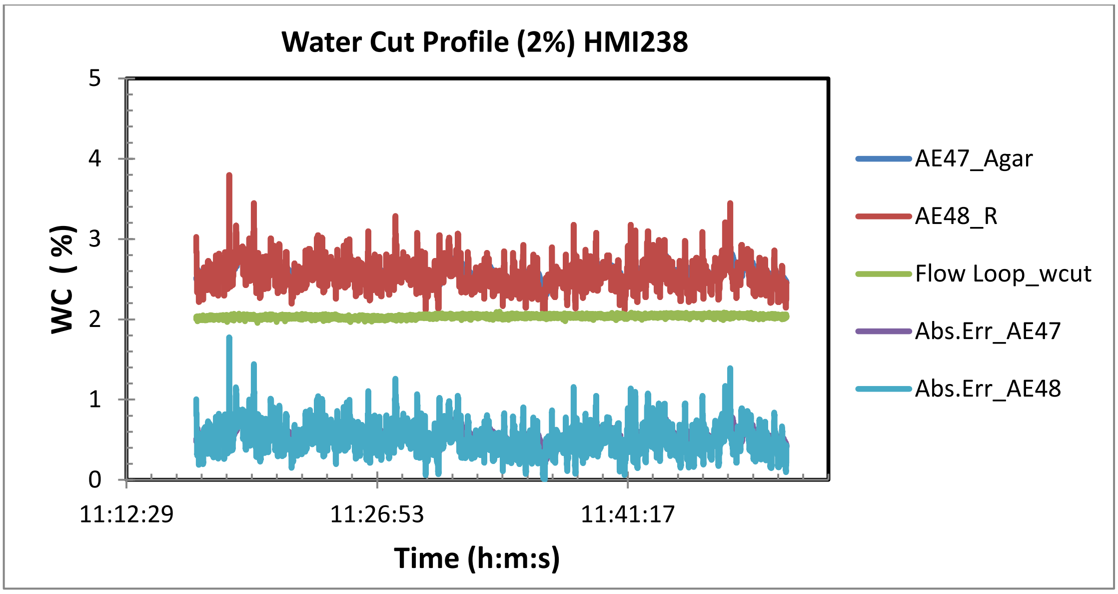


Figure 6. Water cut measured using two types of WIOM (AE47 and AE48) compared to the loop water cut calulated based on the oil- and water-flowmeters. The percent water cut difference between the water cut meters is shown as an error.

From Figure 6, the two water cut meters (AE47 and AE48) read almost similar water cut values but higher than the loop water cut that is calculated based on the water and oil flow rates. The mean absolute error and the relative errors of AE47 and AE48 are 0.55%.and 0.26% respectively. This shows the level of mixing to be within the limits of the APS requirements.

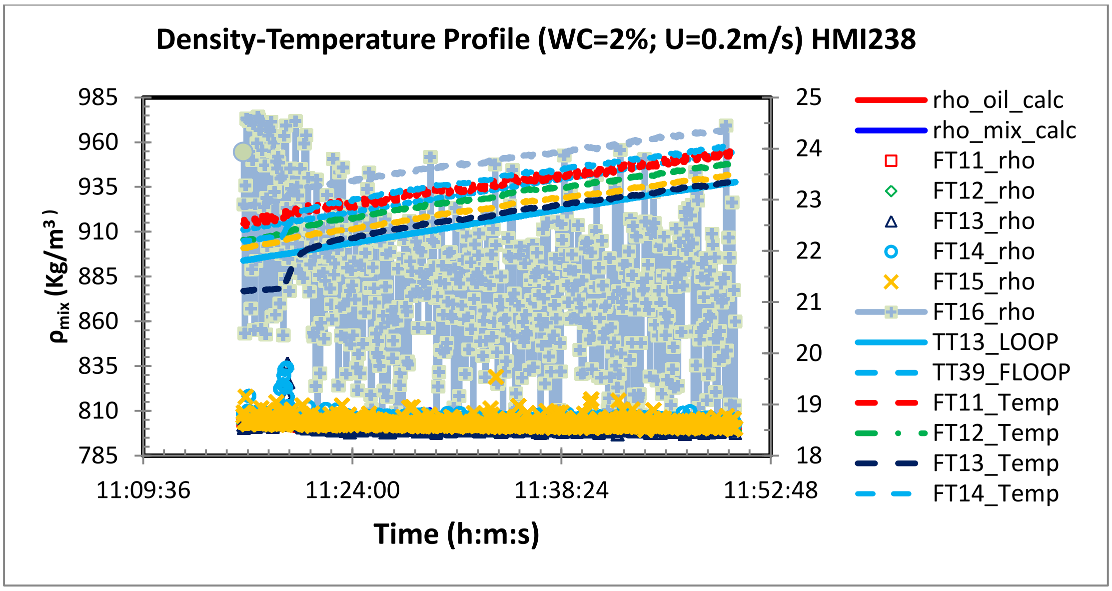


Figure7. Density and Temperature profiles through the MPP probes. The oil (rho_oil_calc) density is calculated as function of temperatures while the mixture (rho_mix_calc) density profile is calculated as a function of temperature and water cut.

On the other hand, Figure7 shows the density and temperature profiles where there is variation in the fluid temperature – both in the MPP and in the loop. The loop temperature varies between 21.9-23.4 ^{0}C, which is less than the ±2 ^{0}C operational limit. However, the fluid in the fast loop varies between 22.2 – 24.4 ^{0}C just exceeding the loop temperature operational limit. This is due to the heat generated by the fast loop pump and the fluid flow rate being substantially a small portion of the flow in the pipe. It is interesting to observe the density profiles, except for the port at the base of the pipe, are all very similar. But, at the base of the pipe, the density fluctuates between the density of oil and the density of nearly pure water. This MPP profiling proved very effective to detect even small globules of water at the base of the pipe which we have seen in FT16 density profile. This will be masked if only water cut meters were used. We also observed in our earlier investigation that the slightest stratification was resolved adequately using the MRI method (7).

It is well know that the most challenging mixing duty is where the stream flow is low and the pipe is horizontal, the oil is light and has low viscosity while the water is more saline (heavy). To demonstrate, we raised the stream velocity by 25% (from 0.2m/s to 0.25m/s) from the test case shown above, which we called it now HMI242 and depicted by Figure 8 to 10. This case demonstrates the requirements of isokinetic sampling. As the name implies, Isokinetic sampling requires the matching of velocities between the stream velocity and the velocity in the probes, a task very difficult to achieve. Owing to the challenge, the APS standards provide a large variation in the velocity matching. Although the basis of the requirement could be attributed to the water droplet size in water-in-oil sampling applications, the reason behind for the range of the acceptable "isokinetic" velocity is questionable.

In Figure 8, the band for the Isokinetic velocity values (minimum, maximum) both by ISO and API are shown by the lines (ISO_IK_min, ISO_IK_max) and (API_IK_min, API_IK_max), respectively. Our MPP unit has achieved an almost exact match between the oil-water mixture stream velocity (umix) of the main pipeline and the flow velocities in the probes (top, U11) and base of the pipe (U16). This ensures both the correct physical sampling and the continuous in-line measurement of flow rate and composition (density) profiles.

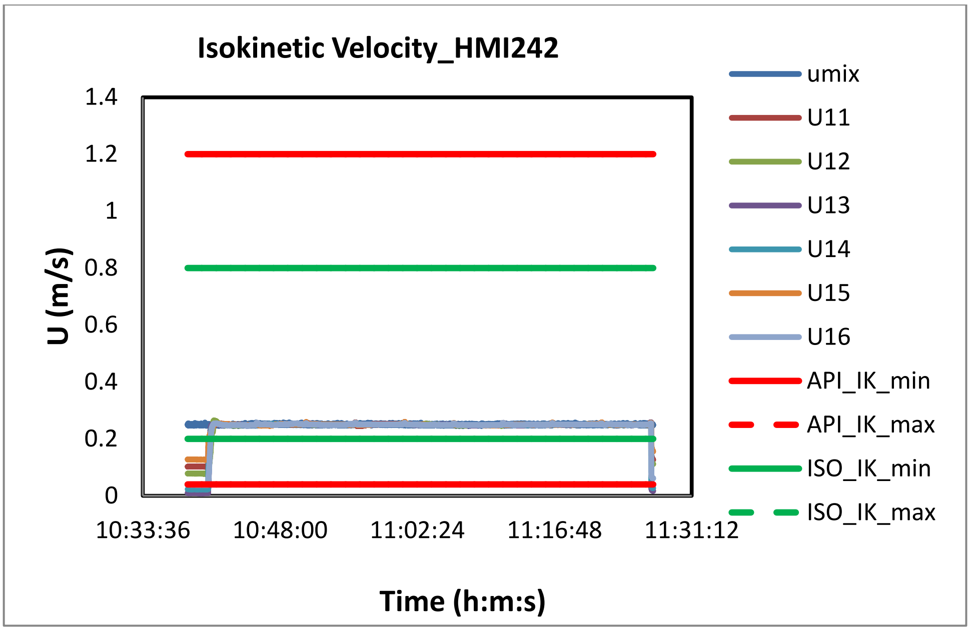


Figure 8 Isokinetic velocities through the MPP probes u11(top) -u16(base), with u13 at the centre and compared to the stream velocity (umix) and the ISO and API min/max ranges for velocity matching. The MPP achieved almost an excat match to the stream velocity.

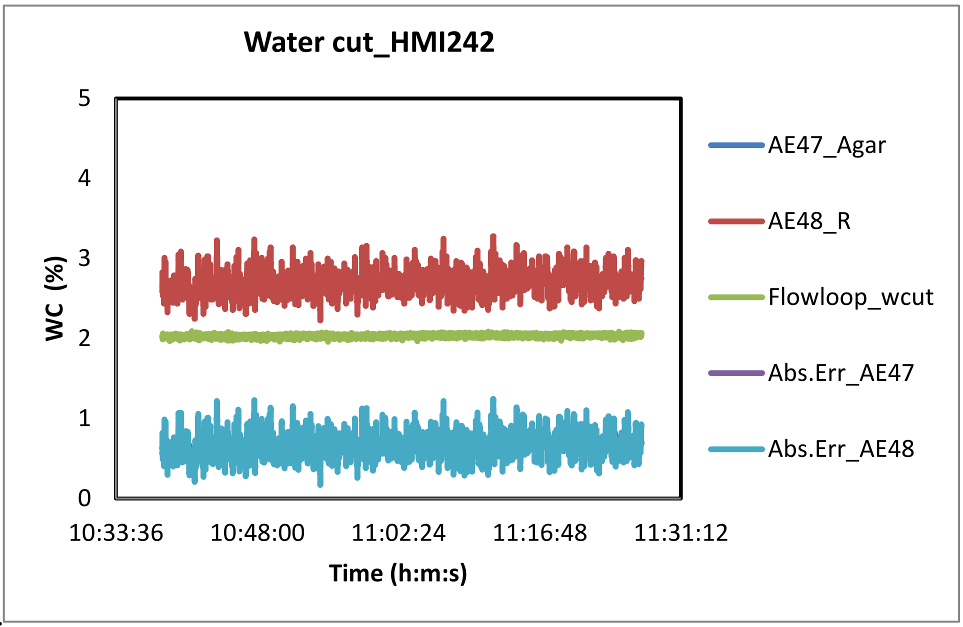


Figure 9 Water cut measured using two types of WIOM (AE47 and AE48) compared to the loop water cut calulated based on the oil- and water-flowmeters. The percent water cut difference between the water cut meters is shown as an error.

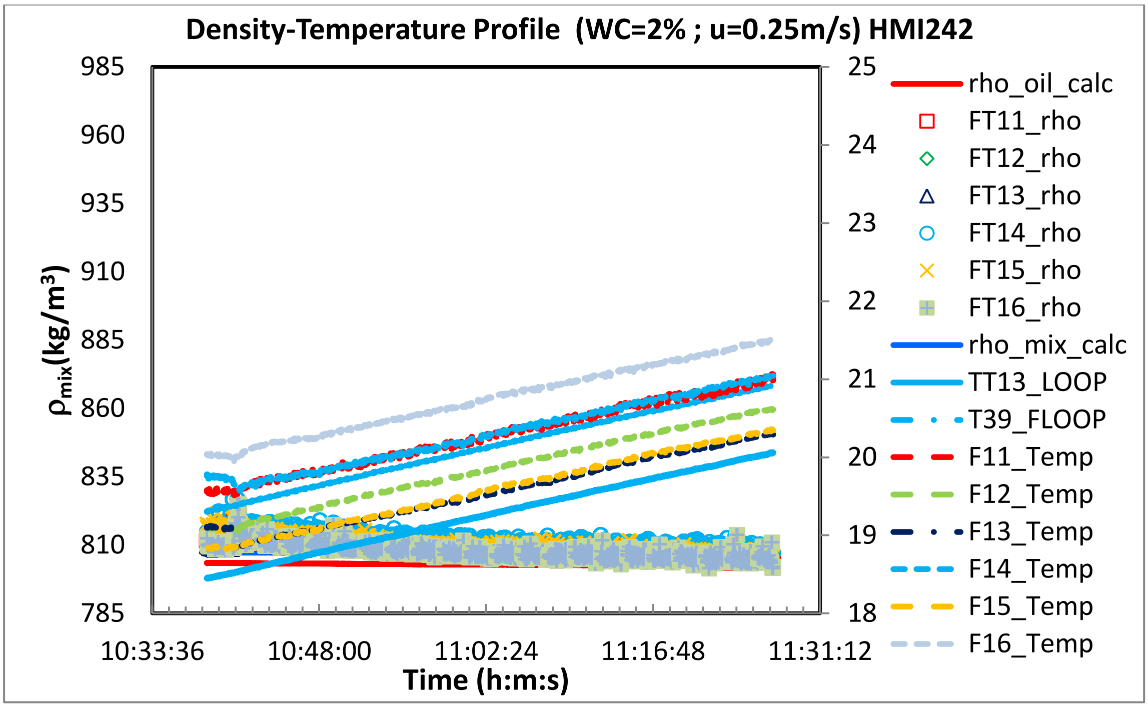


Figure10 Density (left y-axis) and Temperature (right y-axis) profiles through the MPP probes, where FT11_rho-FT16_rho show the density profiles.

Water cut profiles measured by AE47 and AE48 in each of the case detailed by Figure 6 and Figure 9 are marginally similar but there is significant difference in the mixing homogeneity as described by Figure 7 and Figure 10. This shows the advantage of using the MPP method with in-line measurement of the type used here – namely, density measurement. Other cases are presented in Figure 11 and Figure 12 where homogeneous mixing is achieved.

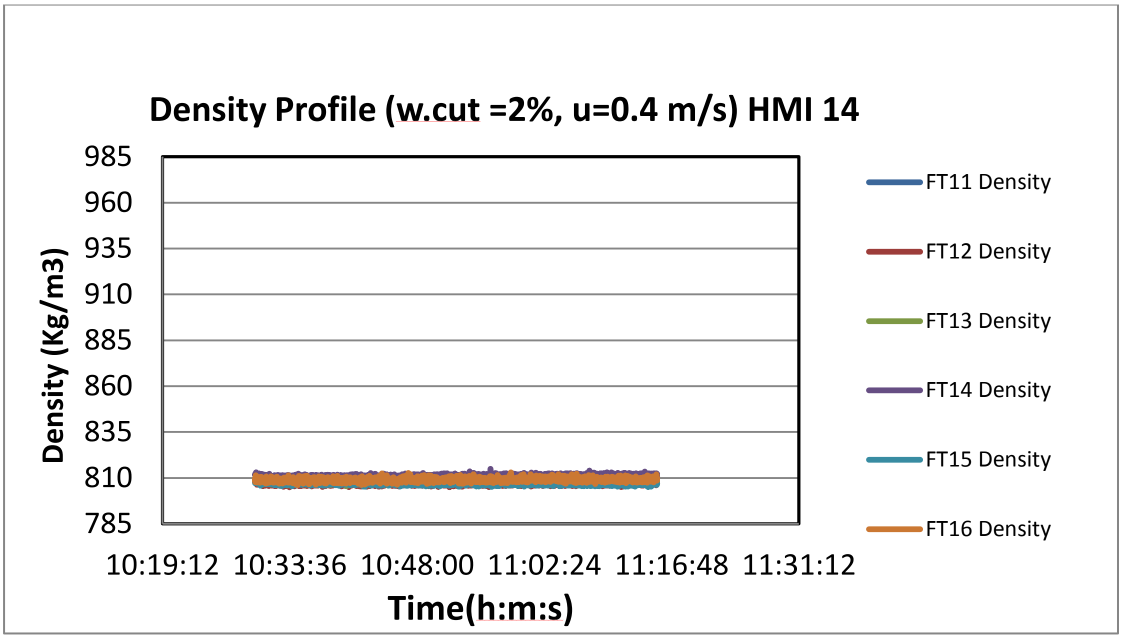


Figure 11 Density profiles through the MPP probes

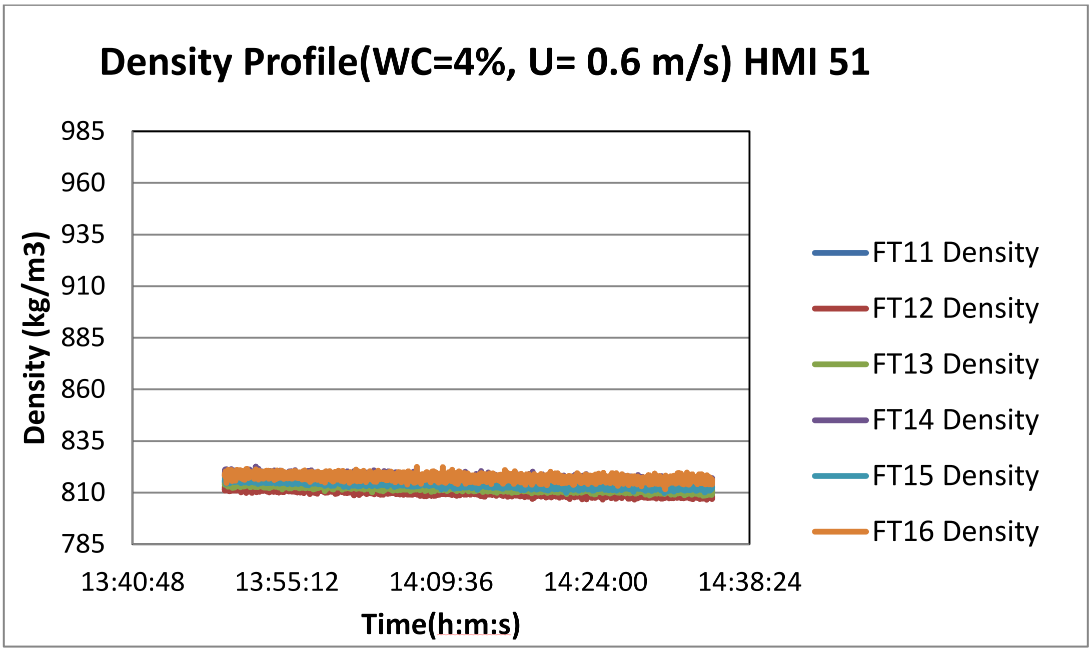


Figure 12 Density profiles through the MPP probes

4.3 MPP as a Proving and Quality Measurement Tool

In this section, we discuss the preliminary results from MPP that may serve as an alternative and effective in-line quality measurement tool. We will also demonstrate the ability of computational models to be used as digital MPP tools especially when design optimisation in large diameter pipes is practically impossible and is the only way to test a mixing system of such sizes via CFD tools.

4.3.1 Computational Fluid Dynamics

Details of advanced CFD model development to optimize the nozzles as well as to capture the oil-water two phase flows were discussed by Huang et al (18) and Maru et al (19). These authors show encouraging results to suggest that CFD could be used at least as a reliable design guide to design nozzle-scoop configurations for mixing systems as well as MPP composition profiles. Figure 13 show MPP results using 2LM model, namely R1M4 and R1M5 (u= 0.2 m/s with WC=1%) and R4M4 and R4M5 (u=0.2m/s with WC=2%). M4 and M5 indicate the entrainment ratio or injection rate, where M4 < M5. As discussed in Huang et al (18) and Maru et al (19), the 2LM model is based on two-liquid mixture model of immiscible fluids with artificial turbulent diffusion to capture the oil-water transport and mixing in a pipeline. These results indicated that by increasing the injection rate, the mixing homogeneity could be improved (see Figures 13 and 14), where the higher injection rate show more horizontal profile with WC.

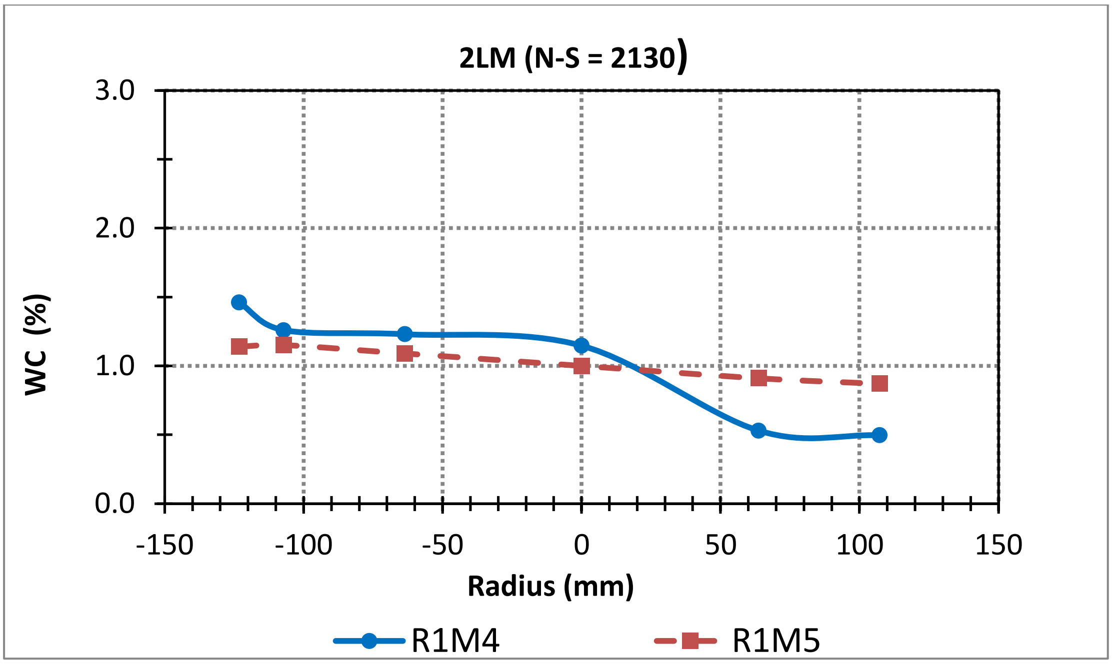


Figure 13 R1M4 and R1M5 (u=0.2m/s and WC=1%)

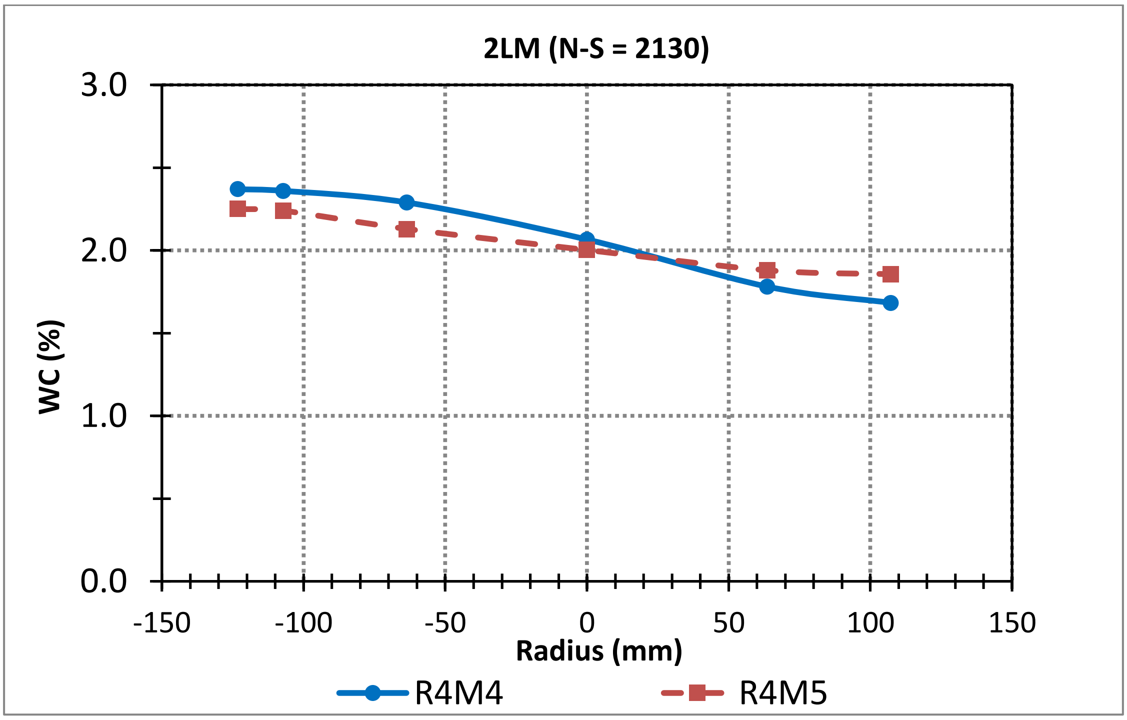


Figure 14 R4M4 and R4M5 (u=0.2m/s and WC=2%)

4.3.2 Mixing Efficiency through MPP Sampling

Once we showed the limitations of water cut meters in non-homogeneous mixing by comparing in-line composition (or density) measurements of the MPP device, we now embark on its usefulness to quantify the homogeneity.

To quantify the homogeneity of a mixture, APS standards recommend a two point measurements or sampling method as a ratio of C1/C2. The ratio must lie within 0.9 < C1/C2 < 1.1 for a homogeneous mixed conditions. Mixture component concentration measured from upper half of the pipe (referred as C1) and the lower half of the pipe (C2) are used to quantify the homogeneity of mixing. Although the recommended numbers of probes for pipes lower than 12" nominal diameter is three, we placed six instead to capture more data points. The C1/C2 ratios of mixture density from the Coriolis Meter are shown in Figure 15. From the density measurement we have also calculated ratio of water cut as:

$$\frac{\alpha 1}{\alpha 2} = \left[\frac{\rho mix1}{\rho mix2}\right] * \left[\frac{1 + (\frac{\rho oil1}{\rho mix})}{1 + (\frac{\rho oil2}{\rho mix})}\right]$$

Where 1& 2 are probe locations and corresponding mixture density and oil density is used to calculate the water cut ratio. The water cut ratios are shown in Figure 16. It shows that the homogeneous mixing is achieved in all the cases at these three different positions.

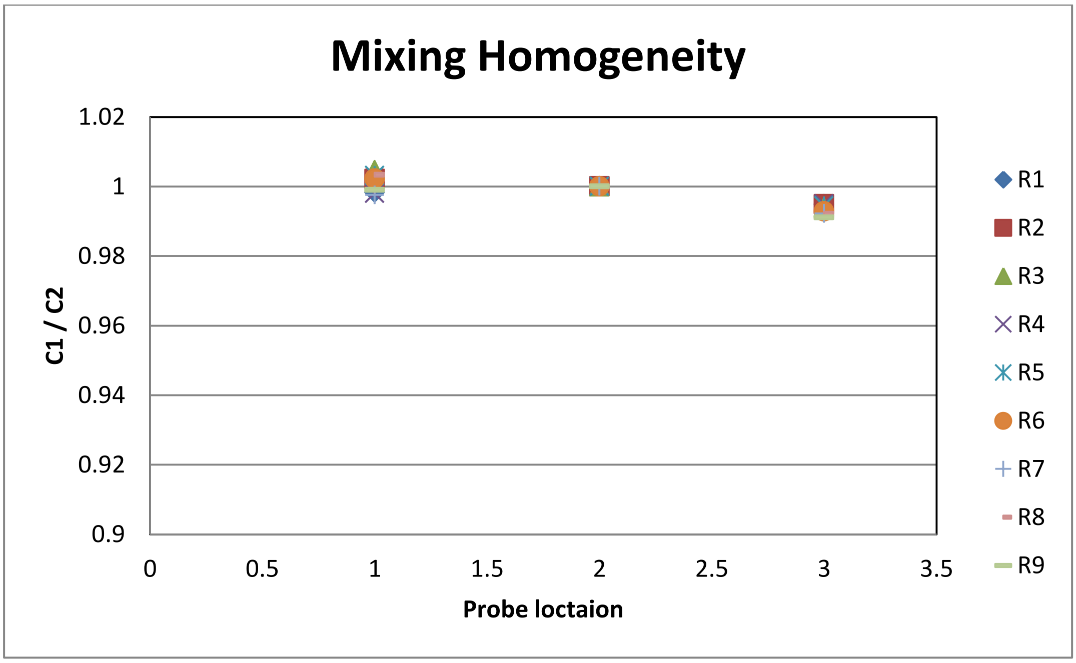


Figure 15 C1/C2 ratio via MPP probes

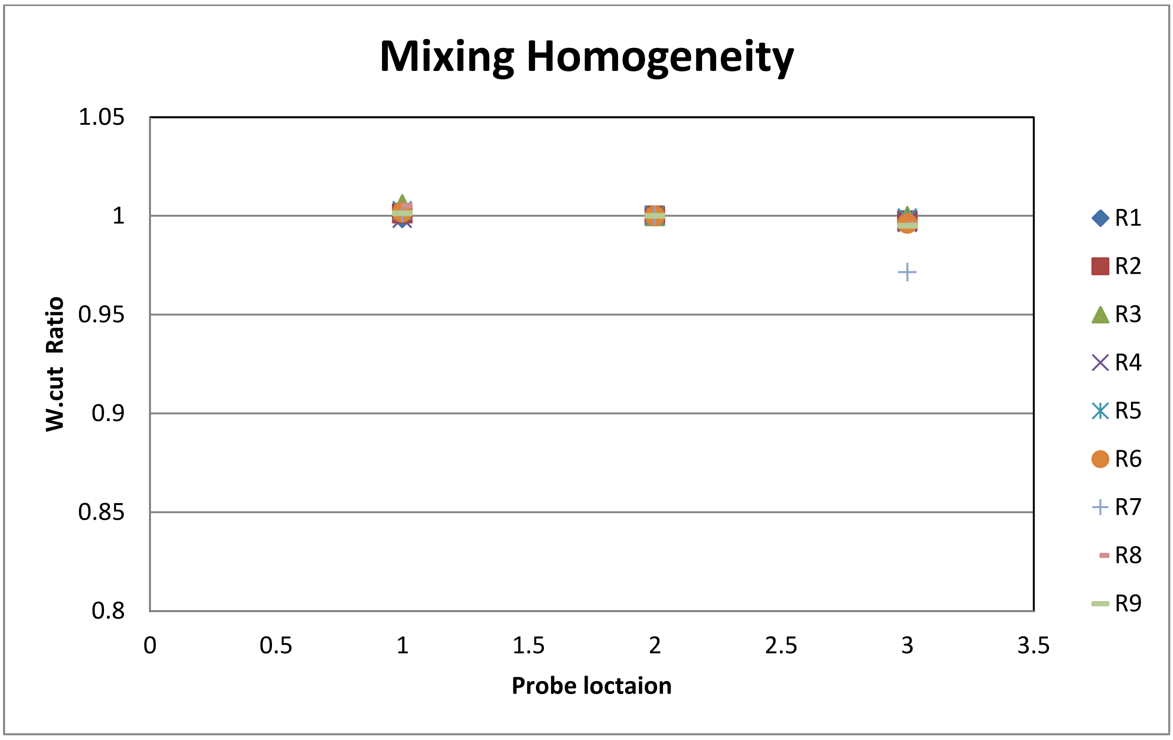


Figure 16 Water cut ratio via MPP probes

Conclusion

We have in the past developed a prototype mixing system in our SMPFL, which was characterised and optimised using magnetic resonance imaging (MRI). This MRI data showed a number of features that would have been impossible to measure more traditional methods. This encouraging investigation culminated in the development of our SmartMix® device that used liquid jet in cross flow (LJICF) configuration by employing a strong jet weak jet interaction. This was achieved using twin-nozzle design and by exploiting knowledge of turbulence from computational fluid dynamics (CFD) simulations. In particular, we developed a MPP device to prove the homogeneity of mixing for custody transfer applications. The investigation demonstrated that in situations where complete homogeneity is not achieved, traditional water cut meters may not provide the complete picture of the mixing while MPP provided a highly resolved spectrum indicating the presence of water droplet or globules in the pipe.

This preliminary result, with such distinct advantage from current methods, will be developed further owing to the fact that it also has some shortcomings. For example, the MPP ports are small with nominal diameter of 8mm. These may be prone for blockages in real field application such as from wax and other deposits. However, heating and further improvement in engineering design could be made to circumvent such difficulties. Furthermore, the in-line measurement system that accompanies the MPP device is relatively expensive Coriolis flow meters that may also be prone for regular maintenance. However, as a proving device, such duty may be less severe that what can be imagined. Considering the exposure and the loss in revenue in underestimating or over estimating the water cut in custody transfer application, the MPP device is an accurate system that the industry may look in to in detail – not only to compliment and improve the current standard but also to use it as a highly accurate quality measurement system that can correct the flow meters used for quantity measurement. Because, sampling is not just another function of measurement but it is the heart and soul of the profit figure. Therefore, it must start correctly in mixing and its quantification if it is to end well. Otherwise it remains as the elephant in the room.

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