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TP/IFE/007: THREEPLEX WP4 – Fluid properties and two-phase fluid characterisation experiments

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Summary

This report describes the lab facility and gives an overview of the fluid properties for the gas, the water and the oils that have been used in IFE's Work Package no. 4 (WP4) in the EC-project THREEPLEX. The main activity in THREEPLEX has been experimental study of three-phase oil-water-gas slug flow.

This report also includes the results from two different sets of experiments that have been done to characterise the fluids with respect to 1) oil-water slip and oil-water phase inversion, and 2) gas entrainment in liquid layers. These experiments have been carried out for the same fluids and in the same flow loop as the slug flow experiments being the main part of WP4.

The results demonstrate the usefulness of this type of more basic fluid characterisation experiments in order to better understand more complex flows.
The work has also demonstrated the capabilities of the ECT tomography system for quantification of gas entrainment in liquid layers

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Contents

Conclusions

The various fluid parameters that typically enter a multiphase flow model include standard, measurable fluid properties like viscosity, density and interfacial surface tension. Of importance are also parameters that give information on how the fluids interact in a dynamic situation, for example various types of entrainment and dispersions.

This report gives an overview of the standard fluid properties for all the fluids that have been used in Work Package 4 (WP4) of THREEPLEX. In addition to the gas phase SF_6, the other fluids have been ordinary tap water and two different oils. The one oil has been a 2 cP viscosity, kerosene type oil, while the second type was a white mineral oil with viscosity 12 cP. Both the oils are stable, transparent, low aromatic, non-reactive oils. This yields good control of the experimental conditions, gives excellent reproducibility of the results, and the transparent oils (and pipes) make direct visual observation possible.

Further, two different sets of experiments have therefore been done to characterise the fluids with respect to 1) oil-water slip and oil-water phase inversion, and 2) gas entrainment in liquid layers. These experiments have been carried out for the same fluids and in the same flow loop as the entire slug flow experiments being part of WP4. The oil-water experiments as well as the stratified gas-liquid experiments were made in a horizontal pipe.

The results from the oil-water flow experiments show that the two oils exhibit different behaviour with respect to onset of phase inversion and oil-water slip. The 2 cP viscosity oil typically inverts at a water-cut value near 45%, while the 12 cP oil inverts near a water-cut value of 20%. A 3-layer oil-o/w-water flow regime prevails for intermediate water-cuts for both oils and this 3-layer flow is clearly associated with a drag reducing effect.

The stratified gas-liquid flow experiments were made to characterise the gas-liquid interaction, particularly with respect to entrainment of gas in the liquid layer. The ECT-system was used to quantify entrained gas fraction. The results show systematic differences between the two oils, with less gas being entrained in the more viscous oil, as could be expected from a turbulence consideration.

The work has also demonstrated the capabilities of the ECT-system for this type of gas entrainment measurements.

The experiments on oil-water flow and stratified gas-liquid flow in a horizontal pipe were motivated by the need for improved knowledge of fluid-fluid interaction processes. The results demonstrate the usefulness of this type of more basic fluid characterisation experiments in order to better understand, and model, more complex flow regimes. The reported data will hopefully give better knowledge of dispersed oil-water and gas-liquid flows in general, and for the THREEPLEX slug flow experiments in particular.

1 Introduction

The various fluid properties that typically enter the multiphase flow models include standard, measurable fluid properties like viscosity, density and interfacial surface tension. Of importance are also parameters that give information on how the fluids interact in a dynamic situation. Two different types of carefully controlled experiments have therefore been done to further characterise the fluids with respect to:

1) Oil-water slip and oil-water phase inversion
2) Gas entrainment in liquid layers

It is IFE's Well Flow Loop that has been used in all the loop experiments that have been carried out in WP4 of THREEPLEX. This is a loop that uses the high molecular weight gas sulphur hexafluoride, SF_6, for the gas phase. The water has been ordinary tap water, while oils with two different viscosities (2 and 12 cP) have been used. A brief description of the loop and an overview of the standard fluid properties are summarised in Chapter 2.

Both the oil-water experiments and the stratified gas-liquid experiments were done in the Well Flow Loop, with the 250 D long test pipe in horizontal position. Pressure gradients, phase holdup and phase distribution were measured. The results are presented and discussed in Chapter 3 and 4, respectively. Tables are included in appendices.

2 The experimental test facility and fluid properties

2.1 The test rig

The Well Flow Loop is a closed loop, for the THREEPLEX experiments operated at pressures of 4 or 8 bara. The test section, which has an internal diameter of 100 mm, is 250 D long for pipe inclinations below 7 degrees and 150 D for steeper inclinations. The test section can be positioned at any pipe inclination between vertical and horizontal. The loop utilises a dense gas at medium pressure in order to simulate high-pressure flow conditions found in oil and gas pipelines. The flow rig consists of a flow test section, a return section, a gas-liquid separator, an oil-water separator, pumps, a gas compressor, and a flow rate control system.

The gas is cooled after compression and an automatic control system maintains a constant gas temperature at the inlet of the test section. The oil and water are circulated through the loop by centrifugal pumps or, for very low flow rates, by dosage pumps. An outline of the test rig is shown in *Figure 2-1*.

A flexible hose, indicated as the black section of item 17 (the test section) in *Figure 2-1,* connects the 100 D long extension to the 'original' 150 D long test section. This flexible hose makes it possible to do dip-geometry experiments. The test pipe is equipped with valves and instruments as indicated in *Figure 2-2*. The position of the instruments can change between measurement campaigns, but an indication of typical configuration is given along with *Figure 2-2*.

The main specifications for the loop are given in *Table 2-1*.

Maximum pressure	10 bar		Superficial oil velocity	0.0005 -2 m/s
Test section diameter	10 cm		Superficial water velocity	0.0005 -2 m/s
Test section length	25 m for incl. 0-7 deg. 15 m for incl. 7-90 deg.		Inclination of test section (upward and downward)	$0 - 90^o$
Superficial gas velocity	0.3 – 12 m/s			

Table 2-1. General specifications for the Well Flow Loop

An integrated computer system is used for the operational control of the loop as well as for data acquisition. The data acquisition system is based on DM2 from Measurement Systems Ltd. It is PC-based and uses a real-time, multitasking operating system, OS-9000. It comprises two data logging subsystems, one for low data acquisition rates (<5 Hz) and another for high rates (<1 kHz), called Datascan and DAP respectively.

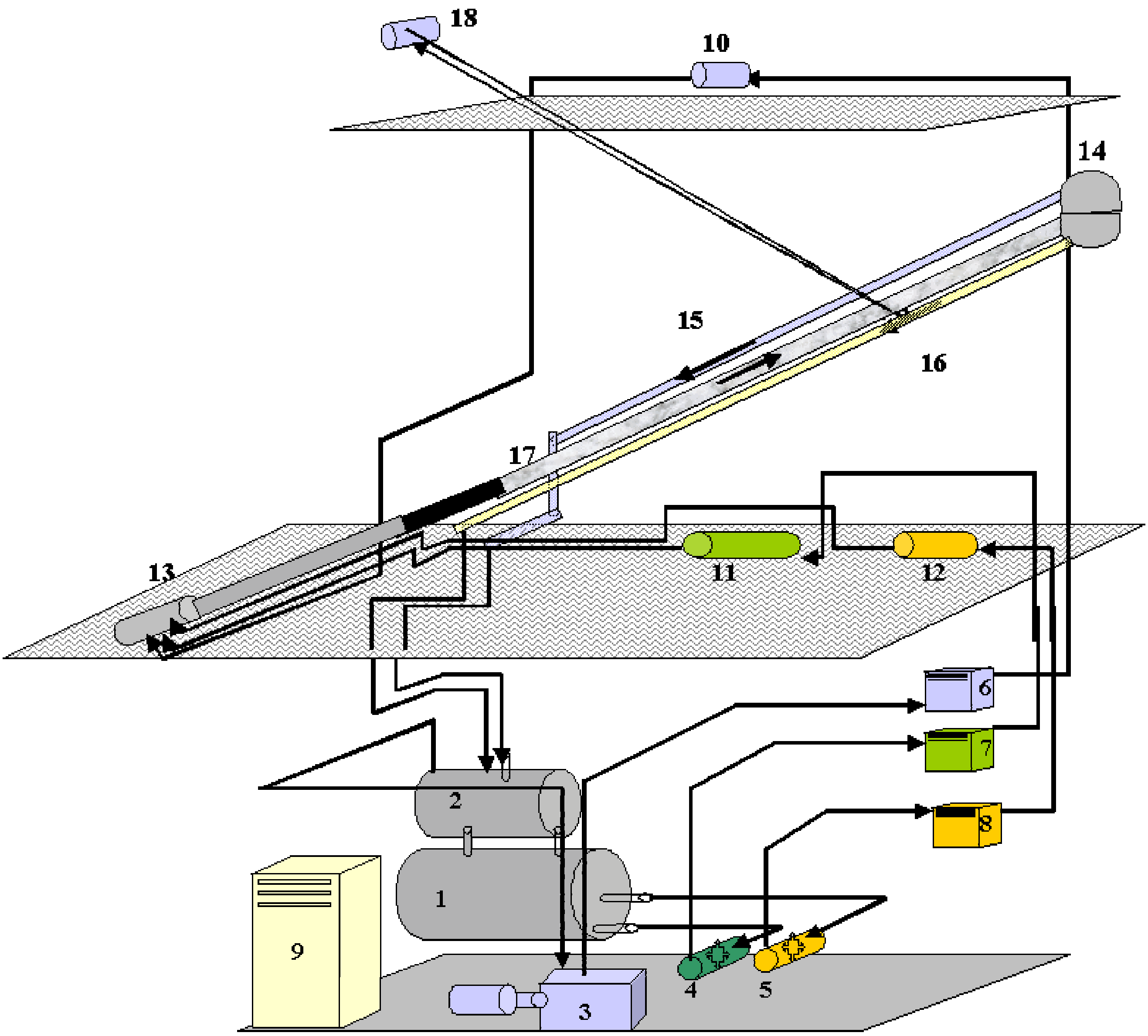
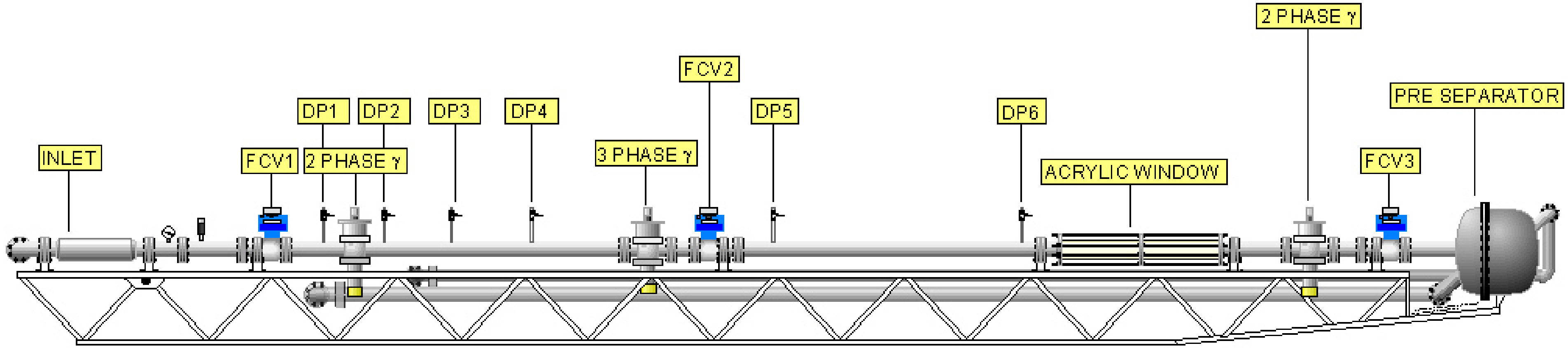


Figure 2-1. Schematic drawing of process components and the piping of the Well Flow Loop

1 : Oil-water separator	*2: Gas-liquid separator*	*3: Gas compressor*
4 : Water pump	*5: Oil pump*	*6: Heat exchanger, gas*
7 : Heat exch.,water	*8: Heat exch., oil*	*9: Main switch board*
10.: Gas turbine meter	*11:Water el.mag. meter*	*12: Oil Coriolis meter*
13: Inlet mixing section	*14: Slug catcher, preseparator*	*15: Return pipe, gas*
16: Return pipe, liquid	*17: Test section*	*18: Winch*



Tag	Distance from inlet [m]	Explanation	Tag	Distance from inlet [m]	Explanation
FCV1	13.11	Fast closing valve, ball valve	3 Phase γ	18.11	Intermediate 3-phase γ-densitometer
DP1	13.57	Pressure tap no.1	FCV2	18.37	Fast closing valve, ball valve
2 Phase γ	13.84	Upstream 2-phase γ-densitometer	DP5	20.08	Pressure tap no.5
DP2	14.57	Pressure tap no.2	DP6	20.95	Pressure tap no.6
DP3	15.57	Pressure tap no.3	2 Phase γ	23.40	Downstream 2-phase γ-densitometer
DP4	16.57	Pressure tap no.4	FCV3	23.77	Fast closing valve, ball valve

Figure 2-2. Schematic illustration of the test section. Relative position of the instruments given in the table is for the 250D loop configuration. The positions are typical and not identical to the positions used in the reported work (see Figure 3-1). The illustration is not to scale.

2.2 Fluid properties

Oil and water viscosity, surface tension (to air) and oil-water interfacial tension have been measured both for samples of oil and water from the loop and for clean ExxsolD80 and tap water. A White Surface and Interfacial Tension Balance Meter, Type 0/74124, and a viscometer of type Viscolab LC100 from Physica Instr. were used for these measurements, all carried out at atmospheric pressure and room temperature.

2.2.1 The gas phase SF_6

The gas phase sulphur hexafluoride (SF_6) has a molecular weight of 146.056; about five times that of air. This gas is used in order to obtain high gas densities at moderate pressures, enabling use of transparent pipes for visual observation of the flow at conditions similar to those found in petroleum pipelines.

Fluid properties for SF_6 are tabulated in *Table 2-2*. The interfacial tensions between SF_6-saturated ExxsolD80 and pure SF_6 at 4 and 8 bara pressure are taken from measurements done at the thermo physical laboratory at IKU (now Sintef Petroleum Research) in 1995[1].

Since minor volumes of air are inevitably mix with the SF_6 gas, as a consequence of loop modification work, the gas density is frequently measured by weighing of the gas in a pressure bottle with exactly known volume (2.125 dm^3). The bottle is connected to the loop via a standard pressure tap and left in-line with the loop until equilibrium condition (p, T) is reached. As can be seen from *Table 2-2* the deviation in density between the gas in the loop and that for pure SF_6 is in the order of 10%. The weighing method has been qualified using uncontaminated SF_6, which gave a density close to the literature data given below.

Physical property	Value and unit
Dielectric constant	1.00204
Heat capacity	119.5 J/(mol K)
Dynamic viscosity (20°C)	0.015 mPas (cP)
Density measured at 7.2 bar pressure and 20°C	42.3 ± 0.5 kg/m^3
Density measured at 4.4 bar pressure and 20°C	22.8 ± 0.5 kg/m^3
Interfacial tension ExxsolD80/SF_6 at 7.2 bar pressure (interpolated)	0.021 N/m
Interfacial tension ExxsolD80/SF_6 at 4.4 bar pressure (interpolated)	0.023 N/m
Other relevant properties	
Density, pure SF_6 at 8.0 bar pressure (literature)	54.5 kg/m^3
Density, pure SF_6 at 4.0 bar pressure (literature)	25.5 kg/m^3
Interfacial tension ExxsolD80/air at atmospheric pressure and 20°C	0.028 ± 0.001 N/m
Interfacial tension water/air at atmospheric pressure and 20°C	0.069 ± 0.001 N/m
Interfacial tension Marcol/air at atmospheric pressure and 20°C	0.031 ± 0.001 N/m

Table 2-2. Fluid properties for the gas SF_6

[1] J. Sandvik, 1995. Analysis of fluid properties, IKU, Trondheim, Norway

2.2.2 The water phase

The water that is on the loop is ordinary tap water without any additives. Negligible amounts of gas are absorbed in the water phase, which means that the water density is not influenced by the high gas density. The most important fluid properties for the water phase are given in *Table 2-3*.

Physical property	Value and unit
Dynamic viscosity (20°C)	1.0 mPas (cP)
Density (20°C)	1000 kg/m^3
Other relevant properties	
Interfacial tension water/air at atmospheric pressure and 20°C	0.069 ± 0.003 N/m
Interfacial tension loop water/ExxsolD80 at atm. pressure and 20°C	0.021 ± 0.001 N/m
Interfacial tension loop water/Marcol at atmospheric pressure and 20°C	0.033 ± 0.001 N/m
Interfacial tension ‘clean’ water/ExxsolD80 at atm. pressure and 20°C	0.035 ± 0.001 N/m

Table 2-3. Fluid properties for the loop water

2.2.3 The oil ExxsolD80

The oil ExxsolD80 is a transparent, light, solvent oil. SF_6-saturated ExxsolD80 has a density that is higher than ExxsolD80 at atmospheric conditions. The Coriolis meters, which are primarily used to measure the flow rates, have also been used to measure the in-situ oil density. The most important fluid properties for the oil ExxsolD80 are given in *Table 2-4*.

Physical property	Value and unit
Dynamic viscosity at atmospheric pressure and 20°C	1.7 mPas (cP)
Density, SF_6-saturated and measured at 7.2 bar pressure and 20°C	823 ± 0.5 kg/m^3
Density, SF_6-saturated and measured at 4.4 bar pressure and 20°C	815 ± 0.5 kg/m^3
Interfacial tension ExxsolD80/SF_6 at 7.2 bar pressure (interpolated)	0.021 N/m
Interfacial tension ExxsolD80/SF_6 at 4.4 bar pressure (interpolated)	0.023 N/m
Other relevant properties	
Interfacial tension ExxsolD80/air at atmospheric pressure and 20°C	0.028 ± 0.001 N/m
Interfacial tension loop water/ExxsolD80 at atm. pressure and 20°C	0.021 ± 0.001 N/m
Interfacial tension ‘clean’ water/ExxsolD80 at atm. pressure and 20°C	0.035 ± 0.001 N/m

Table 2-4. Fluid properties for the oil ExxsolD80

2.2.4 The oil Marcol

The Marcol oil is a mixture of the two oils Marcol 82 and Marcol 52. Marcol is a medical white oil without colour and odour. A mixture ratio of 3:2 between the 82 and 52 oils should give a mixture viscosity close to 20 cP, but the actual viscosity proved to be significantly lower. The most likely explanation for this is that minor volumes of ExxsolD80 had 'hidden' in the loop, and that this has influenced the mixture viscosity. As for the ExxsolD80, also Marcol changes its density significantly when it is SF_6-saturated. The most important fluid properties for the Marcol are listed in *Table 2-5*.

Physical property	Value and unit
Dynamic viscosity at atmospheric pressure and 20°C	12 mPas (cP)
Density, SF_6-saturated and measured at 7.2 bar pressure and 20°C	848 $\pm$ 0.5 kg/m^3
Density, SF_6-saturated and measured at 4.4 bar pressure and 20°C	843 $\pm$ 0.5 kg/m^3
Other relevant properties	
Interfacial tension Marcol/air at atm. pressure and 20°C	0.031 $\pm$ 0.001 N/m
Interfacial tension loop water/Marcol at atm. pressure and 20°C	0.033 $\pm$ 0.001 N/m

Table 2-5. Fluid properties for the Marcol oil

3 Two-phase oil-water flow

3.1 Background

A vast amount of two-phase oil-water flow experiments are known from the literature, see for example the review given in Valle (1998). These works represent a large span in oil densities, viscosities, interfacial tensions, pipe diameters, pipe inclinations, pipe wall material and flow rates. The resulting data typically yields one or more of the following dependent variables: pressure drop, holdup, local phase fraction, flow pattern and drop size distribution. However, compared to gas-liquid flow, it is far more difficult to draw general conclusions about oil-water flow. This is because of the more complex interfacial chemistry, the much wider span in possible viscosity ratios, and density ratios relatively close to unity (thus reducing gravity separation and promoting dispersions to be formed) that is found in oil-water systems.

A consequence of this is that we, as part of the THREEPLEX WP4 work, decided to conduct a series of oil-water flow experiments, using the same fluids and the same pipe diameter and pipe material as was used during the slug flow experiments reported in WP4. To characterise typical features of oil-water flow is a logic approach to better understand the three-phase oil-water-gas slug flow results from the main work of THREEPLEX.

3.2 Experimental set-up, test procedure and test matrix

These experiments were all carried out in IFE's Well Flow Loop, configured with a 25 m (250D) long, straight pipe test section (mainly PVC) with internal diameter 0.1 m. Oil and water were mixed at the test section inlet and the flow was allowed to develop for 150D before phase holdup and pressure drop were measured, and flow pattern observations were made. Phase holdup was measured with three gamma densitometers, while the pressure drop was measured with three differential pressure transducers. The gamma densitometers were distributed along the downstream 150D of the test section as schematically illustrated in *Figure 3-1*.

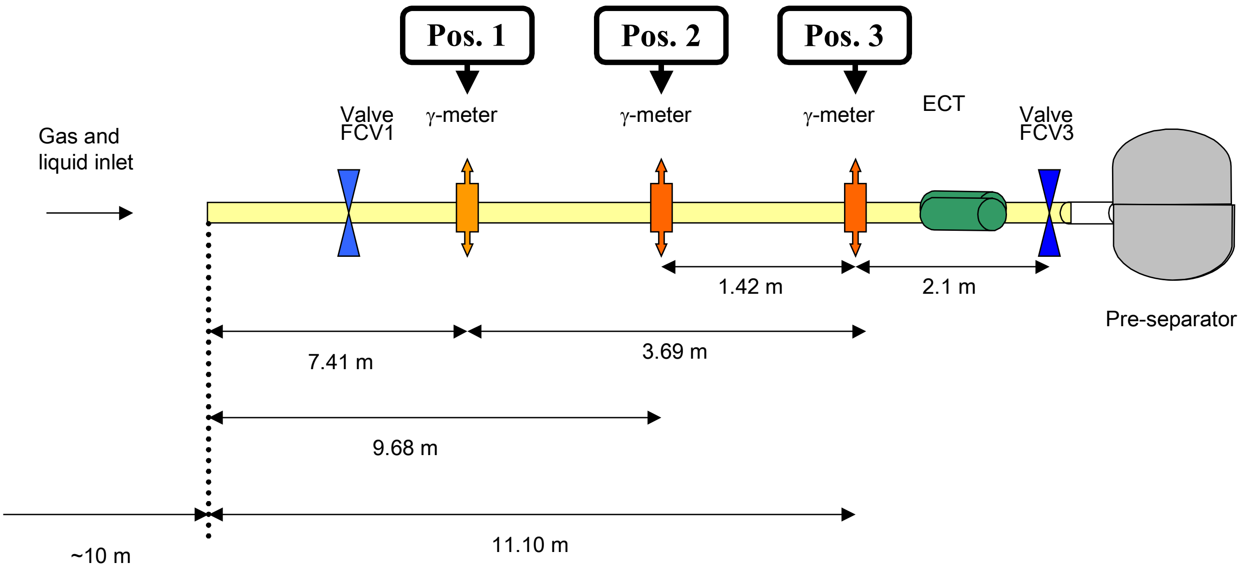


Figure 3-1. Schematic layout of the experimental set-up for the oil-water flow experiments

The experiments are divided in separate series, each series representing one of the two fluid combinations (12cP Marcol oil)/(water) and (2 cP ExxsolD80)/(water), and a given mixture velocity. The measurements started, typically, with single-phase water flow, and then gradually decreasing the water cut until eventually reaching single phase water flow. This sequence of test conditions (WC-values), in the following called a WC-traverse, was completed without turning off the pumps. To check for hysteresis effects, some of the tests were repeated with gradually increasing the water cut.

The following test conditions have been covered:

1. *Pipe inclinations*: Horizontal flow only
2. *Superficial mixture velocities*: U_{sl}= 1.0, 1.5 and 2m/s
3. *Liquid-liquid combinations*: 2 cP ExxsolD80/water and 12 cP Marcol/water
4. *Water cut step*: 30-35 different WC-values, both increasing and decreasing the WC
5. *Pressure*: 7.1 bara

A total of 8 WC-traverses have been done. An overview of these is given in *Table 3-1*.

#	Fluid system	Usl	WC	Exp. ID
1	ExxsolD80/water	1.0 m/s	Decreasing	IFE0401- IFE0428
2	ExxsolD80/water	1.5 m/s	Decreasing	IFE0447- IFE0475
3	ExxsolD80/water	2.0 m/s	Decreasing	IFE0501- IFE0527
4	Marcol/water	1.0 m/s	Decreasing	IFE0601- IFE0621
5	Marcol/water	1.0 m/s	Increasing	IFE0722- IFE0742
6	Marcol/water	1.5 m/s	Decreasing	IFE0685- IFE0721
7	Marcol/water	2.0 m/s	Increasing	IFE0821- IFE0849
8	Marcol/water	2.0 m/s	Decreasing	IFE0801- IFE0820

Table 3-1. Overview of the oil-water experiments

3.3 Results

3.3.1 General

The results from these oil-water flow experiments consist of pressure drop measurements, holdup measurements and visual flow regime observations. There are no time series data files available for these experiments, only average values are reported. All the averaged data are gathered in *Table A-2* in Appendix A. The reported pressure gradient and holdup values are the average values for the three respective instruments. There was no systematic difference observed between the instruments.

3.3.2 Oil-water flow patterns

We have classified the flow in the following flow regimes:

S: Stratified flow, virtually no mixing or drops observed
S_M: Stratified flow with mixing (drops) at the interface
S_Dw/o&w: Stratified flow with water drops dispersed in an oil continuous layer above a water layer
3L: An oil water mixture layer exists between an oil continuous layer at the top of the pipe and a water continuous layer at the bottom
M_Dw/o: Mixed flow, water drops dispersed in an oil continuous bulk phase
M_Do/w: Mixed flow, oil drops dispersed in a water continuous bulk phase

It should be added that it is not a straightforward matter to determine the flow regimes. However, using spotlights appropriately proved to be beneficial and was in fact crucial for the identification of the 3L-regime. The electrical capacitance tomography (ECT) system was also used during these experiments, and although the ECT did not give quantitative results, it clearly indicated when we had a water continuous dispersion.

3.3.3 Single-phase pressure drop

Experience from previous experiments in liquid-liquid flow systems has shown that pressure gradient measurements can be troublesome. The subset of the present measurements that represents single-phase oil or water flow has therefore been compared with single-phase pipe flow theory, using a pipe roughness of $7 * 10^{-5}$ m. The results are summarised in *Table* 3-2. As can be seen there is in general good agreement between measured and predicted pressure gradients, although a 10% deviation can be seen for water at the highest flow rates.

We conclude that the pressure gradient measurements are consistent with single-phase flow theory, that the repeatability of the measurements are good, and therefore also give confidence to the oil-water pressure drop measurements.

	Usl=1.0 m/s			Usl=1.5 m/s			Usl=2.0 m/s		
	dp/dx_{theory}	dp/dx_{meas}	Re	dp/dx_{theory}	dp/dx_{meas}	Re	dp/dx_{theory}	dp/dx_{meas}	Re
ExxsolD80	95	98	40750	201	184	61125	345	339	81500
Marcol	147	148	4225	299	304	6338	495	522	8450
Water	104	101	100000	226	203	150000	392	351	200000

Table 3-2. Comparison between measured and predicted pressure gradients in single-phase, liquid pipe flow at 8 bara pressure

3.3.4 Oil-water flow – pressure gradients and flow regimes

In the discussion of the results we start with the pressure gradient measurements, the typical features observed and how these are linked to the flow regime observations. The measurements are presented in *Figure 3-2*, where each plot gives the dp/dx-values for the two fluid systems for a given mixture velocity. The results are discussed below.

We start with the lowest mixture velocity of 1.0 m/s. In this case we have separated oil-water flow with mixing/drops near the interface in each end of the WC-traverse. These two regions of S_M flow are separated by a region with the so-called 3L flow regime, i.e. a situation where the phenomenon of drops near the oil-water interface has grown in thickness and constitutes a separate layer between an oil layer at the top and a water layer at the bottom of the pipe. *Figure 3-3* illustrates what this 3L regime looks like in the laboratory.

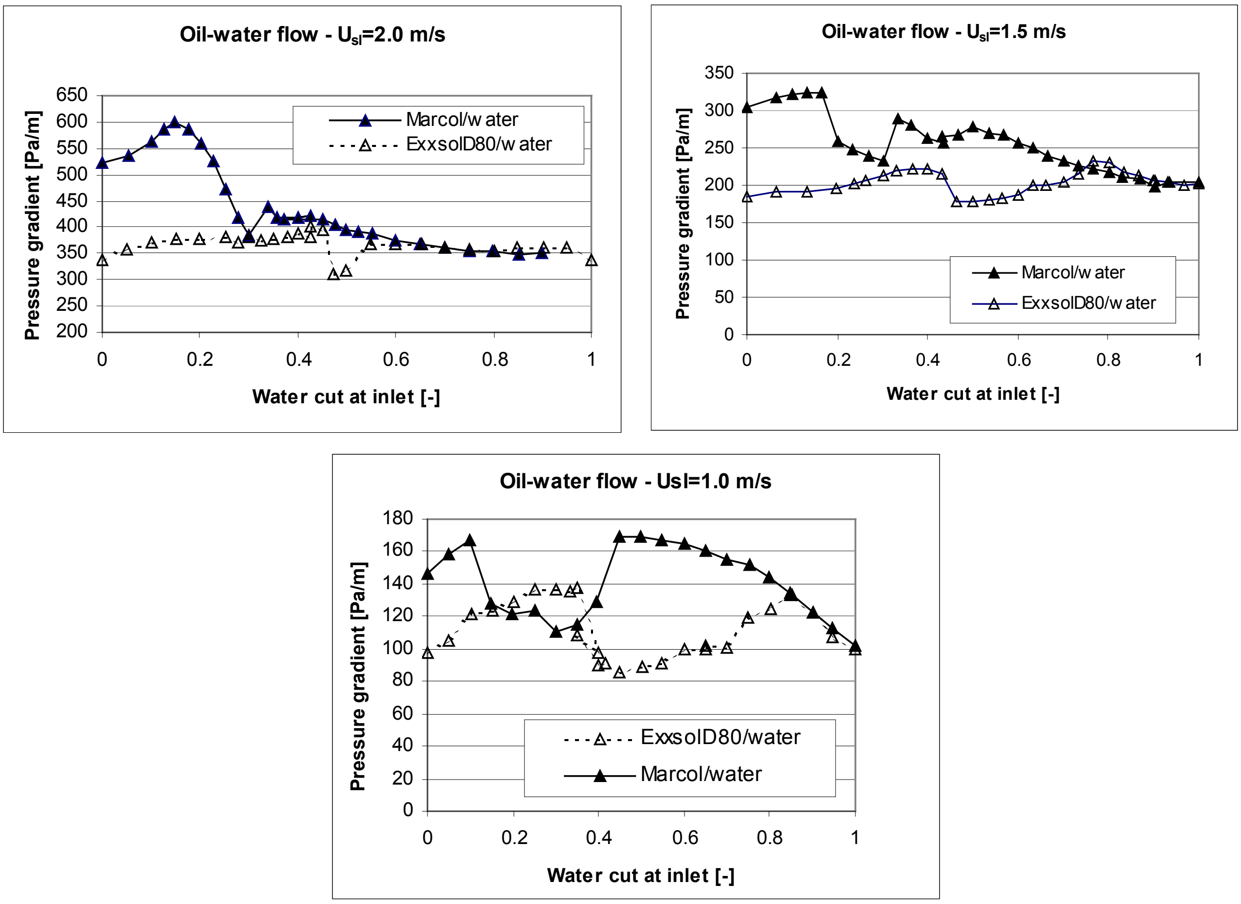


Figure 3-2. Pressure gradient versus WC for horizontal oil-water flow; U_{sl}=2.0 m/s (upper left), U_{sl}=1.5 m/s (upper right), U_{sl}=1.0 m/s (bottom)

Figure 3-3. The 3L flow regime as observed for Marcol/water with U_{sl}=1.0 m/s and 40% WC; the intermediate mixture layer appears in dark grey colour on the picture

In the pressure gradient plots the appearance of this 3L-region is recognised as a region with reduced pressure gradients. For the ExxsolD80/water system we observe, in fact, minimum overall pressure gradient inside this region, not only for U_{sl} =1.0 m/s, but for U_{sl} =1.5 and 2.0

m/s as well. The 3L-region exists for WCs between 0.4-0.8 for ExxsolD80/water and for WCs 0.1-0.5 for Marcol/water, still for U_{sl} =1.0 m/s.

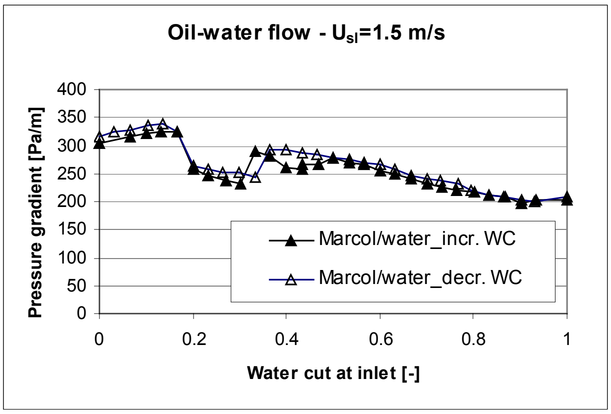
Increasing the flow to U_{sl}=1.5 m/s, we find very much the same trends, but the 3L region is now surrounded by mixed flow, except for the low WC-side for the ExxsolD80/water system, where the regime is characterised as S_Dw/o&w. Again we can confirm that the 3L-region is associated with reduced pressure gradients and we observe that the region appears in two entirely different WC-windows for the two fluid systems. The region has shrunk compared to U_{sl} =1.0 m/s. In the high WC-end of the traverse, where we have a water continuous dispersion, the pressure gradients for the two fluid systems are more or less the same, as could be expected. This observation also applies for U_{sl} =2.0 m/s.

For the highest velocity, 2.0 m/s, we have a situation where the 3L region could not be observed in the pipe, but a small dip can be seen in the dp/dx data over a very narrow WC-region. Even for this relatively high flow rate we do not have a situation where the fluids invert from oil to water continuous for a very small change in the WC. Particularly for the Marcol/water system, the process of inversion seems to be a gradual process, starting at WC~0.17 and finishing near WC=0.3.

The differences found between the two oil-water systems are most likely ascribed to the reduced turbulence, and therefore ability to keep the water phase dispersed, for the 12 cP viscosity oil system.

3.3.5 Hysteresis effects

It has been reported by others that oil-water flow experiments carried out by a gradual change in the water cut can be significantly influenced by whether the WC is increased or decreased. Several of our measurement series were therefore made with both increasing and decreasing the WC for examination of possible hysteresis effects. The results indicate that hysteresis effects have no significant impact on the results for flow rates where we have dispersions, but can be important when the oil-water flow is stratified. This is illustrated in *Figure 3-4*.



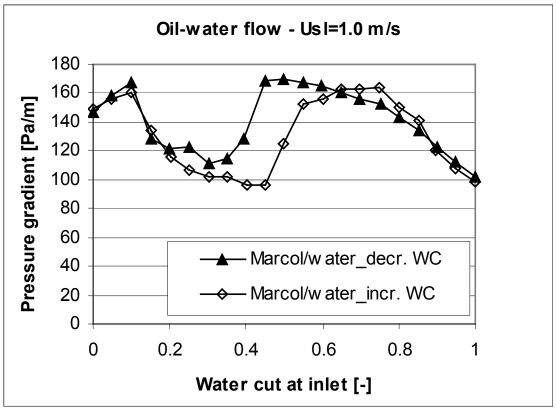


Figure 3-4. Hysteresis effects due to increasing versus decreasing the WC in oil-water flow

3.3.6 Oil-water flow – slip

The gamma densitometers give the oil and water holdup values, from which we have estimated the in-situ average water and oil velocities. In the discussion that follows we have used the ratio between the in-situ velocities as a measure for the slip, $S=U_{oil}/U_{water}$. The slip data are presented in *Figure 3-5*, in a similar way as the pressure gradient data in the previous section. There is, admittedly, some scatter in these data, probably due to short averaging time for the gamma densitometer signals.

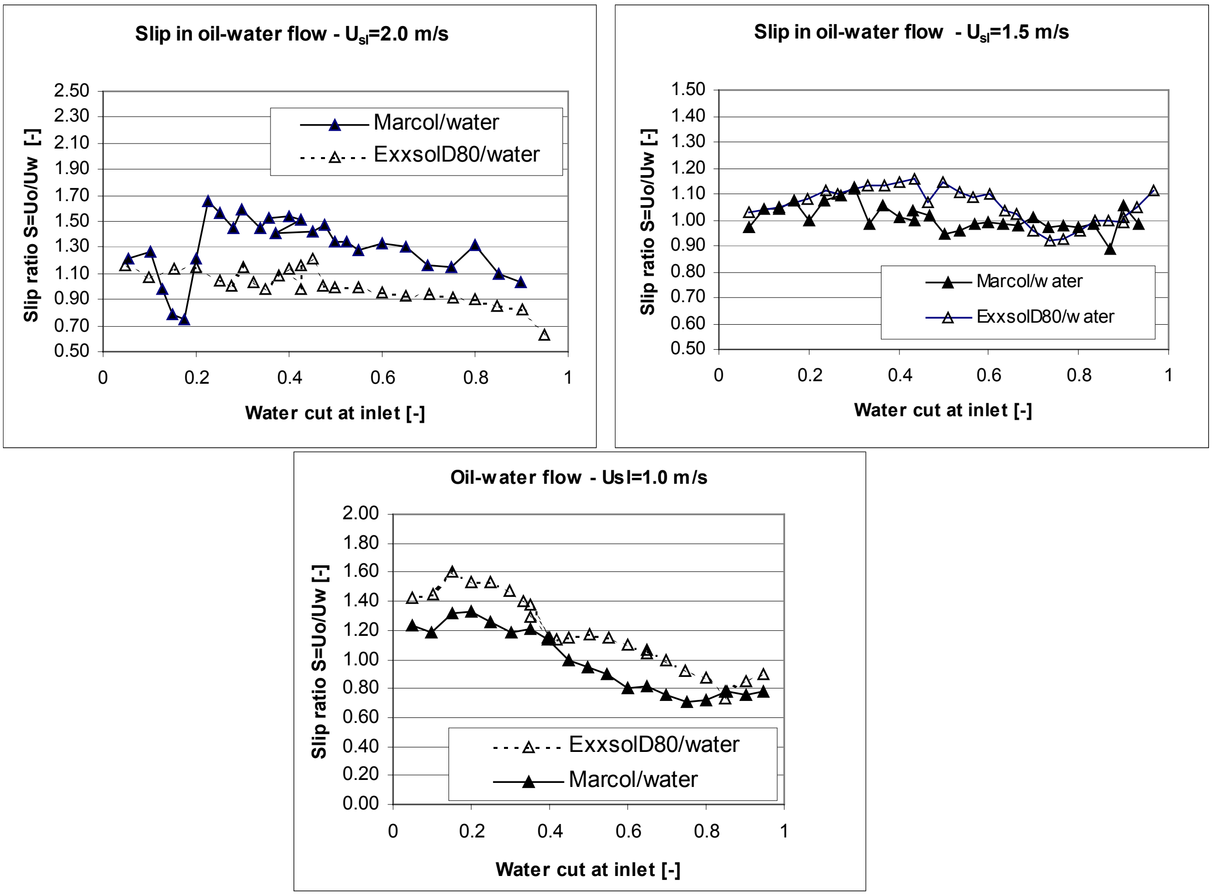


Figure 3-5. Oil-water slip data for horizontal oil-water flow; U_{sl}=2.0 m/s (upper left), U_{sl}=1.5 m/s (upper right), U_{sl}=1.0 m/s (bottom)

For Usl=1.0 m/s, the oil and water is transported in separate layers and we see a continuous decrease in the slip with increasing WC. For the ExxsolD80 the slip varies between typically 1.5 at low WC to 0.8 for high WC, a trend which is as expected from a simple distribution slip analysis. The slip is systematically lower for the more viscous Marcol experiments, which is also reasonable if one accepts that increase of the oil viscosity gives reduced average velocity, and thus need a larger cross-sectional area to give the same volumetric through-put.

Once we get an oil-water dispersion or a 3L structure, as we do for Usl=1.5 and 2.0 m/s, the interpretation of the slip results becomes more difficult. In general, however, we have close to no-slip conditions for these cases. The most striking deviation from no-slip is seen for Marcol/water at Usl=2.0 m/s, where we observe that when the oil is the dispersed phase, then the dispersed phase travels significantly faster than the continuous phase. This can be explained by distribution slip if the oil drops tend to be centred near the pipe axis for high flow rates, analogous to Taylor bubbles in slug flow. Such a phenomenon has been reported by others, Valle & Utvik (1997) and Angeli (1996), and appears to be the case for the Marcol/water U_{sl}=2.0 m/s tests reported here, as well.

3.4 Concluding remarks

The most important result from the oil-water flow experiments is the strong connection found between the appearance of a 3L-structure in the flow and some kind of a drag reduction effect. For the ExxsolD80/water system we found an overall minimum dp/dx (given the U_{sl}) for a WC that is in this region. Although the 3L structure has been described by others, the impact on the pressure gradient has not been as obvious as demonstrated with the present data. This illustrates what was said initially about the complexity in oil-water flow systems and the difficulty in drawing general conclusions. In the three-phase gas-oil-water slug flow experiments we also found trends that were unexpected, for example that we for high liquid flow rates in near horizontal pipes observed minimum pressure gradient for 50% WC, Langsholt et al. (2002) and Andersson et al. (2003). This, and other results are easier to understand in light of the knowledge gained in the present work, and demonstrate the usefulness of this type of fluid characterisation experiments.

4 Two-phase stratified gas-liquid flow

4.1 Background

In co-flowing streams of two fluids a condition can be reached where the two fluids start to mix due to mechanical action such as turbulent mixing, droplet generation and interfacial waves. An example of such mixing was seen in the previous chapter for oil-water flow, where we could observe a thin o/w-mixing layer, a relatively thick 3L-region and fully dispersed o/w-flow, all depending on the flow rates and the fluid properties. The latter includes parameters such as the interfacial tension, density ratios and viscosities.

In stratified two-phase gas-liquid pipe flow we can have liquid drops being entrained in the gas and gas bubbles being entrained in the liquid layer. Both these phenomena can have a large impact on the pressure drop and liquid holdup in the pipe and are therefore important to understand and to include in the multiphase flow models. This chapter deals with the phenomenon of gas entrainment in the liquid layer, also denoted as void in film, VIF. The entrained gas affects the liquid layer density and thus also the turbulence, the wall shear stress, the interfacial structure, etc. Another important effect is that the entrained gas lifts the interface between the liquid continuous layer and the gas layer, leaving a smaller cross-sectional area available for the gas transport, with increased pressure drop as a possible consequence.

The phenomenon of gas entrainment in the liquid layer in stratified pipe flow has not been much focused in the literature. At IFE, we have previously studied and quantified liquid layer void fraction using a combination of gamma densitometry and digital image processing of video records of the flow, Lunde (1996) and Nuland (1998). This method is quite cumbersome, and it also has some inherent weaknesses. With the tomography system that is now installed in the Well Flow Loop, measurement of liquid layer void fraction is feasible in a much simpler way. The present work is the first application of the Electrical Capacitance Tomography system (ECT), see *Figure 4-1*, for this type of measurements.

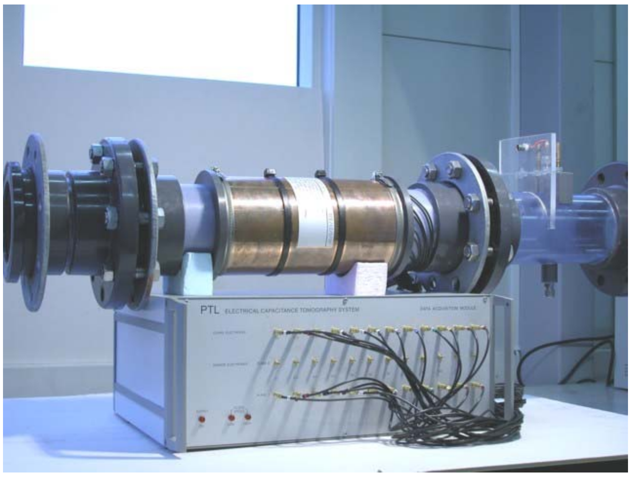


Figure 4-1. The ECT sensor with the signal analysis unit

4.2 Experimental set-up, test procedure and test matrix

The experimental set-up for the gas entrainment experiments was the same as for the oil-water experiments described in section 3.2. The ECT-system is an instrument that is calibrated online for the high (liquid) and low (gas) permeability fluids. Since the calibration of the instrument tends to drift, it was calibrated frequently, which in practise means at least every hour. Phase holdup was measured with three gamma densitometers and with the ECT, while the pressure drop was measured with three differential pressure transducers. The gamma densitometers and the ECT were distributed along the downstream 150D of the test section as schematically illustrated in *Figure* 3-1.

The experiments were all carried out in a horizontal pipe. ExxsolD80, Marcol and water were used as the liquid phase, while SF_6 was the gas phase. The test procedure was as follows:

a) The test section was set in horizontal position

b) Gamma densitometers, dp-transducers and ECT were calibrated

c) The pumps were started; the liquid flow rate was adjusted to the pre-selected value and the gas flow rate was set to the lowest value included in the test. The lowest U_{sg} was normally set high enough to avoid large waves and slug flow.

d) When steady state condition was reached, the instruments were logged for typically 30 sec.

e) The gas velocity was then increased in steps of typically 0.5 m/s, keeping U_{sl} unchanged, until the maximum U_{sg} was reached. This set of experiments, i.e. having a fixed U_{sl} and gradually increasing U_{sg}, is called an U_{sg}-traverse.

f) An U_{sg}-traverse was carried out for each of the fluid combinations, pressures and liquid flow rates that were included in the test matrix

The following test conditions have been covered.

1. <u>*Pipe inclinations*</u>: Horizontal flow only
2. <u>*Superficial liquid velocities*</u>: U_{sl}= 0.15, 0.5, 1.0, 1.5 and 2 m/s
3. <u>*Superficial gas velocities*</u>: U_{sg}=1.0 – 7.0 m/s
4. <u>*Gas-liquid combinations*</u>: ExxsolD80/SF_6, Marcol/SF_6 and Water/SF_6
5. <u>*Pressure*</u>: 4.4 and 7.1 bara

An overview of the gas entrainment experiments is given in *Table 4-1*.

Fluids	Pressure	Usl [m/s]	Usg [m/s]	Exp. ID
ExxsolD80/SF_6	7.1 bara	0.15	1.0-7.0	IFE0146 – IFE0157
ExxsolD80/SF_6	7.1 bara	0.5	2-7.0	IFE0101 – IFE0110
ExxsolD80/SF_6	7.1 bara	1.0	1.5-7.0	IFE0111 – IFE0121
ExxsolD80/SF_6	7.1 bara	1.5	1.0-7.0	IFE0122 – IFE0131
ExxsolD80/SF_6	7.1 bara	2.0	1.0-7.0	IFE0134 – IFE0145
Marcol/SF_6	4.4 bara	0.5	2.0-7.0	IFE0201 – IFE0210
Marcol/SF_6	4.4 bara	1.0	1.5-7.0	IFE0211 – IFE0221
Marcol/SF_6	4.4 bara	1.5	1.0-7.0	IFE0222 – IFE0233
Marcol/SF_6	4.4 bara	2.0	1.0-7.0	IFE0234 – IFE0245
Water/SF_6	4.4 bara	0.5	2.0-7.0	IFE0246 – IFE0255
Water/SF_6	4.4 bara	1.0	3.0-7.0	IFE0256 – IFE0263
Water/SF_6	4.4 bara	1.5	2.0-7.0	IFE0264 – IFE0269
Water/SF_6	4.4 bara	2.0	1.0-7.0	IFE0146 – IFE0157
Marcol/SF_6	7.1 bara	0.5	2-0-7.0	IFE0301 – IFE0310
Marcol/SF_6	7.1 bara	1.0	2-0-7.0	IFE0315 – IFE0324
Marcol/SF_6	7.1 bara	1.5	2-0-7.0	IFE0325 – IFE0334
Marcol/SF_6	7.1 bara	2.0	2-0-5.0	IFE0335 – IFE0341

Table 4-1. Overview of the stratified gas-liquid experiments

4.3 Analysis of the ECT data

The ECT-instrument has a 12-electrode sensor, which results in 66 unique permittivity measurements. Based on these 66 measurements, and the calibration data, the instrument software constructs[1] a 32x32 matrix containing the cross-sectional holdup values. Only 812 of the 1024 points are actually part of the cross-section. An example of such a 32x32 matrix of holdup fractions is shown in *Figure 4-2*. The instrument was logged with a frequency of 50 Hz. However, the analysis of the ECT-data has been based on time averaged cross-sectional holdup distributions. The data files that are included in the THREEPLEX databank, the IFE0n.img-files, also contain these time averaged holdup fractions.

The ECT-system has severe limitations when we have a water continuous layer in the pipe. Although the average holdup was fairly good measured with the ECT in the water/SF_6 experiments, it was not capable to detect gas bubbles in a water continuous dispersion. Therefore, no img-files are included for these experiments. For the Marcol/SF_6 experiments at 4.4 bara, we discovered drift in the calibration and consequently added uncertainty in the results. Although some of these img-files are reported, we have not included any void fraction results from experiments IFE0201-IFE0245 in this report.

0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.05	0.05	0.02	0.07
0.04	0.02	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.04	0.09	0.10	0.17	0.18	0.14	0.16	0.17	0.20	0.20
0.07	0.06	0.07	0.03	0.01	0.04	0.01	0.05	0.01	0.05	0.01	0.06	0.04	0.07	0.04	0.08	0.14	0.09	0.11	0.18	0.18	0.22	0.20	0.26	0.25	0.29	0.31	0.35	0.38	0.27	0.31	0.29
0.11	0.14	0.12	0.13	0.12	0.13	0.14	0.16	0.17	0.13	0.18	0.23	0.20	0.23	0.27	0.29	0.32	0.29	0.32	0.37	0.37	0.37	0.41	0.38	0.44	0.48	0.47	0.46	0.46	0.49	0.53	0.51
0.19	0.21	0.18	0.22	0.26	0.22	0.29	0.26	0.31	0.34	0.40	0.42	0.44	0.43	0.47	0.46	0.52	0.53	0.52	0.54	0.56	0.52	0.59	0.58	0.64	0.60	0.61	0.62	0.66	0.68	0.64	0.59
0.32	0.27	0.32	0.30	0.36	0.35	0.48	0.45	0.54	0.52	0.55	0.55	0.60	0.60	0.69	0.70	0.71	0.74	0.71	0.74	0.74	0.77	0.71	0.72	0.70	0.71	0.76	0.74	0.75	0.72	0.74	0.68
0.62	0.35	0.40	0.46	0.54	0.53	0.60	0.59	0.67	0.67	0.73	0.78	0.84	0.82	0.83	0.84	0.86	0.88	0.88	0.95	0.85	0.90	0.88	0.94	0.85	0.86	0.80	0.81	0.80	0.82	0.81	0.74
0.00	0.48	0.50	0.55	0.62	0.63	0.72	0.78	0.80	0.85	0.88	0.91	0.95	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.88	0.88	0.90	0.92	0.93	0.86	0.89	0.83	0.00
0.00	0.59	0.61	0.69	0.72	0.79	0.82	0.88	0.90	0.96	0.99	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.98	0.98	0.97	0.88	0.89	0.85	0.86	0.88	0.85	0.00
0.00	0.00	0.70	0.76	0.78	0.85	0.89	0.95	0.98	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.97	0.99	0.93	0.95	0.88	0.88	0.85	0.00	0.00
0.00	0.00	0.76	0.81	0.88	0.91	0.95	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.96	1.00	0.87	0.87	0.83	0.84	0.83	0.00	0.00
0.00	0.00	0.00	0.84	0.91	0.94	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.84	0.83	0.81	0.81	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.93	0.94	0.96	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.83	0.79	0.80	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.94	0.94	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.84	0.80	0.79	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.92	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.82	0.81	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.84	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.79	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.83	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 4-2. Example of the 32x32 matrix containing the cross-sectional holdup fractions. Value 1.0=Liquid; 0.0=gas

The time averaging of the 50 Hz snap shots represents a simplification and means that the interfacial waves and the hollow regions between the waves are interpreted as being part of the gasified liquid layer. For the highest gas flow rates (U_{sg} >~6 m/s) drops were entrained in the gas, resulting in a drop rich gas layer on top of the liquid continuous layer. This layer has in the present analysis been included in the liquid layer, and results in an overestimation in VIF at high gas velocities.

A simple Matlab program has been used to convert the local holdup data into a cross-sectional average liquid layer void fraction. The average holdup and the liquid layer void fraction have been calculated as follows:

[1] The ECT software was run using the Maxwell permittivity model with 800 iterations, a GAIN factor of 0.9 and the STANDARD algorithm

- *Average holdup*: (The sum of all 812 holdup fractions)/812
- *Holdup in the liquid continuous layer*: (The sum of all 812 holdup fractions)/(No of cells with holdup>0)
- *Liquid layer void fraction*: 1 – Holdup in liquid layer
- To compensate for the simplified handling of interfacial waves and drops the calculated liquid layer void fraction has been systematically given an offset of -0.1.
- By using a similar technique for each row we have also estimated the cross-sectional void distribution as a function of the distance from the bottom of the pipe.

4.4 Results

4.4.1 General

The results from these gas-liquid flow experiments consist of average pressure drop measurement, average holdup measurements, visual flow regime observations and the cross-sectional holdup distribution. All the averaged data are gathered in *Table B-2* in Appendix B. The reported pressure gradient and holdup values are the average values from the three respective instruments. There were no systematic differences observed between the instruments.

The cross-sectional holdup distributions are given as img-files (ASCII-format) in the THREEPLEX databank. Each file represents one experiment and consists of the 32x32 holdup fractions. There are no time series data files available for these experiments, only average values are reported.

4.4.2 Gas-liquid flow patterns

We have used the following flow regimes to classify the gas-liquid flow:

SW:	Stratified flow with small interfacial waves
SLW:	Stratified flow with large waves at the interface
SW_Dg/o:	Stratified flow with gas bubbles dispersed in the liquid layer
SW_Dg/o&Do/g:	Stratified flow with gas bubbles dispersed in the liquid layer and liquid drops entrained in the gas

The flow regime denoted SW_Dg/o&Do/g, i.e. with drop transport in the gas, implies that the pipe wall in the upper gas continuous part of the cross-section was wetted by a liquid film. Typically, this regime occurred when U_{mix}>~6 m/s.

4.4.3 Pressure drop and holdup

The pressure gradients and average holdup values will not be discussed in any detail in this report. All the data are made available in *Table B-2* in Appendix B, and further exploration of the results has to be carried out in subsequent work. Due to the additional information of gas entrainment in the liquid layer, these data should be particularly beneficial to use in modelling and testing of multiphase flow models for dispersed stratified flow. All the data are plotted in *Figure 4-5*, one plot for each of the four fluid and pressure combinations.

More interesting is it to make comparison plots as the one shown in *Figure 4-3,* which represents U_{sl}=1.0 m/s. This plot shows, for example, that we have systematically higher pressure drop for 4.4 bara water (1 cP) than we have for ExxsolD80 (2 cP) at 7.2 bara pressure, and that the 4.4 and 7.2 bara Marcol data yields the same dp/dx and holdup values for U_{sg}<~4 m/s. This illustrates that predictive models for stratified, dispersed gas-liquid flow is a need to account for fluid properties as well as flow phenomena like the interfacial structure, the void fraction in the liquid and the effective wall roughness in the upper part of the pipe.

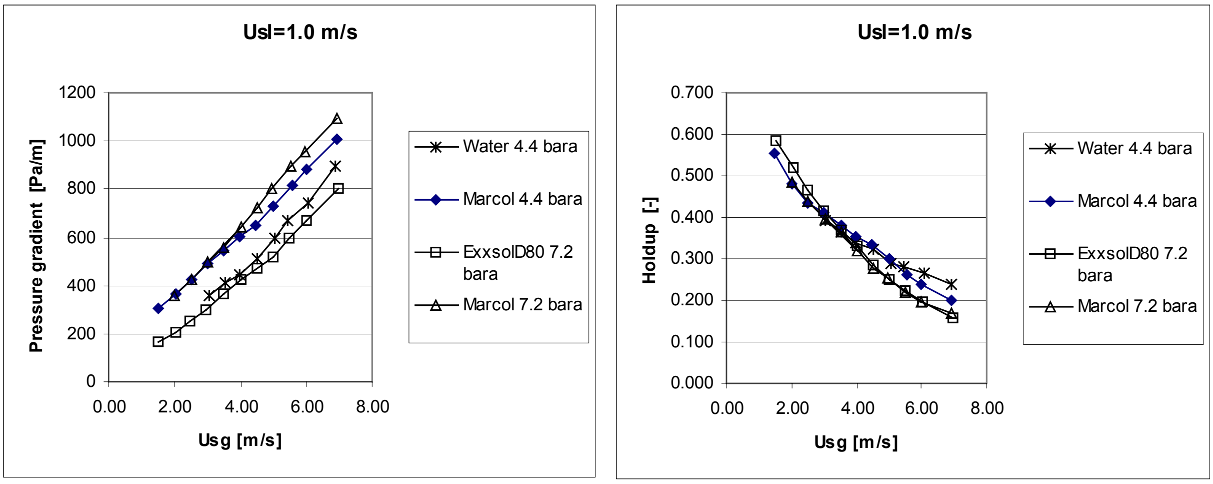


Figure 4-3. Pressure gradients (left) and holdup values (right) for Usl=1.0 m/s, all fluid combinations

4.4.4 Void fraction in the liquid layer

Void fractions for the oil-continuous layer have been estimated as outlined in the previous section. The cross-sectional average void in film values (VIF) for the 7.2 bara ExxsolD80 and Marcol experiments are included in *Table B-2*. A few experiments from this work are identical (same fluids, flow rates, pipe inclination, pressure) to previous VIF-measurements carried out at IFE, see section 4.1. There is good correspondence between the void fractions found using the two different methods.

Figure 4-4 shows examples of ECT-images for two of the ExxsolD80/SF_6 experiments, one without (left) and one with (right) gas entrainment in the liquid layer.

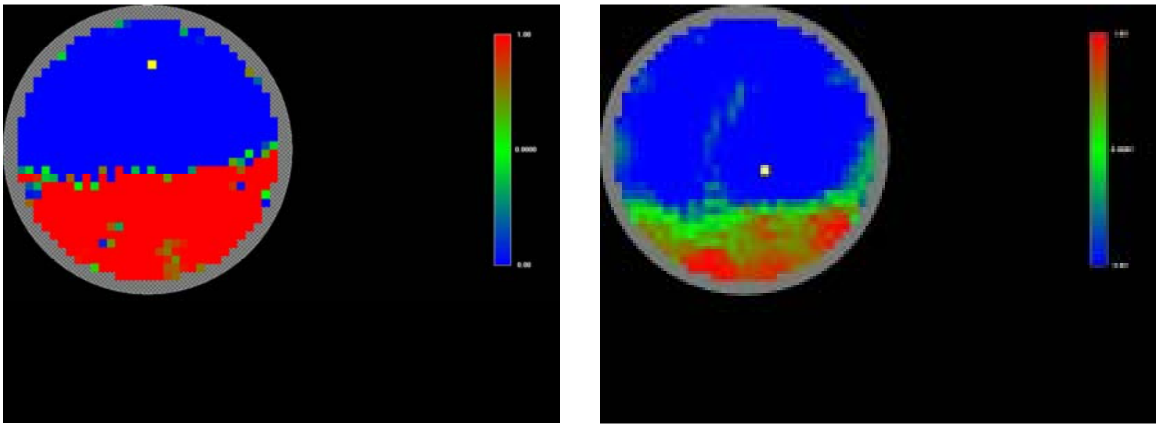


Figure 4-4. ECT-images for two of the ExxsolD80/SF_6 experiments for U_{sl}=0.5 m/s; Left: U_{sg}=2 m/s (exp. # IFE0101); Right: U_{sg}=6 m/s (exp. # IFE0109). Colour code: Blue: Holdup=0.0 (gas), Red: Holdup=1.0 (liquid)

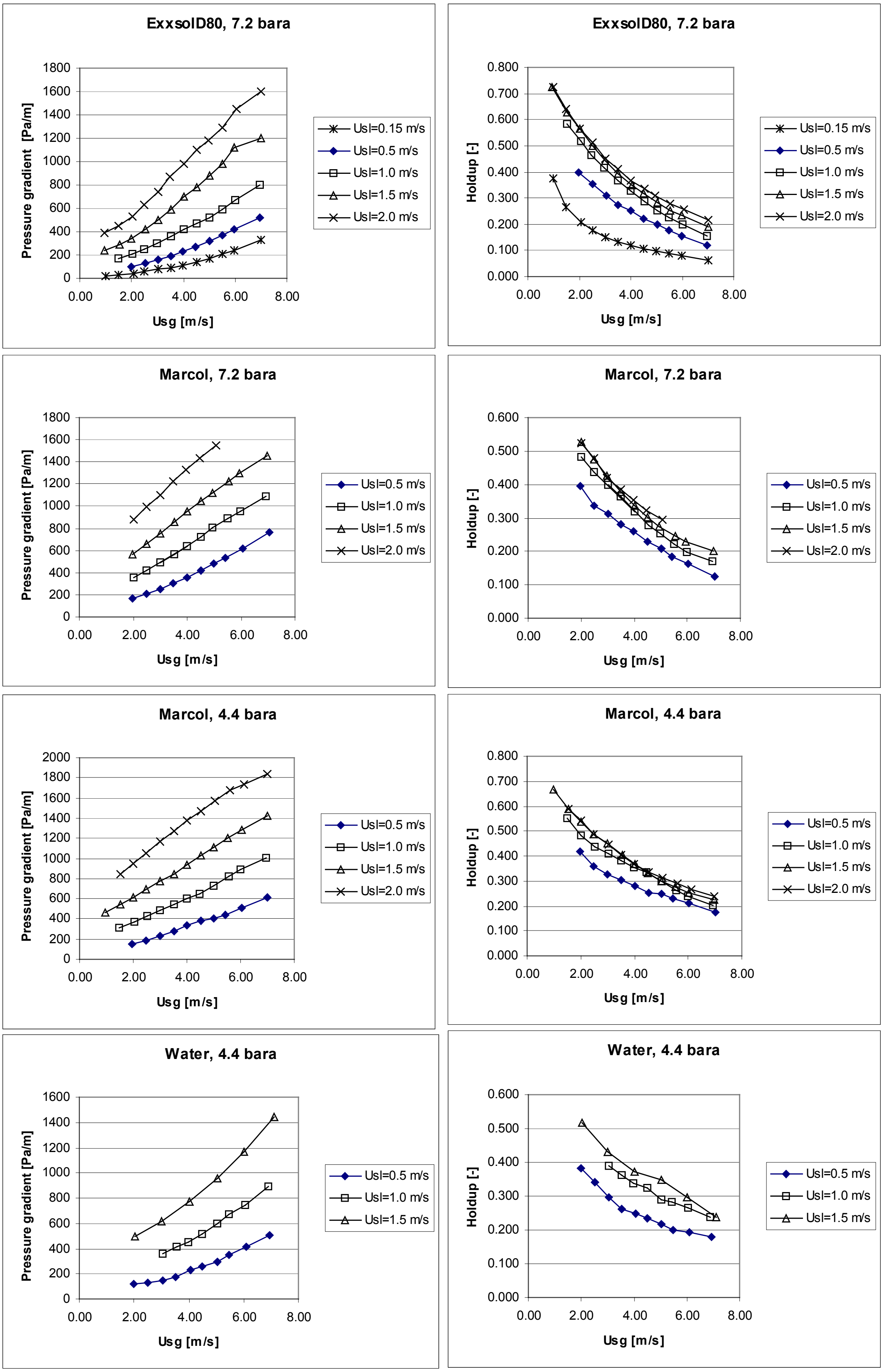


Figure 4-5. Pressure drop and holdup for the four fluid and pressure combinations

Figure 4-6 shows the VIF-data for all the 7.2 bara ExxsolD80 and Marcol experiments. The data exhibits several typical features. First of all we see that the void fraction, for all the different U_{sl}-values, correlates quite well to U_{mix}, for given fluids. The void fraction increases with increasing mixture velocity, as expected. There seems to be a threshold value at U_{mix}=~4 m/s for the onset of gas entrainment, a value that is in good agreement with previous results. (If we plot the void fraction against U_{sl}, we will see a systematic increase in the void fraction with increasing U_{sl}, for fixed U_{sg}.) We can also state that the entrained fraction is significantly higher for the less viscous oil. This is shown even more clearly with the direct comparison plotted in *Figure 4-7*.

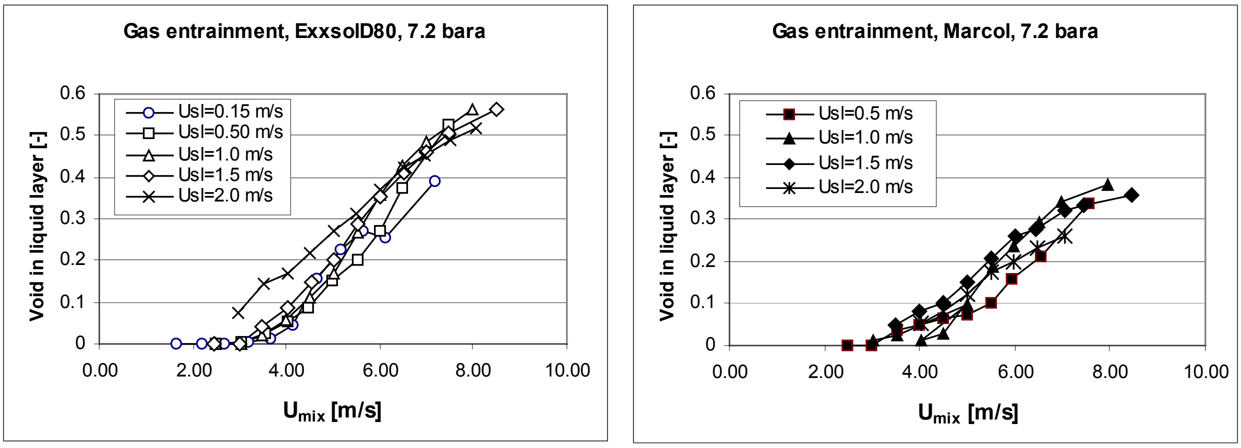


Figure 4-6. Void fraction in the liquid layer for the 7.2 bara ExxsolD80 (left) and Marcol (right) experiments

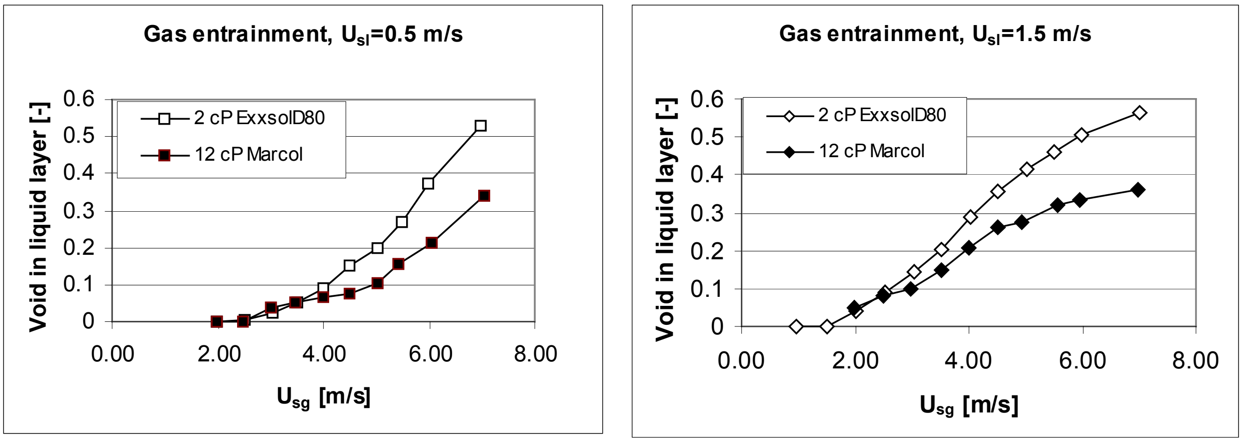


Figure 4-7. Comparison between liquid layer void fraction forExxsolD80 and Marco at 7.2 bara pressure; U_{sl}=0.5 m/s (left) and U_{sl}=1.5 m/s (right)

In section 4.3 we said that we had also analysed the cross-sectional holdup fractions to find depth-averaged holdup distributions. Examples of the holdup distribution along a vertical diameter, for two of the ExxsolD80 experiments, are shown in *Figure 4-8*. We see that for the experiment representing the highest gas velocity, the void fraction in the liquid layer decreases gradually towards the bottom of the pipe, and that gas is entrained in the whole liquid layer. For the 4.0 m/s gas velocity experiment, we see that virtually no gas is entrained below the position y/D=0.2.

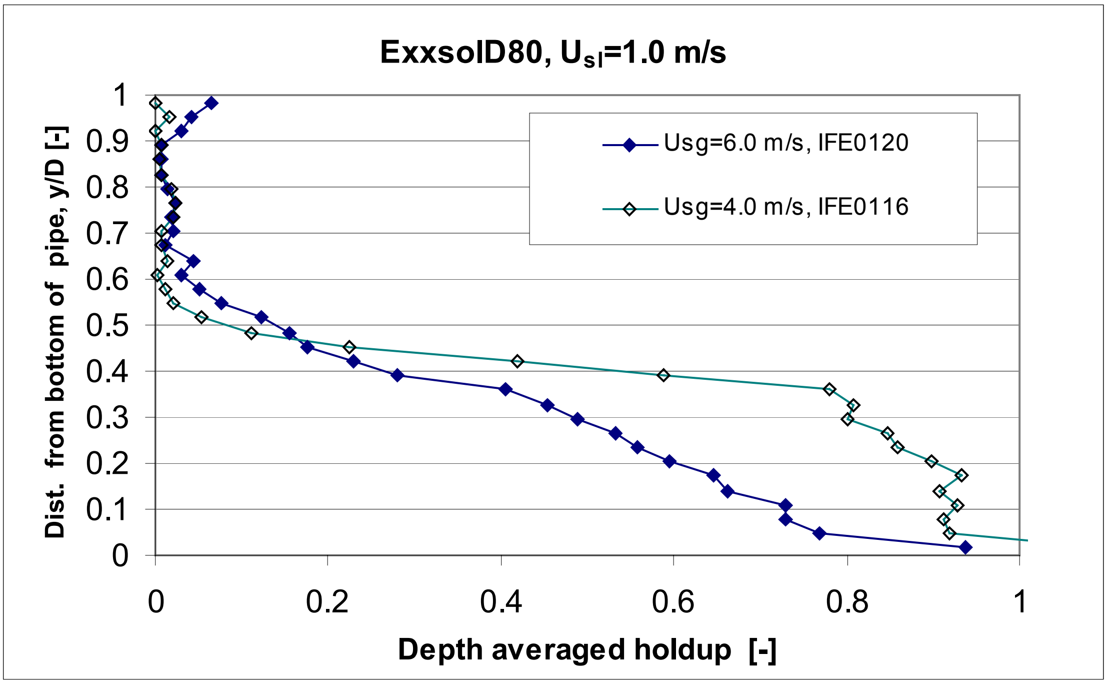


Figure 4-8. Depth-averaged holdup distribution for two of the ExxsolD80 experiments: IFE0116, U_{sg}=4 m/s: Holdup= 0.33 and VIF=0.17; IFE0120, U_{sg}=6 m/s: Holdup= 0.20 and VIF=0.48

4.5 Concluding remarks

The present experiments on stratified gas-liquid flow in a horizontal pipe were motivated by the need for characterisation of fluid-fluid interaction processes through basic experiments, in order to better understand, and model, more complex flow regimes. The reported data will hopefully give better knowledge of dispersed gas-liquid flow in general, and for the THREEPLEX slug flow experiments in particular.

The work has also demonstrated the capabilities of the ECT-system for this type of measurements.

5 Nomenclature

D	Pipe diameter, (m)
dp/dx	Pressure gradient, (Pa/m)
H	Total liquid holdup, (-)
H_{oil}	Oil holdup, (-)
H_{wat}	Water holdup, water fraction in holdup, (-)
p	Loop pressure, (Bara)
R	Pipe radius, (m)
Re	Reynolds number, (-)
S	Oil-water slip, = U_{oil} / U_{gas} , (-)
U_{gas}	In-situ gas velocity, $=U_{sg} /(1-H)$, (m/s)
U_{mix}	Mixture velocity, sum of the gas and liquid superficial velocities, (m/s)
U_{oil}	In-situ oil velocity, $=U_{sl} /H$, (m/s)
U_{sg}	Superficial gas velocity, (m/s)
U_{sl}	Superficial liquid velocity, (m/s)
U_{so}	Superficial oil velocity, (m/s)
U_{sw}	Superficial water velocity, (m/s)
U_{wat}	In-situ water velocity, $=U_{sw} /H_{wat}$, (m/s)
VIF	Void fraction in the liquid layer, (-)
WC	Water cut, water fraction at the inlet, $=U_{sw}/U_{sl}$
φ	Angle of pipe inclination with the horizontal (deg.)
ν	Kinematic viscosity (m^2/s)
μ_{LIQ}	liquid dynamic viscosity, (cP)
μ_G	Gas dynamic viscosity, (cP)
ρ_G	Gas density, (kg/m^3)
ρ_{LIQ}	Liquid density, (kg/m^3)
σ	Interfacial tension, (N/m)

6 References

Andersson, P. et al. (2003), *TP/IFE/005 –Experiments on three-phase slug flow in inclined pipes using a 12 cP oil. Comparison with 2 cP data.* IFE/KR/F-2003/236, IFE report with limited availability (confidential)

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Valle, A., and Utvik, O.H. (1997), *Pressure drop, flow pattern and slip for two-phase crude oil/water flow: Experiments and model predictions*, International Symposium on Advances in Liquid-Liquid Two-Phase Flow and Transient Phenomena, Antalya, Turkey, Nov. 1997

Appendix A. Tables – Oil-water flow experiments

The results from the oil-water experiments are given *Table A- 2*. Each page contains the data from one of the 8 WC-traverses that have been carried out, see table A-1.

Page	**Fluid system**	**Usl**	**WC**	**Exp. ID**
28	ExxsolD80/water	1.0 m/s	Decreasing	IFE0401- IFE0428
29	ExxsolD80/water	1.5 m/s	Decreasing	IFE0447- IFE0475
30	ExxsolD80/water	2.0 m/s	Decreasing	IFE0501- IFE0527
31	Marcol/water	1.0 m/s	Decreasing	IFE0601- IFE0621
32	Marcol/water	1.0 m/s	Increasing	IFE0722- IFE0742
33	Marcol/water	1.5 m/s	Decreasing	IFE0685- IFE0721
34	Marcol/water	2.0 m/s	Increasing	IFE0821- IFE0849
35	Marcol/water	2.0 m/s	Decreasing	IFE0801- IFE0820

Table A- 1. Overview of the different oil-water experiments

Exp.no #	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0401	ExxsolD80/water	1.01	0.00	1.01	1.00	S_M	99	1.00	0.00	1.00	-	1.01	-
IFE0402	ExxsolD80/water	1.00	0.05	0.95	0.95	S_M	107	0.94	0.06	0.99	0.91	1.01	0.90
IFE0403	ExxsolD80/water	1.00	0.10	0.90	0.90	S_M	122	0.88	0.12	0.98	0.86	1.02	0.85
IFE0404	ExxsolD80/water	1.00	0.15	0.85	0.85	S_M	133	0.82	0.18	0.96	0.82	1.04	0.78
IFE0405	ExxsolD80/water	1.00	0.15	0.85	0.85	S_M	134	0.81	0.19	0.95	0.78	1.06	0.73
IFE0406	ExxsolD80/water	1.00	0.20	0.80	0.80	S_M	125	0.78	0.22	0.97	0.89	1.02	0.87
IFE0407	ExxsolD80/water	1.00	0.25	0.75	0.75	3L	119	0.73	0.27	0.98	0.95	1.02	0.93
IFE0408	ExxsolD80/water	1.00	0.30	0.70	0.70	3L	101	0.70	0.30	1.00	0.99	1.00	0.99
IFE0409	ExxsolD80/water	1.00	0.35	0.65	0.65	3L	102	0.67	0.33	1.02	1.05	0.98	1.07
IFE0410	ExxsolD80/water	1.00	0.35	0.65	0.65	3L	100	0.66	0.34	1.01	1.02	0.99	1.04
IFE0411	ExxsolD80/water	1.00	0.40	0.60	0.60	3L	100	0.62	0.38	1.04	1.06	0.96	1.10
IFE0412	ExxsolD80/water	1.00	0.45	0.55	0.55	3L	91	0.58	0.42	1.06	1.09	0.94	1.15
IFE0413	ExxsolD80/water	1.00	0.50	0.50	0.50	3L	89	0.54	0.46	1.08	1.09	0.93	1.17
IFE0414	ExxsolD80/water	1.00	0.55	0.45	0.45	3L	86	0.48	0.52	1.08	1.07	0.93	1.15
IFE0415	ExxsolD80/water	1.00	0.58	0.42	0.42	3L	91	0.45	0.55	1.08	1.06	0.93	1.14
IFE0416	ExxsolD80/water	1.00	0.60	0.40	0.40	3L	90	0.43	0.57	1.09	1.06	0.92	1.15
IFE0417	ExxsolD80/water	1.00	0.65	0.35	0.35	3L	109	0.43	0.57	1.21	1.14	0.83	1.37
IFE0418	ExxsolD80/water	1.00	0.60	0.40	0.40	3L	98	0.43	0.57	1.08	1.06	0.92	1.15
IFE0419	ExxsolD80/water	1.00	0.65	0.35	0.35	S_M	138	0.41	0.59	1.18	1.11	0.85	1.30
IFE0420	ExxsolD80/water	1.00	0.67	0.33	0.33	S_M	136	0.41	0.59	1.23	1.13	0.81	1.40
IFE0421	ExxsolD80/water	1.00	0.70	0.30	0.30	S_M	136	0.39	0.61	1.29	1.15	0.78	1.47
IFE0422	ExxsolD80/water	1.00	0.75	0.25	0.25	S_M	136	0.34	0.66	1.35	1.13	0.74	1.53
IFE0423	ExxsolD80/water	1.01	0.80	0.20	0.20	S_M	130	0.28	0.72	1.39	1.11	0.72	1.54
IFE0424	ExxsolD80/water	1.00	0.85	0.15	0.15	S_M	124	0.22	0.78	1.47	1.10	0.68	1.61
IFE0425	ExxsolD80/water	1.00	0.90	0.10	0.10	S_M	122	0.14	0.86	1.38	1.05	0.72	1.45
IFE0426	ExxsolD80/water	1.00	0.95	0.05	0.05	S_M	105	0.07	0.93	1.40	1.02	0.72	1.43
IFE0427	ExxsolD80/water	1.01	1.01	0.00	0.00	-	98	0.00	1.00	-	1.01	-	-
IFE0428	ExxsolD80/water	1.01	1.01	0.00	0.00	-	98	0.00	1.00	-	1.01	-	-

Table A-2. Results from the oil-water flow experiments

Exp.no # 	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0447	ExxsolD80/water	1.50	0.00	1.50	1.00	-	202	1.00	0.00	1.00	-	1.50	-
IFE0448	ExxsolD80/water	1.50	0.05	1.45	0.97	M_Do/w	199	0.97	0.03	1.00	1.66	1.49	1.11
IFE0449	ExxsolD80/water	1.51	0.11	1.40	0.93	M_Do/w	204	0.93	0.07	1.00	1.58	1.50	1.05
IFE0450	ExxsolD80/water	1.50	0.15	1.35	0.90	M_Do/w	207	0.90	0.10	1.00	1.51	1.50	1.01
IFE0451	ExxsolD80/water	1.50	0.15	1.35	0.90	M_Do/w	205	0.90	0.10	1.00	1.48	1.50	0.99
IFE0452	ExxsolD80/water	1.50	0.20	1.30	0.87	M_Do/w	212	0.87	0.13	1.00	1.50	1.50	1.00
IFE0453	ExxsolD80/water	1.50	0.25	1.25	0.83	M_Do/w	218	0.83	0.17	1.00	1.49	1.50	1.00
IFE0454	ExxsolD80/water	1.50	0.30	1.20	0.80	M_Do/w	231	0.79	0.21	0.99	1.45	1.51	0.96
IFE0455	ExxsolD80/water	1.50	0.35	1.15	0.77	M_Do/w	232	0.75	0.25	0.98	1.41	1.53	0.92
IFE0456	ExxsolD80/water	1.50	0.40	1.10	0.73	M_Do/w	216	0.72	0.28	0.98	1.41	1.53	0.92
IFE0457	ExxsolD80/water	1.50	0.45	1.05	0.70	3L	205	0.69	0.31	0.99	1.46	1.52	0.96
IFE0458	ExxsolD80/water	1.49	0.50	0.99	0.66	3L	199	0.67	0.33	1.01	1.51	1.48	1.02
IFE0459	ExxsolD80/water	1.50	0.55	0.95	0.63	3L	199	0.64	0.36	1.01	1.54	1.48	1.04
IFE0460	ExxsolD80/water	1.50	0.60	0.90	0.60	3L	188	0.62	0.38	1.04	1.59	1.45	1.10
IFE0461	ExxsolD80/water	1.51	0.65	0.85	0.57	3L	182	0.59	0.41	1.04	1.58	1.46	1.09
IFE0462	ExxsolD80/water	1.50	0.70	0.81	0.54	3L	180	0.56	0.44	1.05	1.59	1.44	1.11
IFE0463	ExxsolD80/water	1.50	0.75	0.75	0.50	3L	177	0.53	0.47	1.07	1.61	1.41	1.15
IFE0464	ExxsolD80/water	1.51	0.81	0.70	0.47	3L	179	0.48	0.52	1.04	1.56	1.45	1.07
IFE0465	ExxsolD80/water	1.50	0.85	0.65	0.43	S_Dw/o&w	216	0.47	0.53	1.08	1.60	1.38	1.16
IFE0466	ExxsolD80/water	1.51	0.90	0.60	0.40	S_Dw/o&w	221	0.43	0.57	1.08	1.60	1.39	1.15
IFE0467	ExxsolD80/water	1.50	0.95	0.55	0.37	S_Dw/o&w	222	0.40	0.60	1.08	1.58	1.39	1.13
IFE0468	ExxsolD80/water	1.51	1.01	0.50	0.33	S_Dw/o&w	220	0.36	0.64	1.09	1.58	1.39	1.13
IFE0469	ExxsolD80/water	1.50	1.05	0.45	0.30	S_Dw/o&w	213	0.32	0.68	1.08	1.56	1.39	1.12
IFE0470	ExxsolD80/water	1.50	1.11	0.40	0.26	S_Dw/o&w	206	0.28	0.72	1.07	1.54	1.40	1.10
IFE0471	ExxsolD80/water	1.51	1.15	0.36	0.24	S_Dw/o&w	202	0.26	0.74	1.08	1.54	1.39	1.11
IFE0472	ExxsolD80/water	1.50	1.20	0.30	0.20	S_Dw/o&w	195	0.21	0.79	1.06	1.52	1.41	1.08
IFE0473	ExxsolD80/water	1.50	1.30	0.20	0.13	S_Dw/o&w	192	0.14	0.86	1.04	1.51	1.44	1.05
IFE0474	ExxsolD80/water	1.50	1.40	0.10	0.07	S_Dw/o&w	191	0.07	0.93	1.03	1.50	1.46	1.03
IFE0475	ExxsolD80/water	1.50	1.50	0.00	0.00	-	184	0.00	1.00	-	1.50	-	-

Table A-2. Results from the oil-water flow experiments

Exp.no #	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0501	ExxsolD80/water	2.00	0.00	2.00	1.00	-	337	1.00	0.00	1.00	-	2.00	-
IFE0502	ExxsolD80/water	2.00	0.10	1.90	0.95	M_Do/w	360	0.92	0.08	0.97	1.29	2.06	0.63
IFE0503	ExxsolD80/water	2.00	0.20	1.80	0.90	M_Do/w	360	0.88	0.12	0.98	1.68	2.05	0.82
IFE0504	ExxsolD80/water	2.01	0.30	1.71	0.85	M_Do/w	362	0.83	0.17	0.97	1.76	2.06	0.85
IFE0505	ExxsolD80/water	2.00	0.40	1.60	0.80	M_Do/w	356	0.78	0.22	0.98	1.83	2.04	0.90
IFE0506	ExxsolD80/water	2.00	0.50	1.50	0.75	M_Do/w	358	0.73	0.27	0.98	1.87	2.05	0.91
IFE0507	ExxsolD80/water	2.00	0.60	1.40	0.70	M_Do/w	360	0.69	0.31	0.98	1.93	2.04	0.94
IFE0508	ExxsolD80/water	2.00	0.70	1.30	0.65	M_Do/w	368	0.64	0.36	0.98	1.91	2.05	0.93
IFE0509	ExxsolD80/water	2.01	0.81	1.20	0.60	M_Do/w	369	0.59	0.41	0.98	1.96	2.04	0.96
IFE0510	ExxsolD80/water	2.00	0.90	1.10	0.55	M_Do/w	367	0.55	0.45	0.99	1.99	2.01	0.99
IFE0511	ExxsolD80/water	2.01	1.01	1.01	0.50	S/3L?	318	0.50	0.50	0.99	2.00	2.03	0.99
IFE0512	ExxsolD80/water	2.00	1.05	0.95	0.47	S/3L?	310	0.47	0.53	1.00	2.00	2.00	1.00
IFE0513	ExxsolD80/water	2.00	1.10	0.90	0.45	S/3L?	396	0.50	0.50	1.11	2.19	1.80	1.21
IFE0514	ExxsolD80/water	2.00	1.15	0.85	0.43	S_Dw/o&w	403	0.46	0.54	1.09	2.14	1.83	1.17
IFE0515	ExxsolD80/water	2.00	1.15	0.85	0.43	S_Dw/o&w	380	0.42	0.58	0.99	1.98	2.03	0.98
IFE0516	ExxsolD80/water	2.00	1.19	0.80	0.40	S_Dw/o&w	387	0.43	0.57	1.08	2.11	1.85	1.14
IFE0517	ExxsolD80/water	1.99	1.24	0.75	0.38	S_Dw/o&w	381	0.40	0.60	1.05	2.05	1.90	1.08
IFE0518	ExxsolD80/water	2.00	1.30	0.70	0.35	S_Dw/o&w	379	0.35	0.65	0.99	1.99	2.03	0.98
IFE0519	ExxsolD80/water	2.00	1.36	0.65	0.32	S_Dw/o&w	375	0.33	0.67	1.02	2.02	1.96	1.03
IFE0520	ExxsolD80/water	2.01	1.40	0.60	0.30	M_Dw/o	381	0.33	0.67	1.10	2.09	1.83	1.14
IFE0521	ExxsolD80/water	2.00	1.45	0.55	0.28	M_Dw/o	371	0.28	0.72	1.01	2.00	1.99	1.01
IFE0522	ExxsolD80/water	2.01	1.50	0.51	0.25	M_Dw/o	381	0.26	0.74	1.04	2.03	1.94	1.05
IFE0523	ExxsolD80/water	2.00	1.60	0.40	0.20	M_Dw/o	378	0.22	0.78	1.11	2.06	1.80	1.14
IFE0524	ExxsolD80/water	2.01	1.70	0.30	0.15	M_Dw/o	378	0.17	0.83	1.11	2.05	1.81	1.13
IFE0525	ExxsolD80/water	2.00	1.80	0.20	0.10	M_Dw/o	371	0.11	0.89	1.06	2.01	1.88	1.07
IFE0526	ExxsolD80/water	2.00	1.90	0.10	0.05	M_Dw/o	358	0.06	0.94	1.16	2.01	1.73	1.16
IFE0527	ExxsolD80/water	2.00	2.00	0.00	0.00	-	339	0.00	1.00	-	2.00	-	-

Table A-2. Results from the oil-water flow experiments

Exp.no # 	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0601	Marcol/water	1.02	0.00	1.02	1.00	-	102	1.00	0.00	1.00	-	1.02	-
IFE0602	Marcol/water	1.01	0.05	0.96	0.95	S_M	112	0.93	0.07	0.98	0.79	1.03	0.77
IFE0603	Marcol/water	1.00	0.10	0.90	0.90	S_M	123	0.87	0.13	0.97	0.78	1.03	0.76
IFE0604	Marcol/water	1.00	0.15	0.85	0.85	S_M	134	0.82	0.18	0.96	0.81	1.04	0.78
IFE0605	Marcol/water	1.00	0.20	0.80	0.80	S_M	144	0.74	0.26	0.93	0.77	1.08	0.71
IFE0606	Marcol/water	0.99	0.25	0.75	0.75	S_M	152	0.68	0.32	0.90	0.77	1.10	0.70
IFE0607	Marcol/water	1.00	0.30	0.70	0.70	S_M	156	0.63	0.37	0.91	0.83	1.10	0.75
IFE0608	Marcol/water	1.00	0.35	0.65	0.65	S_M	160	0.60	0.40	0.93	0.88	1.08	0.82
IFE0609	Marcol/water	1.01	0.40	0.60	0.60	S_M	165	0.55	0.45	0.91	0.89	1.10	0.81
IFE0610	Marcol/water	1.00	0.45	0.55	0.55	S_M	167	0.52	0.48	0.95	0.95	1.05	0.90
IFE0611	Marcol/water	1.00	0.50	0.50	0.50	3L	169	0.49	0.51	0.97	0.98	1.03	0.95
IFE0612	Marcol/water	1.00	0.55	0.45	0.45	3L	169	0.45	0.55	1.00	1.00	1.00	0.99
IFE0613	Marcol/water	1.00	0.60	0.39	0.40	3L	129	0.43	0.57	1.08	1.05	0.92	1.14
IFE0614	Marcol/water	1.00	0.65	0.35	0.35	3L	115	0.39	0.61	1.12	1.07	0.89	1.20
IFE0615	Marcol/water	1.00	0.70	0.30	0.30	3L	111	0.34	0.66	1.12	1.06	0.90	1.18
IFE0616	Marcol/water	1.00	0.75	0.25	0.25	3L	123	0.29	0.71	1.18	1.07	0.85	1.25
IFE0617	Marcol/water	1.00	0.80	0.20	0.20	3L	122	0.25	0.75	1.25	1.07	0.80	1.33
IFE0618	Marcol/water	1.00	0.85	0.15	0.15	S_M	128	0.19	0.81	1.26	1.05	0.79	1.32
IFE0619	Marcol/water	1.01	0.91	0.10	0.10	S_M	167	0.12	0.88	1.17	1.03	0.86	1.19
IFE0620	Marcol/water	1.00	0.95	0.05	0.05	S_M	158	0.06	0.94	1.22	1.01	0.82	1.23
IFE0621	Marcol/water	1.00	1.00	0.00	0.00	-	146	0.00	1.00	-	1.00	-	-

Table A-2. Results from the oil-water flow experiments

Exp.no #	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0722	Marcol/water	1.01	1.01	0.00	0.00	-	149	0.00	1.00	-	1.01	-	-
IFE0723	Marcol/water	1.00	0.95	0.05	0.05	S_M	155	0.04	0.96	0.85	1.00	1.19	0.84
IFE0724	Marcol/water	1.00	0.90	0.10	0.10	S_M	161	0.10	0.90	1.00	1.00	1.00	1.00
IFE0725	Marcol/water	1.01	0.85	0.15	0.15	S_M	135	0.15	0.85	1.00	1.01	1.01	1.00
IFE0726	Marcol/water	1.01	0.80	0.20	0.20	S_M	116	0.21	0.79	1.04	1.02	0.96	1.06
IFE0727	Marcol/water	1.00	0.75	0.25	0.25	3L	107	0.27	0.73	1.06	1.02	0.94	1.09
IFE0728	Marcol/water	1.01	0.70	0.30	0.30	3L	102	0.33	0.67	1.11	1.05	0.91	1.16
IFE0729	Marcol/water	1.00	0.65	0.35	0.35	3L	102	0.39	0.61	1.09	1.05	0.91	1.15
IFE0730	Marcol/water	1.01	0.60	0.40	0.40	3L	97	0.43	0.57	1.06	1.05	0.95	1.11
IFE0731	Marcol/water	1.00	0.55	0.45	0.45	3L	97	0.47	0.53	1.04	1.04	0.96	1.08
IFE0732	Marcol/water	1.00	0.50	0.50	0.50	3L	125	0.49	0.51	0.98	0.99	1.02	0.97
IFE0733	Marcol/water	1.00	0.45	0.55	0.55	S_M	153	0.53	0.47	0.96	0.95	1.04	0.92
IFE0734	Marcol/water	1.00	0.40	0.60	0.60	S_M	156	0.55	0.45	0.91	0.89	1.09	0.81
IFE0735	Marcol/water	1.00	0.35	0.65	0.65	S_M	162	0.58	0.42	0.90	0.84	1.12	0.75
IFE0736	Marcol/water	1.00	0.30	0.70	0.70	S_M	162	0.63	0.37	0.90	0.81	1.12	0.72
IFE0737	Marcol/water	1.00	0.25	0.75	0.75	S_M	164	0.68	0.32	0.91	0.78	1.10	0.71
IFE0738	Marcol/water	1.00	0.20	0.80	0.80	S_M	150	0.73	0.27	0.92	0.75	1.09	0.69
IFE0739	Marcol/water	1.00	0.15	0.85	0.85	S_M	141	0.81	0.19	0.95	0.79	1.05	0.75
IFE0740	Marcol/water	1.01	0.11	0.90	0.90	S_M	120	0.86	0.14	0.96	0.77	1.04	0.74
IFE0741	Marcol/water	1.00	0.05	0.95	0.95	S_M	108	0.95	0.05	1.00	1.03	1.00	1.03
IFE0742	Marcol/water	1.00	0.00	1.00	1.00	-	99	1.00	0.00	1.00	-	1.00	-

Table A-2. Results from the oil-water flow experiments

Exp.no #	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0685	Marcol/water	1.51	0.00	1.51	1.00	-	204	1.00	0.00	1.00	-	1.51	-
IFE0686	Marcol/water	1.50	0.10	1.40	0.93	M_Do/w	204	0.93	0.07	1.00	1.47	1.50	0.98
IFE0687	Marcol/water	1.50	0.15	1.35	0.90	M_Do/w	197	0.91	0.09	1.01	1.58	1.49	1.06
IFE0688	Marcol/water	1.50	0.20	1.30	0.87	M_Do/w	208	0.85	0.15	0.98	1.35	1.52	0.88
IFE0689	Marcol/water	1.50	0.25	1.25	0.83	M_Do/w	212	0.83	0.17	1.00	1.48	1.51	0.98
IFE0690	Marcol/water	1.50	0.30	1.20	0.80	M_Do/w	217	0.80	0.20	0.99	1.46	1.51	0.97
IFE0691	Marcol/water	1.50	0.35	1.15	0.77	M_Do/w	221	0.76	0.24	1.00	1.48	1.51	0.98
IFE0692	Marcol/water	1.50	0.40	1.10	0.73	M_Do/w	227	0.73	0.27	0.99	1.47	1.51	0.97
IFE0693	Marcol/water	1.50	0.45	1.05	0.70	M_Do/w	232	0.70	0.30	1.00	1.51	1.49	1.01
IFE0694	Marcol/water	1.49	0.50	0.99	0.67	M_Do/w	239	0.66	0.34	0.99	1.47	1.50	0.98
IFE0695	Marcol/water	1.50	0.55	0.95	0.63	M_Do/w	249	0.63	0.37	1.00	1.49	1.51	0.99
IFE0696	Marcol/water	1.50	0.60	0.90	0.60	M_Do/w	256	0.60	0.40	1.00	1.49	1.51	0.99
IFE0697	Marcol/water	1.50	0.65	0.85	0.57	M_Do/w	266	0.56	0.44	0.99	1.49	1.51	0.98
IFE0698	Marcol/water	1.50	0.70	0.80	0.53	M_Do/w	270	0.52	0.48	0.98	1.46	1.53	0.96
IFE0699	Marcol/water	1.50	0.75	0.75	0.50	3L	277	0.49	0.51	0.97	1.46	1.54	0.95
IFE0708	Marcol/water	1.50	0.80	0.70	0.47	3L	267	0.47	0.53	1.01	1.51	1.49	1.02
IFE0707	Marcol/water	1.50	0.85	0.65	0.43	3L	266	0.44	0.56	1.02	1.53	1.47	1.03
IFE0709	Marcol/water	1.50	0.85	0.65	0.43	3L	257	0.43	0.57	1.00	1.49	1.50	0.99
IFE0710	Marcol/water	1.49	0.90	0.60	0.40	3L	262	0.40	0.60	1.01	1.50	1.49	1.01
IFE0711	Marcol/water	1.50	0.96	0.55	0.36	3L	280	0.38	0.62	1.04	1.54	1.45	1.06
IFE0712	Marcol/water	1.50	1.00	0.50	0.33	3L	289	0.33	0.67	0.99	1.49	1.52	0.98
IFE0713	Marcol/water	1.50	1.05	0.45	0.30	3L	232	0.33	0.67	1.08	1.56	1.39	1.12
IFE0714	Marcol/water	1.50	1.10	0.40	0.27	3L	239	0.29	0.71	1.07	1.54	1.41	1.09
IFE0715	Marcol/water	1.50	1.15	0.35	0.23	M_Dw/o	247	0.25	0.75	1.06	1.53	1.42	1.08
IFE0716	Marcol/water	1.50	1.20	0.30	0.20	M_Dw/o	258	0.20	0.80	1.00	1.50	1.50	1.00
IFE0717	Marcol/water	1.50	1.25	0.25	0.17	M_Dw/o	323	0.18	0.82	1.06	1.52	1.42	1.07
IFE0718	Marcol/water	1.50	1.30	0.20	0.13	M_Dw/o	323	0.14	0.86	1.03	1.50	1.45	1.04
IFE0719	Marcol/water	1.50	1.35	0.15	0.10	M_Dw/o	322	0.10	0.90	1.04	1.51	1.45	1.04
IFE0720	Marcol/water	1.50	1.40	0.10	0.07	M_Dw/o	317	0.06	0.94	0.97	1.49	1.53	0.97
IFE0721	Marcol/water	1.49	1.49	0.00	0.00	-	304	0.00	1.00	-	1.49	-	-

Table A-2. Results from the oil-water flow experiments

Exp.no #	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0821	Marcol/water	2.00	2.00	0.00	0.00	-	522	0.00	1.00	-	2.00	-	-
IFE0822	Marcol/water	1.98	1.88	0.10	0.05	M_Dw/o	537	0.06	0.94	1.21	2.01	1.64	1.22
IFE0823	Marcol/water	2.01	1.81	0.20	0.10	M_Dw/o	564	0.12	0.88	1.23	2.06	1.63	1.26
IFE0824	Marcol/water	1.99	1.74	0.25	0.13	M_Dw/o	588	0.12	0.88	0.98	1.98	2.02	0.98
IFE0825	Marcol/water	2.01	1.71	0.30	0.15	M_Dw/o	601	0.12	0.88	0.82	1.95	2.46	0.79
IFE0826	Marcol/water	2.01	1.66	0.35	0.18	M	587	0.14	0.86	0.79	1.92	2.55	0.75
IFE0827	Marcol/water	2.00	1.60	0.40	0.20	M	559	0.23	0.77	1.16	2.08	1.72	1.21
IFE0828	Marcol/water	2.00	1.55	0.45	0.23	M	526	0.33	0.67	1.44	2.30	1.39	1.65
IFE0829	Marcol/water	1.98	1.48	0.50	0.25	M	472	0.34	0.66	1.37	2.26	1.45	1.56
IFE0830	Marcol/water	2.00	1.44	0.56	0.28	M	419	0.36	0.64	1.29	2.25	1.55	1.45
IFE0831	Marcol/water	2.01	1.41	0.60	0.30	M	385	0.40	0.60	1.36	2.37	1.48	1.60
IFE0832	Marcol/water	1.93	1.28	0.65	0.34	M_Do/w	438	0.43	0.57	1.26	2.23	1.53	1.45
IFE0833	Marcol/water	1.97	1.27	0.70	0.36	M_Do/w	418	0.46	0.54	1.28	2.33	1.53	1.52
IFE0835	Marcol/water	2.00	1.20	0.80	0.40	M_Do/w	419	0.51	0.49	1.27	2.43	1.58	1.54
IFE0836	Marcol/water	2.00	1.15	0.85	0.43	M_Do/w	420	0.53	0.47	1.24	2.44	1.62	1.51
IFE0837	Marcol/water	2.00	1.26	0.74	0.37	M_Do/w	414	0.45	0.55	1.22	2.31	1.64	1.41
IFE0838	Marcol/water	2.01	1.10	0.90	0.45	M_Do/w	415	0.54	0.46	1.19	2.38	1.68	1.42
IFE0839	Marcol/water	2.00	1.05	0.95	0.48	M_Do/w	405	0.57	0.43	1.20	2.45	1.66	1.47
IFE0840	Marcol/water	2.00	1.00	1.00	0.50	M_Do/w	395	0.57	0.43	1.15	2.34	1.74	1.34
IFE0841	Marcol/water	2.00	0.95	1.05	0.52	M_Do/w	392	0.60	0.40	1.14	2.37	1.76	1.35
IFE0842	Marcol/water	2.00	0.90	1.10	0.55	M_Do/w	388	0.61	0.39	1.11	2.31	1.81	1.28
IFE0843	Marcol/water	1.99	0.80	1.20	0.60	M_Do/w	375	0.67	0.33	1.11	2.39	1.79	1.33
IFE0844	Marcol/water	2.00	0.70	1.30	0.65	M_Do/w	367	0.71	0.29	1.09	2.39	1.84	1.30
IFE0845	Marcol/water	2.00	0.60	1.40	0.70	M_Do/w	360	0.73	0.27	1.04	2.23	1.92	1.16
IFE0846	Marcol/water	2.00	0.50	1.50	0.75	M_Do/w	353	0.78	0.22	1.03	2.23	1.93	1.15
IFE0847	Marcol/water	2.01	0.40	1.61	0.80	M_Do/w	355	0.84	0.16	1.05	2.53	1.91	1.32
IFE0848	Marcol/water	1.99	0.30	1.69	0.85	M_Do/w	348	0.86	0.14	1.01	2.15	1.97	1.09
IFE0849	Marcol/water	1.99	0.20	1.79	0.90	M_Do/w	351	0.90	0.10	1.00	2.04	1.99	1.03

Table A-2. Results from the oil-water flow experiments

Exp.no #	Fluid system oil/water	Superficial liquid vel. U_{sl} [m/s]	Superficial oil velocity U_{so} [m/s]	Superficial water vel. U_{sw} [m/s]	Water cut at inlet WC [-]	Flow regime liq-liq	Pressure gradient (dp/dx) [Pa/m]	Water Holdup H_{wat} [-]	Oil Holdup H_{oil} [-]	Water accumul. H_{wat}/WC [-]	In-situ oil vel. U_{oil} [m/s]	In-situ water vel. U_{wat} [m/s]	Slip ratio $S=U_{oil}/U_{wat}$ [-]
IFE0801	Marcol/water	1.98	0.19	1.79	0.91	M_Do/w	347	0.90	0.10	0.99	1.89	1.99	0.95
IFE0802	Marcol/water	2.01	0.31	1.70	0.85	M_Do/w	351	0.86	0.14	1.02	2.19	1.98	1.11
IFE0803	Marcol/water	2.01	0.40	1.60	0.80	M_Do/w	349	0.82	0.18	1.02	2.22	1.96	1.13
IFE0804	Marcol/water	2.00	0.50	1.50	0.75	M_Do/w	354	0.78	0.22	1.04	2.29	1.92	1.19
IFE0805	Marcol/water	2.01	0.60	1.41	0.70	M_Do/w	366	0.74	0.26	1.06	2.31	1.90	1.22
IFE0806	Marcol/water	2.01	0.70	1.30	0.65	M_Do/w	374	0.70	0.30	1.08	2.33	1.86	1.25
IFE0807	Marcol/water	2.00	0.80	1.20	0.60	M_Do/w	379	0.66	0.34	1.10	2.36	1.82	1.30
IFE0808	Marcol/water	2.01	0.90	1.11	0.55	M_Do/w	395	0.62	0.38	1.12	2.37	1.78	1.33
IFE0809	Marcol/water	2.00	1.00	1.01	0.50	M_Do/w	410	0.58	0.42	1.16	2.38	1.73	1.38
IFE0810	Marcol/water	2.02	1.12	0.90	0.45	M_Do/w	427	0.55	0.45	1.22	2.46	1.65	1.49
IFE0811	Marcol/water	2.00	1.20	0.80	0.40	M	444	0.51	0.49	1.28	2.46	1.56	1.58
IFE0812	Marcol/water	2.03	1.33	0.70	0.35	M	407	0.41	0.59	1.18	2.24	1.72	1.30
IFE0813	Marcol/water	2.00	1.40	0.60	0.30	M	416	0.42	0.58	1.42	2.43	1.41	1.72
IFE0814	Marcol/water	2.03	1.52	0.50	0.25	M	526	0.27	0.73	1.08	2.08	1.88	1.11
IFE0815	Marcol/water	1.97	1.57	0.40	0.20	M	547	0.20	0.80	1.00	1.97	1.97	1.00
IFE0816	Marcol/water	2.00	1.70	0.30	0.15	M_Dw/o	578	0.20	0.80	1.37	2.14	1.46	1.46
IFE0817	Marcol/water	2.01	1.81	0.20	0.10	M_Dw/o	552	0.14	0.86	1.43	2.10	1.40	1.50
IFE0818	Marcol/water	2.00	1.89	0.11	0.05	M_Dw/o	541	0.07	0.93	1.37	2.04	1.46	1.40
IFE0820	Marcol/water	1.99	1.99	0.00	0.00	M_Dw/o	529	0.01	0.99	-	2.00	-	-

Table A-2. Results from the oil-water flow experiments

Appendix B. Tables – Stratified gas-liquid flow experiments

The results from the stratified gas-liquid experiments are given *Table B- 2*. An overview of the experiments is given in *Table B- 1.*

Fluids	Pressure	Usl [m/s]	Usg [m/s]	Exp. ID
ExxsolD80/SF_6	7.1 bara	0.15	1.0-7.0	IFE0146 – IFE0157
ExxsolD80/SF_6	7.1 bara	0.5	2-7.0	IFE0101 – IFE0110
ExxsolD80/SF_6	7.1 bara	1.0	1.5-7.0	IFE0111 – IFE0121
ExxsolD80/SF_6	7.1 bara	1.5	1.0-7.0	IFE0122 – IFE0131
ExxsolD80/SF_6	7.1 bara	2.0	1.0-7.0	IFE0134 – IFE0145
Marcol/SF_6	4.4 bara	0.5	2.0-7.0	IFE0201 – IFE0210
Marcol/SF_6	4.4 bara	1.0	1.5-7.0	IFE0211 – IFE0221
Marcol/SF_6	4.4 bara	1.5	1.0-7.0	IFE0222 – IFE0233
Marcol/SF_6	4.4 bara	2.0	1.0-7.0	IFE0234 – IFE0245
Water/SF_6	4.4 bara	0.5	2.0-7.0	IFE0246 – IFE0255
Water/SF_6	4.4 bara	1.0	3.0-7.0	IFE0256 – IFE0263
Water/SF_6	4.4 bara	1.5	2.0-7.0	IFE0264 – IFE0269
Water/SF_6	4.4 bara	2.0	1.0-7.0	IFE0146 – IFE0157
Marcol/SF_6	7.1 bara	0.5	2-0-7.0	IFE0301 – IFE0310
Marcol/SF_6	7.1 bara	1.0	2-0-7.0	IFE0315 – IFE0324
Marcol/SF_6	7.1 bara	1.5	2-0-7.0	IFE0325 – IFE0334
Marcol/SF_6	7.1 bara	2.0	2-0-5.0	IFE0335 – IFE0341

Table B- 1. Overview of the stratified gas-liquid flow experiments

Exp. ID	Fluid system l/g	Loop Pressure p [Bara]	Liquid density ρ_{LIQ} [kg/m^3]	Dyn. visc liquid μ_{LIQ} [cP][mPas]	Gas density ρ_G [kg/m^3]	Dyn. visc gas μ_G [cP][mPas]	Interfacial tension σ [N/m]	Superficial gas velocity U_{sg} [m/s]	Superficial liquid vel. U_{sl} [m/s]	Flow regime [gas-liquid]	Pressure gradient (dp/dx) [Pa/m]	Liquid Holdup H [-]	Void fraction in liquid layer VIF [-]
IFE0146	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	1.01	0.15	SW	21	0.375	0
IFE0147	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	1.50	0.15	SW	25	0.266	0
IFE0148	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.06	0.15	SW	44	0.207	0
IFE0149	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.51	0.15	SW	57	0.178	0
IFE0150	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.02	0.15	SW	76	0.150	0.006
IFE0151	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.52	0.15	SW	94	0.131	0.014
IFE0152	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.99	0.15	SW	113	0.118	0.047
IFE0153	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.51	0.15	SW_Dg/o	140	0.105	0.158
IFE0154	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.00	0.15	SW_Dg/o	168	0.096	0.227
IFE0155	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.50	0.15	SW_Dg/o&Do/g	206	0.087	0.272
IFE0156	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.98	0.15	SW_Dg/o&Do/g	245	0.079	0.254
IFE0157	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	7.01	0.15	SW_Dg/o&Do/g	329	0.064	0.392
IFE0101	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	1.99	0.50	SW	104	0.400	0
IFE0102	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.52	0.50	SW	130	0.352	0.006
IFE0103	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.04	0.50	SW	159	0.308	0.025
IFE0104	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.52	0.50	SW	190	0.275	0.054
IFE0105	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.99	0.50	SW	228	0.251	0.088
IFE0106	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.50	0.50	SW_Dg/o	270	0.222	0.151
IFE0107	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.03	0.50	SW_Dg/o	321	0.201	0.2
IFE0108	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.50	0.50	SW_Dg/o	366	0.178	0.27
IFE0109	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.98	0.50	SW_Dg/o&Do/g	418	0.154	0.375
IFE0110	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	6.98	0.50	SW_Dg/o&Do/g	524	0.119	0.528
IFE0111	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	1.51	1.00	SW	167	0.583	0
IFE0112	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.05	1.01	SW	208	0.518	0
IFE0113	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.49	1.01	SW	249	0.465	0.02
IFE0114	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.98	1.01	SW	301	0.415	0.056
IFE0115	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.51	1.00	SW_Dg/o	362	0.367	0.111
IFE0116	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.00	1.00	SW_Dg/o	422	0.329	0.168
IFE0117	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.52	1.01	SW_Dg/o	469	0.286	0.267
IFE0118	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.02	1.00	SW_Dg/o	519	0.250	0.358
IFE0119	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.50	1.00	SW_Dg/o&Do/g	594	0.223	0.428
IFE0120	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	6.02	1.00	SW_Dg/o&Do/g	672	0.197	0.484
IFE0121	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	6.98	1.00	SW_Dg/o&Do/g	799	0.157	0.565

Table B-2. results from experiments on gas entrainment in liquid layer

Exp. ID	Fluid system l/g	Loop Pressure p [Bara]	Liquid density ρ_{LIQ} [kg/m^3]	Dyn. visc liquid μ_{LIQ} [cP][mPas]	Gas density ρ_G [kg/m^3]	Dyn. visc gas μ_G [cP][mPas]	Interfacial tension σ [N/m]	Superficial gas velocity U_{sg} [m/s]	Superficial liquid vel. U_{sl} [m/s]	Flow regime [gas-liquid]	Pressure gradient (dp/dx) [Pa/m]	Liquid Holdup H [-]	Void fraction in liquid layer VIF [-]
IFE0122	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	0.96	1.50	SW	244	0.726	0
IFE0123	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	1.52	1.50	SW	286	0.627	0
IFE0124	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.00	1.50	SW	344	0.564	0.04
IFE0125	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.52	1.50	SW	420	0.499	0.088
IFE0126	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.03	1.50	SW_Dg/o	503	0.442	0.146
IFE0127	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.51	1.50	SW_Dg/o	595	0.395	0.201
IFE0128	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.03	1.50	SW_Dg/o	698	0.350	0.288
IFE0129	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.50	1.50	SW_Dg/o&Do/g	778	0.316	0.355
IFE0130	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.03	1.50	SW_Dg/o&Do/g	883	0.285	0.413
IFE0131	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.51	1.50	SW_Dg/o&Do/g	983	0.252	0.462
IFE0132	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.99	1.50	SW_Dg/o&Do/g	1118	0.232	0.505
IFE0133	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	7.00	1.50	SW_Dg/o&Do/g	1204	0.192	0.563
IFE0134	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	0.97	2.00	SW	392	0.723	0.072
IFE0135	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	1.50	2.00	SW	453	0.639	0.145
IFE0136	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.02	2.00	SW_Dg/o	528	0.567	0.168
IFE0137	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	2.50	2.00	SW_Dg/o	631	0.511	0.217
IFE0138	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.03	2.00	SW_Dg/o	745	0.453	0.272
IFE0139	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	3.50	2.00	SW_Dg/o	874	0.412	0.314
IFE0140	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.01	2.00	SW_Dg/o&Do/g	981	0.368	0.368
IFE0141	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.52	2.00	SW_Dg/o&Do/g	1099	0.334	0.425
IFE0142	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	4.96	2.00	SW_Dg/o&Do/g	1184	0.309	0.454
IFE0143	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	5.52	2.00	SW_Dg/o&Do/g	1292	0.279	0.488
IFE0144	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	6.06	1.99	SW_Dg/o&Do/g	1455	0.254	0.519
IFE0145	ExxsolD80/SF6	7.2	823	1.7	42.3	0.015	0.021	7.02	1.99	SW_Dg/o&Do/g	1602	0.218	0.452

Table B-2. results from experiments on gas entrainment in liquid layer

Exp. ID	Fluid system l/g	Loop Pressure p [Bara]	Liquid density ρ_{LIQ} [kg/m^3]	Dyn. visc liquid μ_{LIQ} [cP][mPas]	Gas density ρ_G [kg/m^3]	Dyn. visc gas μ_G [cP][mPas]	Interfacial tension σ [N/m]	Superficial gas velocity U_{sg} [m/s]	Superficial liquid vel. U_{sl} [m/s]	Flow regime [gas-liquid]	Pressure gradient (dp/dx) [Pa/m]	Liquid Holdup H [-]	Void fraction in liquid layer VIF [-]
IFE0301	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	1.98	0.51	SW	167	0.396	0
IFE0302	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.49	0.50	SW	207	0.338	0
IFE0303	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	3.02	0.50	SW	255	0.313	0.037
IFE0304	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	3.49	0.50	SW	299	0.282	0.05
IFE0305	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.00	0.50	SW	352	0.260	0.066
IFE0306	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.51	0.50	SW_Dg/o	417	0.230	0.074
IFE0307	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	5.01	0.50	SW_Dg/o	480	0.207	0.103
IFE0308	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	5.43	0.50	SW_Dg/o	537	0.185	0.158
IFE0309	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	6.05	0.50	SW_Dg/o&Do/g	622	0.162	0.212
IFE0310	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	7.05	0.50	SW_Dg/o&Do/g	760	0.125	0.34
IFE0315	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.00	1.01	SW	358	0.483	0.011
IFE0316	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.51	1.00	SW	424	0.439	0.025
IFE0317	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.00	1.00	SW_Dg/o	644	0.320	0.1
IFE0318	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	3.02	1.01	SW	495	0.398	0.013
IFE0319	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	3.51	1.00	SW	560	0.366	0.029
IFE0320	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.53	1.00	SW_Dg/o	725	0.279	0.187
IFE0321	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.96	1.00	SW_Dg/o	802	0.252	0.235
IFE0322	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	5.52	1.00	SW_Dg/o&Do/g	894	0.221	0.295
IFE0323	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	5.98	1.00	SW_Dg/o&Do/g	957	0.198	0.344
IFE0324	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	6.94	1.00	SW_Dg/o&Do/g	1093	0.169	0.383
IFE0325	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.00	1.50	SW	567	0.526	0.05
IFE0326	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.50	1.50	SW	659	0.475	0.08
IFE0327	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.99	1.50	SW_Dg/o	756	0.426	0.101
IFE0328	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	3.51	1.50	SW_Dg/o	859	0.378	0.149
IFE0329	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.00	1.50	SW_Dg/o	952	0.335	0.209
IFE0330	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.52	1.50	SW_Dg/o	1050	0.301	0.261
IFE0331	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.94	1.50	SW_Dg/o&Do/g	1121	0.275	0.277
IFE0332	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	5.56	1.50	SW_Dg/o&Do/g	1221	0.247	0.322
IFE0333	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	5.96	1.50	SW_Dg/o&Do/g	1293	0.231	0.334
IFE0334	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	6.97	1.50	SW_Dg/o&Do/g	1459	0.200	0.359
IFE0335	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.02	2.00	SW	882	0.525	0.054
IFE0336	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.49	2.01	SW	990	0.477	0.081
IFE0337	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	2.99	2.00	SW_Dg/o	1102	0.421	0.124
IFE0338	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	3.48	2.01	SW_Dg/o	1220	0.387	0.177
IFE0339	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	3.97	2.00	SW_Dg/o&Do/g	1330	0.353	0.202
IFE0340	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	4.48	1.99	SW_Dg/o&Do/g	1434	0.324	0.233
IFE0341	Marcol/SF6	7.2	848	12	42.3	0.015	0.032	5.06	1.98	SW_Dg/o&Do/g	1550	0.294	0.26

Table B-2. results from experiments on gas entrainment in liquid layer

Exp. ID	Fluid system l/g	Loop Pressure p [Bara]	Liquid density ρ_{LIQ} [kg/m^3]	Dyn. visc liquid μ_{LIQ} [cP][mPas]	Gas density ρ_G [kg/m^3]	Dyn. visc gas μ_G [cP][mPas]	Interfacial tension σ [N/m]	Superficial gas velocity U_{sg} [m/s]	Superficial liquid vel. U_{sl} [m/s]	Flow regime [gas-liquid]	Pressure gradient (dp/dx) [Pa/m]	Liquid Holdup H [-]	Void fraction in liquid layer VIF [-]
IFE0201	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	1.96	0.50	SLW/SL	154	0.418	-
IFE0202	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	2.48	0.50	SLW	190	0.359	-
IFE0203	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.01	0.50	SLW	237	0.327	-
IFE0204	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.51	0.50	SLW	280	0.304	-
IFE0205	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	4.01	0.50	SW	331	0.280	-
IFE0206	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	4.53	0.50	SW	379	0.253	-
IFE0207	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.00	0.50	SW	410	0.247	-
IFE0208	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.45	0.50	SW_Dg/o	444	0.231	-
IFE0209	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	6.04	0.50	SW_Dg/o	506	0.210	-
IFE0210	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	7.01	0.50	SW_Dg/o	616	0.177	-
IFE0211	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	1.48	1.00	SLW/SL	308	0.553	-
IFE0212	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	2.03	1.00	SLW/SL	367	0.482	-
IFE0213	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	2.53	1.00	SLW	423	0.436	-
IFE0214	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.02	1.00	SLW	491	0.410	-
IFE0215	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.51	1.00	SW	545	0.381	-
IFE0216	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.99	1.00	SW	605	0.354	-
IFE0217	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	4.46	1.00	SW	650	0.336	-
IFE0218	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.01	1.00	SW_Dg/o	731	0.298	-
IFE0219	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.55	1.00	SW_Dg/o	818	0.263	-
IFE0220	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	6.00	1.00	SW_Dg/o&Do/g	885	0.238	-
IFE0221	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	6.94	1.00	SW_Dg/o&Do/g	1010	0.201	-
IFE0222	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	0.97	1.50	SLW/SL	460	0.668	-
IFE0223	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	1.53	1.50	SLW/SL	545	0.589	-
IFE0224	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	1.99	1.50	SLW/SL	610	0.537	-
IFE0225	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	2.48	1.50	SLW	688	0.487	-
IFE0226	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.00	1.50	SLW	773	0.449	-
IFE0227	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.54	1.50	SLW	847	0.403	-
IFE0228	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	4.01	1.50	SW_Dg/o	941	0.368	-
IFE0229	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	4.51	1.50	SW_Dg/o	1031	0.332	-
IFE0230	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.02	1.50	SW_Dg/o	1113	0.301	-
IFE0231	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.51	1.50	SW_Dg/o	1201	0.277	-
IFE0232	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	6.04	1.50	SW_Dg/o&Do/g	1288	0.251	-
IFE0233	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	6.98	1.50	SW_Dg/o&Do/g	1426	0.226	-

Table B-2. results from experiments on gas entrainment in liquid layer

Exp. ID	Fluid system l/g	Loop Pressure p [Bara]	Liquid density ρ_{LIQ} [kg/m^3]	Dyn. visc liquid μ_{LIQ} [cP][mPas]	Gas density ρ_G [kg/m^3]	Dyn. visc gas μ_G [cP][mPas]	Interfacial tension σ [N/m]	Superficial gas velocity U_{sg} [m/s]	Superficial liquid vel. U_{sl} [m/s]	Flow regime [gas-liquid]	Pressure gradient (dp/dx) [Pa/m]	Liquid Holdup H [-]	Void fraction in liquid layer VIF [-]
IFE0234	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	1.34	1.98	SLW/SL	776	0.617	-
IFE0235	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	1.54	2.00	SLW/SL	840	0.588	-
IFE0236	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	2.00	2.00	SLW/SL	944	0.543	-
IFE0237	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	2.50	2.01	SLW	1052	0.487	-
IFE0238	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.02	2.00	SLW	1170	0.446	-
IFE0239	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	3.51	2.00	SLW/SL	1267	0.403	-
IFE0240	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	4.00	2.00	SLW/SL	1374	0.368	-
IFE0241	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	4.53	1.99	SLW/SL	1472	0.335	-
IFE0242	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.05	1.98	SW_Dg/o	1569	0.313	-
IFE0243	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	5.61	1.97	SW_Dg/o	1671	0.288	-
IFE0244	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	6.14	1.95	SW_Dg/o&Do/g	1732	0.267	-
IFE0245	Marcol/SF6	4.4	843	12	22.8	0.015	0.032	6.98	1.93	SW_Dg/o&Do/g	1838	0.240	-
IFE0246	Water/SF6	4.4	1000	1	22.8	0.015	0.062	2.00	0.50	SW	118	0.383	-
IFE0247	Water/SF6	4.4	1000	1	22.8	0.015	0.062	2.51	0.50	SW	133	0.340	-
IFE0248	Water/SF6	4.4	1000	1	22.8	0.015	0.062	3.05	0.50	SW	144	0.295	-
IFE0249	Water/SF6	4.4	1000	1	22.8	0.015	0.062	3.52	0.50	SW	177	0.261	-
IFE0250	Water/SF6	4.4	1000	1	22.8	0.015	0.062	4.05	0.50	SW	230	0.247	-
IFE0251	Water/SF6	4.4	1000	1	22.8	0.015	0.062	4.51	0.50	SW_Dg/o	260	0.235	-
IFE0252	Water/SF6	4.4	1000	1	22.8	0.015	0.062	5.02	0.50	SW_Dg/o	294	0.218	-
IFE0253	Water/SF6	4.4	1000	1	22.8	0.015	0.062	5.48	0.50	SW_Dg/o&Do/g	346	0.201	-
IFE0254	Water/SF6	4.4	1000	1	22.8	0.015	0.062	6.11	0.50	SW_Dg/o&Do/g	416	0.192	-
IFE0255	Water/SF6	4.4	1000	1	22.8	0.015	0.062	6.93	0.50	SW_Dg/o&Do/g	503	0.179	-
IFE0256	Water/SF6	4.4	1000	1	22.8	0.015	0.062	3.03	1.00	SLW/SL	360	0.391	-
IFE0257	Water/SF6	4.4	1000	1	22.8	0.015	0.062	3.54	1.00	SLW/SL	414	0.364	-
IFE0258	Water/SF6	4.4	1000	1	22.8	0.015	0.062	3.97	1.00	SLW	447	0.339	-
IFE0259	Water/SF6	4.4	1000	1	22.8	0.015	0.062	4.50	1.00	SLW	513	0.324	-
IFE0260	Water/SF6	4.4	1000	1	22.8	0.015	0.062	5.05	1.00	SW_Dg/o	593	0.288	-
IFE0261	Water/SF6	4.4	1000	1	22.8	0.015	0.062	5.45	1.00	SW_Dg/o	672	0.282	-
IFE0262	Water/SF6	4.4	1000	1	22.8	0.015	0.062	6.06	1.00	SW_Dg/o&Do/g	742	0.266	-
IFE0263	Water/SF6	4.4	1000	1	22.8	0.015	0.062	6.90	1.00	SW_Dg/o&Do/g	896	0.237	-
IFE0264	Water/SF6	4.4	1000	1	22.8	0.015	0.062	2.03	1.50	SLW/SL	499	0.516	-
IFE0265	Water/SF6	4.4	1000	1	22.8	0.015	0.062	3.01	1.50	SLW/SL	617	0.432	-
IFE0266	Water/SF6	4.4	1000	1	22.8	0.015	0.062	4.04	1.50	SW_Dg/o	774	0.371	-
IFE0267	Water/SF6	4.4	1000	1	22.8	0.015	0.062	5.02	1.50	SW_Dg/o	958	0.347	-
IFE0268	Water/SF6	4.4	1000	1	22.8	0.015	0.062	6.00	1.50	SW_Dg/o&Do/g	1172	0.296	-
IFE0269	Water/SF6	4.4	1000	1	22.8	0.015	0.062	7.12	1.50	SW_Dg/o&Do/g	1441	0.239	-

Table B-2. results from experiments on gas entrainment in liquid layer