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DEVELOPMENT OF AN IN-SITU CALIBRATION METHOD FOR MULTIPHASE FLOW METERS USING A RADIOACTIVE TRACER TECHNIQUE

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SUMMARY

A novel technique for in situ calibration of multiphase flow meters is currently being developed at the FORCE Institute.

The method implies injection of a mixture of 3 radioactive tracers each being distributed into one of the 3 phases. From measurements of tracer concentrations by spectral detectors outside the pipe at a downstream position the flows are calculation from the dilution of the injected tracers.

Experiments have been made with tracers in gas, oil and water being present in a static laboratory set-up in various amounts and concentrations. A simulation model for generating supplementary data has been developed and verified. A statistical data treatment method has been applied to estimate tracer concentration from detector measurements with promising results.

The design of a dynamic flow test facility for tracer measurements is presented together with considerations regarding future offshore operation of the calibration method.

1 INTRODUCTION

Multiphase flow meters for measuring mixtures of gas, oil, and water in pipe-lines are rapidly developing and their use in offshore installations increases accordingly. No method has so far been operated for in situ control and calibration of such meters. A development project has been initiated with the aim of providing a method that ultimately can be implemented as a routine calibration method for permanently installed multiphase flowmeters. The method is based on application of radioactive tracers and requires that the phases are separated and arranged according to density difference over the measurement cross section in a horizontal pipe at the measuring point. The method has no inherent limitation of accuracy obtainable, however the target set for initial operations is an uncertainty of ±10% for each phase. The method is intended to be able to control and calibrate both platform and sub sea installed flowmeters.

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2 FLOW MEASUREMENT BY THE USE OF RADIOACTIVE TRACERS

2.1 The concept of tracer

Tracers are often use for studies of flow in various processes. A tracer is a minute amount of matter similar to the bulk material which is added to a flow system without affecting the bulk flow and the concentration of which is measurable. Obtaining information of the tracer flow by measurements provides information about bulk flow properties as illustrated in figure 2.1.1

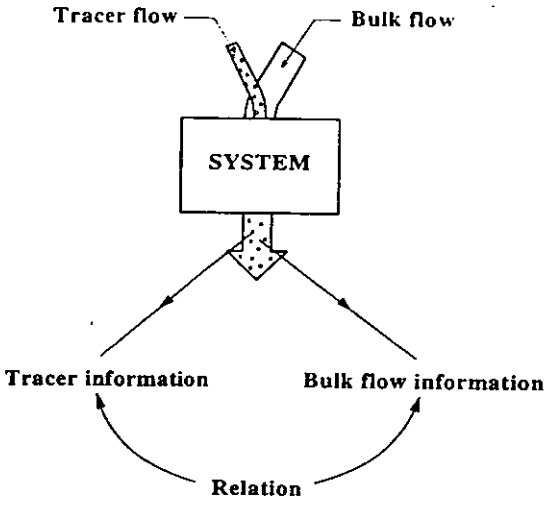

Figure 2.1.1 General principle of tracer methods.

Radioactive tracers show excellent properties as tracers since they are detectable in very low concentrations (i. e. high dilution) and with high specificity. Further γ-emitting radioactive tracers can be measured in situ, through pipe and vessel walls which enables e.g. studies of processes under high pressures, and processes involving a gaseous phase.

2.2 Continuous dilution method for flow measurements

The principle of the continuos dilution method is described in an ISO standard, /1/. The main application of said principle is measurements in open channels and partly filled pipes.

The tracer solution with a concentration of c is injected at a constant rate q into the flow to be measured. At a point downstream, where the tracer is completely mixed with the flow the concentration is measured to c_m. The flow at the injection site Q is thus calculated from a tracer balance (assuming steady state conditions and $q << Q$) as

(1) $$Q = q \cdot c / c_m$$

The accuracy obtained by the single phase continuous dilution method is experienced to be ±1% or better, /2/.

2.3 Simultaneous measurement of three phases using three tracers

For the measurement of more than one flowing phase the same principle can be applied using individual tracers for each phase. Said tracers must be in a form that only distributes into one phase and remains there. Further they must show such differences in the emitting γ-radiation energy spectra that they can be simultaneously detected by on line γ-spectrometry. Preferred candidate tracers for gas, oil and water are listed in table 2.1

Table 2.1 Candidate tracers for water/oil/gas flow measurements.

Phase	Isotope	Half-life	γ radiation of interest (MeV)	Chemical form
Water	^{24}Na	15 hrs	1.37, 2.75	Carbonate salt
	^{140}La	40 hrs	0.33 - 2.54	EDTA-complex
Oil	^{82}Br	36 hrs.	0,55, 1.32	Bromobenzene
Gas	^{85}Kr	10.6 years	0.51	Noble gas

The tracers are injected simultaneously at a constant rate into the flow in the pressurised pipe, and the concentration is detected as series of instantaneous measurements taken downstream after complete mixing. The principle is illustrated in figure 2.3.1.

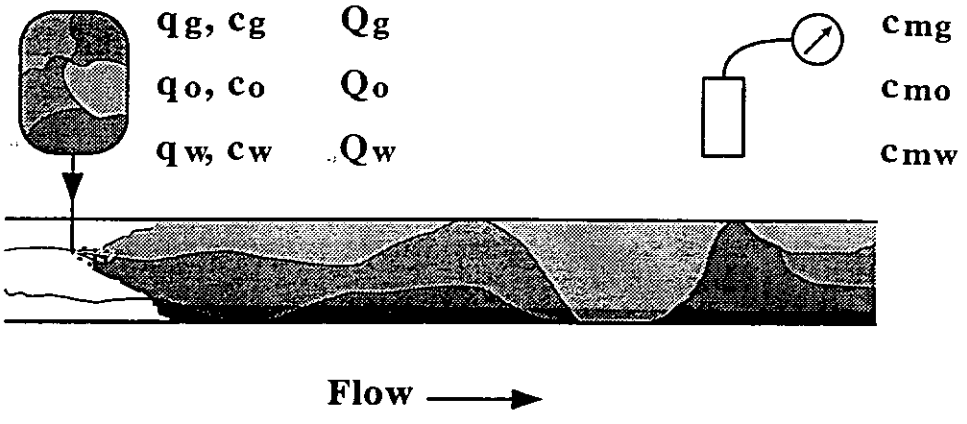

Figure 2.3.1 Principle of 3 phase flow measurements by the continuous dilution tracer method.

The flows at the injection position as functions of time are calculated according to the following equations which are derived correspondingly to equation (1):

(2) $$Q_g(t) = q_g \cdot c_g / c_{mg}(t)$$

(3) $$Q_o(t) = q_o \cdot c_o / c_{mo}(t)$$

(4) $$Q_w(t) = q_w \cdot c_w / c_{mw}(t)$$

The average flow of a given phase is calculated from a number, n, of discrete measurements as:

(5) $$\bar{Q}_p = \Sigma Q_p(t)/n$$

These basic equations are valid under certain assumptions about the flow, such as limited axial dispersion along the pipe in relation to the variations in flow rate during measurements. We assume that these conditions are fulfilled to a satisfactory degree.

3 DETERMINATION OF TRACER CONCENTRATIONS

In situ measurement of the concentration of radioactive tracers in the different phases requires that the phases are separated and arranged according to density difference over the measurement cross section in a horizontal pipe. At the measuring point the tracer method thus covers stratified flow, wavy flow, and slug flow, whereas bubble flow and annular flow can not be measured. The potential appearance of said flow regimes, however, can be observed from the current measurements.

3.1 Gammaspectrometric measurements with 2 detectors

In general, the measurements are performed with two spectral γ-detectors placed on top and bottom of the pipe respectively. The detectors are high sensitive 6x3" Sodium Iodide scintillation detectors with build-in or external multi channel spectrum analyser.

The measurement set-up is outlined in figure 3.1.1

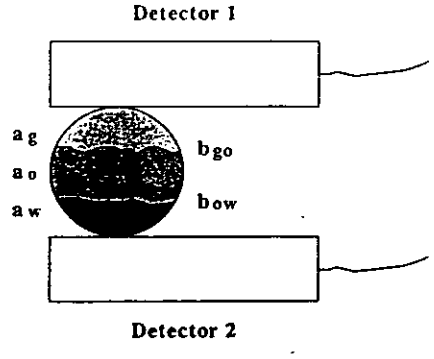

Figure 3.1.1: Detector set-up for tracer measurement in 3 phases.

In the case, where all 3 phases are present, the detector measurements reveal the amounts of tracers in each phase as seen over a unit length of the pipe by the detectors (a_g, a_o, and a_w) and the position of the boundaries between the phases (b_{go} and b_{ow}). The cross section area of each phase is calculated from the latter the inner radius (r) of the pipe using trigonometric formulas. From this the tracer concentrations (c_{mg}, c_{mo}, and c_{mw}) and hence the volume flows of the 3 phases are calculated.

The 3 cases of only two phases being present can be identified from the measurements and similar models for calculation of the concentration have been established. Also the 3 cases of

only one phase being present at a given time (slug flow) can be identified and the concentration calculation from the measurements in these 3 cases is simple.

3.2 Data generation from static laboratory experiments and model simulation

Measurements have been made in a laboratory set-up . The test pipe was made of plexiglass for visual inspection with the dimensions of ∅ 110 mm x 500 mm. Steel plates were inserted between the pipe and the detectors to simulate the steel walls of real pipe. The test pipe could be filled with the 3 phases in any combination of amounts and tracer concentrations. The measurement program with the top and bottom detectors comprises a total of 24 combinations of the 5 key parameters a_g, a_o, a_w, b_{go}, and b_{ow}.

The variability in combinations of the key parameters is very large and the relations between the spectral radiation measurements with the top and bottom detectors and the 5 parameters is by no means simple. An optimal parameter estimation obviously calls for the use of advanced statistical data treatment which in turn requires a considerable amount of data. In order to generate the necessary amount of data modelling was used for simulating detector responses from a given physical geometry.

The model is a Monte Carlo Gamma Simulation model. In a specified, spatial arrangement of detectors, matter of a given density and composition and isotope sources, the MGS model computes the spectral response of said detectors. The MGS model was proven in various contexts including validation on data from the measuring program described above.

Figure 3.2.1 shows a simulation result for ^{82}Br in oil. The identity is sufficient for the purpose at present, but the MGS model is currently being improved.

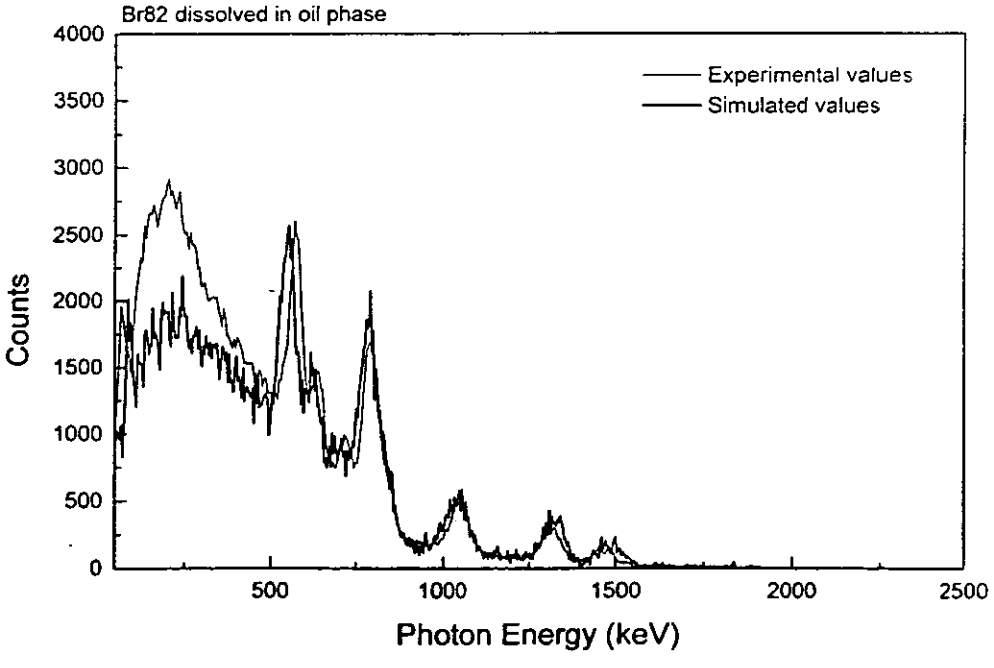

Figure 3.2.1 Measured and simulated γ-spectrum for ^{82}Br in oil.

3.3 Data transformation

Each measurement consists of two 1024 channel γ spectra (D_1 and D_2). The spectrum of ^{24}Na (water), ^{82}Br (oil), and ^{85}Kr (gas) is shown on the same diagram in figure 3.3.1., where the typical peaks of the different isotopes are seen. The measured spectra from the 3 tracers together will be a superimposition of such spectra upon each other with the relative intensity of contribution from each isotope depending on the amount of said isotope. Further the response depend on the distance from the isotope to the detector. The top detector will thus get relatively more response from the gas tracer than the bottom one, and vice versa for the water tracer.

To handle the estimation of the 5 key parameters it is necessary to use *data reduction operations* and to determine the optimal *transfer function* between input data and output parameters.

First D_1 and D_2 are reduced into a number (15) of properly selected windows giving the detector responses (v_{11}, v_{12},.., v_{1i},..v_{115}) and (v_{21}, v_{22},.., v_{2i},..v_{215}). The selection of windows is shown on figure 3.3.1.

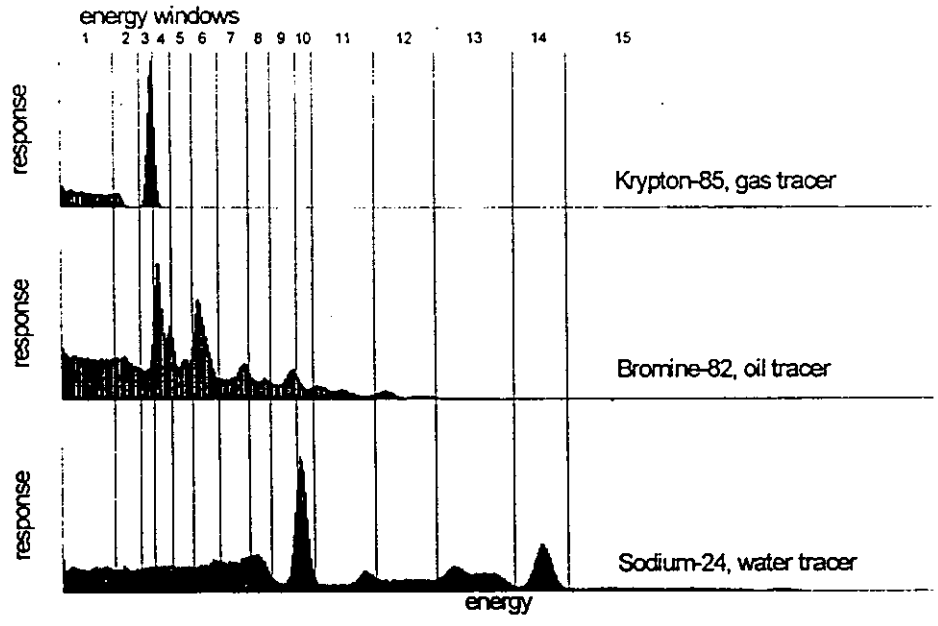

Figure 3.3.1: Spectra of isotope tracers and selection of observation windows.

The data are transformed into the data sets $s_i = v_{1i}+v_{2i}$ which is related to the amount of tracer and $r_i = \ln(v_{1i}/v_{2i})$ which relates to the tracer location.

For the given set-up of pipe and detectors a transfer function is determined for statistically optimal estimation of the 5 key parameter from the reduced data sets. The mathematical/statistical analysis is based on orthogonalisation of window response variance.

Measured data from the static test set-up and data generated by MGS simulation hereof are used for trial calculations. The presented data reduction operations and the determined data

transfer function on these data have shown that it is feasible to determine the 5 key parameters a_g, a_o, a_w, b_{go} and b_{ow} from measurements with γ-spectrometric detector on top and bottom of the flow media pipe.

The accuracy of the estimation method is illustrated in figure 3.3.2. This shows the error distribution for each parameter, the size of which has been normalised to 1.0. It also gives the relative standard deviations for the parameter estimates. It is seen that the best estimate is of the parameter a_w, representing the water tracer, whereas the gas/oil boundary, b_{go} is the most difficult to estimate.

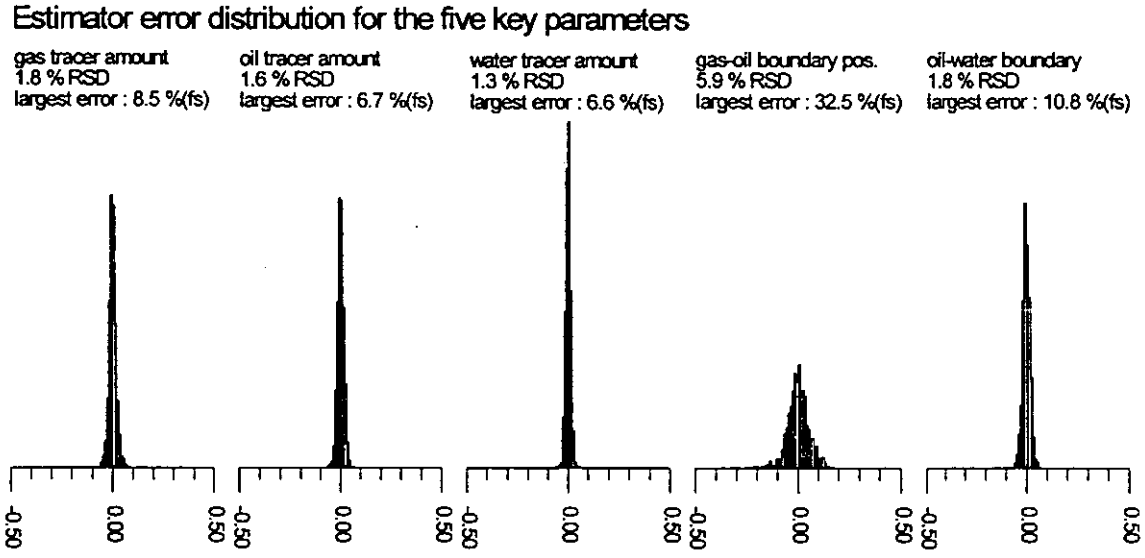

Figure 3.3.2: Error distribution and relative standard deviation for parameter estimates

Even though the estimation method may be refined these results clearly demonstrate that it is possible to determine the key parameter for flow calculation with promising accuracy by the methods proposed.

4 DESIGN OF A DYNAMIC FLOW TEST FACILITY FOR TRACER MEASUREMENTS

After having proved the principles of using 3 tracers for 3 components in a static test rig, a dynamic test facility has been designed. In this facility it will be possible to inject 3 tracers in a flowing liquid consisting of air, oil and water. By changing the relative amounts of the different components it will be possible to explore the phase diagram and asses the limits for the measurement principle. A sketch of the facility is shown in figure 4.1.

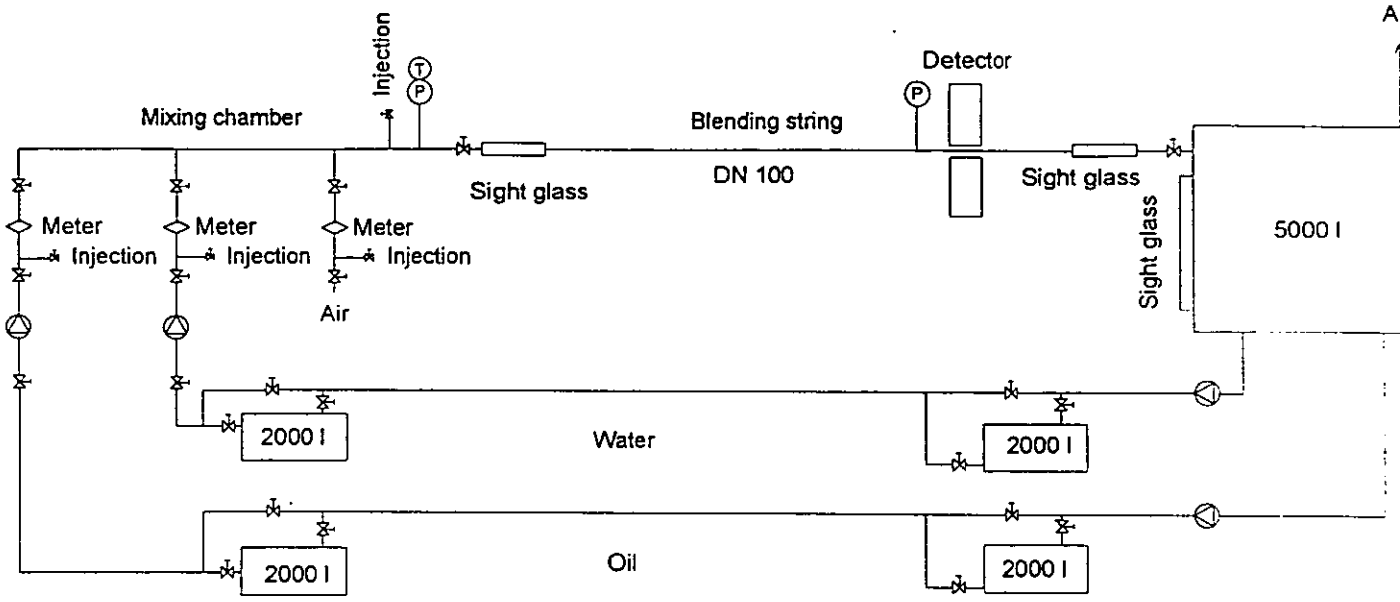

Figure 4.1: Dynamic test facility for 3 phase flow

The facility consists of five tanks, two each for oil and water and one tank for separation. For each liquid there is one tank for fresh fluid, and one tank for used fluid. In the last tanks, the tracer activity will decrease to insignificant level, i.e. a level which will not disturb the measurement, when the liquid is used again. The flow through the measurement string is controlled by variable frequency pumps. The air is supplied by a compressor. The test rig is prepared for recirculating flow, which can be used when we have gained experience with the test facility and with the measurement principle.

The tracers are injected after the mixing chamber, but it will possible to inject tracers in individual components. The detector is placed at the end of the blending string.

The flow rates of the individual components is measured by meters, which have been calibrated at the institutes laboratories.

5 IN-SITU MEASUREMENT SCENARIO

When validated in the dynamic test set-up the method should be implemented for in situ use.

Most of the required measurement equipment is already available as a result of the present project. Equipment for injection of tracers into pressurised pipes is constructed based on experience with existing equipment for injection of liquid and gas respectively.

The initial step in a calibration operation will be to examine the possibilities for *injection* and *detection* of tracers. An outline of the desired set-up is shown in figure 5.1.

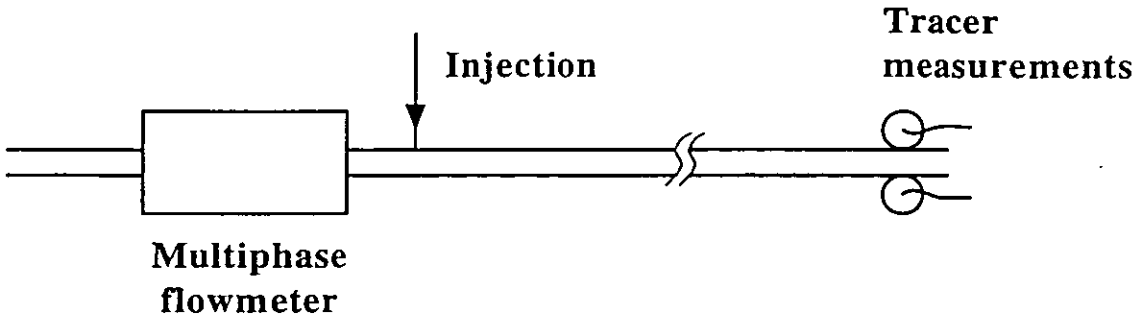

Figure 5.1: Set-up for in situ control and calibration

Since the method gives the flow at the injection position the injection should preferable be close to the multiphase flow meter to be calibrated. The use of radioactive tracers will disturb such multiphase flow meters using any nucleonic gauges, so injection down stream is preferred, but intermittent injection and meter reading is an alternative. It seems most feasible to inject from a platform being manned during the injection. In cases where the multiphase flowmeter is a sub sea device injection could be performed by the use of some form of ROV technology, possibly supplied with tracer through flexible pipes from a platform or a vessel.

The required distance to obtain sufficient mixing and to assure only minor gradients in the tracer concentration along the length of the pipe depends on the actual flow regimes in the pipe from the injection point downstream to the measuring point. When intensive mixing occurs the distance may be small, but if flow with long lasting slugs is dominant the optimal distance may be several kilometres.

At the detection position the flow should be in a horizontal pipe and in a flow regime where the phases are arranged according to their densities as mentioned earlier. Measurements should be performed on a platform or vessel providing power supply etc.

In order to utilise detector data as tracer concentrations for flow measurements it is necessary to establish the optimal data transfer function for each individual detector installation. The MGS model is run with actual pipe dimensions and materials and detector positions for generation of sufficient amount of measurement data from which the data transfer function is determined.

When the practical tasks are solved in accordance with considerations stated the method will operational.

6 CONCLUSION

It has been showed by experiments in a static laboratory set-up and using model simulation and statistical parameter estimation, that it is possible to measure tracer concentrations in a 3 phase gas, oil, water system where the phases are arranged according to their densities with promising accuracies.

The experimental and computational tools developed have provided valuable experience for the design of a dynamic test rig and for the conduction experiments herein.

7 REFERENCES

/1/ International Standard ISO555/3. Liquid flow measurements in open channels - Dilution methods for measurement of steady flow - Part 3: Constant rate injection method and integration method using radioactive tracers. 1982. 08.9

/2/ IAEA, Guidebook on Radioisotope Tracers in Industry, Technical Report Series No. 316, Vienna ,1990