

ONLINE MEASUREMENTS OF LIQUID CARRY-OVER FROM SCRUBBERS USING RADIOACTIVE TRACERS

Are Haugan

Institute for Energy Technology, Kjeller, Norway

Sindre Hassfjell

Institute for Energy Technology, Kjeller, Norway

Anne Finborud

Mator, Porsgrunn, Norway

Abstract: A method to measure liquid carry-over from scrubbers using gamma-emitting tracers is described and results from field tests at two onshore installations are presented. One water/1,2-ethanediol (MEG) and two hydrocarbon liquid (condensate) tracers have been used in the tests. One of the condensate tracers deposited to some extent inside the process pipe, while the other had a too high vapour pressure. The water/MEG tracer showed no MEG carry-over while the carry-over of MEG was documented to be considerable.

1. INTRODUCTION

The objective of this paper is to present a method to measure liquid carry-over from scrubbers by the use of gamma-emitting tracers, and to present results from field tests at two onshore installations.

Scrubbers are vertical separators used to separate liquid from gas at high pressure (typically 50-80 bar). The volume is typically 5-50 m³ and the liquid fraction is normally less than 1 % (v/v). In a scrubber, liquid is separated from the gas by use of gravity and centrifugal forces. Within the scrubber there are different types of demisting arrangements to improve liquid droplets coalescence and gas-liquid separation. In scrubbers there may be two liquid phases to be separated from the gas: a hydrocarbon liquid phase (condensate) and a water/1,2-ethanediol (MEG) phase.

Liquid carry-over from scrubbers may cause operational problems downstream of the scrubbers. Compressors and other liquid intolerant equipment will be upset, leading to process interruption or shut down. In gas processing systems, high separation efficiency is crucial to be able to meet the product specifications. Hence, liquid carry-over is very costly for the gas processing industry and robust techniques are required to verify liquid carry-over. The methods have to quantify liquid carry-over very accurately.

Liquid carry-over from scrubbers can be measured with the following three methods: liquid accumulation tests, gas chromatography in combination with hydrocarbon dew point analysis, and online measurements using radioactive tracer

A liquid accumulation test is easy and inexpensive. A disadvantage is that it may have poor reproducibility. The accuracy of the results is depending on PVT calculations based on an updated feed composition. The configuration of separator internals can interfere with the test results and may result in incorrect quantities of liquid.

Use of gas analysis to quantify hydrocarbon liquid carry-over is generally more accurate than liquid accumulation tests. By this method the compositions are updated and the efficiency may be established in combination with liquid accumulation tests. This method is depending on representative gas samples. Sampling in two-phase regimes requires isokinetic sampling, and representative samples may be hard to obtain.

We have tested the third method, online measurements using radioactive tracers, at two onshore installations. One of these installations has several scrubbers where the liquid carry-

over is well documented through thoroughly testing, and was therefore a suitable installation for our tests. One water/MEG and two condensate tracers have been used in the tests.

2. METHOD

Passive gamma-emitting liquid tracers are used to measure liquid carry-over from scrubbers. The tracer is injected as a pulse upstream of the scrubber, and is detected at the inlet and the gas outlet of the scrubber by collimated detectors mounted on the outside of the pipeline (see Fig. 1). The liquid carry-over is given by the ratio of the integral of the tracer response curves at the gas outlet and the inlet. The tracer needs to be homogeneously mixed with the process fluid within the pipeline upstream of the scrubber, or be completely representative for the process fluid (droplet size distribution and surface tension are important parameters). It is imperative that the tracer stays in the liquid phase, either the condensate or the water/MEG phase. It must passively follow the liquid flow and not evaporate into the gas phase or deposit inside the pipeline or scrubber.

The detectors must be intercalibrated. It is an advantage if the distance between the detectors and the pipe is identical for all detectors, and if the dimensions of the pipe (diameter and thickness of the wall) are identical at all positions where detectors are placed. Further, the tracer velocity and distribution should be identical at the inlet and the gas outlet. If one or more of these conditions are not fulfilled, corrections have to be made.

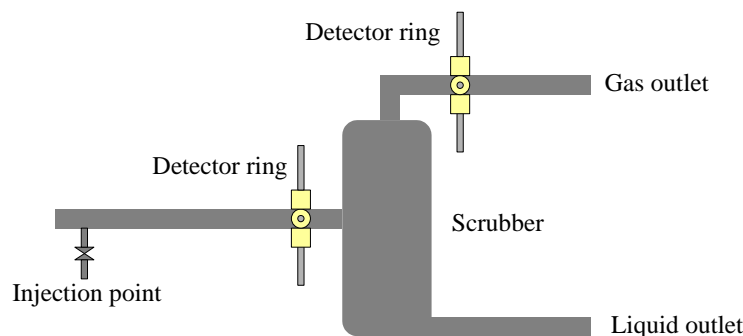


Fig.1. A sketch of the setup.

3. EXPERIMENTAL SETUPS

Four scrubbers, named A, B, C and D in the present paper, have been used in the tests. Liquid carry-over of condensate and water/MEG from the scrubbers B, C and D is well documented through thoroughly testing with different methods.

Scrubber A had a temperature of $-14\text{ }^{\circ}\text{C}$. The pipeline upstream of the scrubber has an inner diameter of 55 cm, and the injection point was 76 m upstream of the scrubber. Three $2''\times 2''$ NaI(Tl) detectors were used to detect the tracer along the gas line. The insulation was removed and the detectors placed below the pipeline. The first detector was placed 16 m downstream of the injection point, the second detector was placed at the scrubber inlet, and the third detector was placed at the gas outlet of the scrubber. The two detectors upstream of the scrubber were used to measure the tracer velocity, using the first moment of the response curves to define the point of times when the tracer passed the detectors.

Scrubber B had a temperature of $9\text{ }^{\circ}\text{C}$. The pipeline upstream of the scrubber has an inner diameter 70 cm, and the injection point was approximately 10 m upstream of the scrubber. A ring of four collimated $2''\times 2''$ NaI(Tl) detectors was mounted both at the inlet

and the gas outlet of the scrubber. The system was not insulated and the detectors were mounted directly on the pipeline.

Scrubber C had a temperature of $-7\text{ }^{\circ}\text{C}$. The pipeline upstream of the scrubber has an inner diameter of 70 cm, and the injection point was approximately 50 m upstream of the scrubber. A ring of collimated $2''\times 2''$ NaI(Tl) detectors was placed both at the inlet and the gas outlet of the scrubber, four detectors at the inlet and three detectors at the outlet. The insulation was removed and the detectors were mounted directly on the pipeline.

Scrubber D had a temperature of $-22\text{ }^{\circ}\text{C}$. The pipeline upstream of the scrubber has an inner diameter of 84 cm, and the injection point was approximately 50 m upstream of the scrubber. A ring of four collimated $2''\times 2''$ NaI(Tl) detectors was placed outside the 10 cm thick insulation both at the inlet and the gas outlet of the scrubber.

4. RESULTS

4.1. $[^{82}\text{Br}]1,3,5$ -tribromobenzene as condensate tracer

$[^{82}\text{Br}]1,3,5$ -tribromobenzene was used as tracer to measure condensate carry-over from scrubber A at different gas velocities. The tracer was produced by neutron activation of 1,3,5-tribromobenzene at IFE's research reactor at Kjeller, Norway. $[^{82}\text{Br}]1,3,5$ -tribromobenzene is a solid, and was dissolved in 10 ml toluene before it was pumped into the pipeline with condensate taken from the process.

Five tracer injections with 0.5 GBq were performed. The measurements were repeatable, but the tracer response curves showed an increasing background during the time the tracer passed the detector. This is illustrated in Fig. 2, showing the tracer response curves used to calculate the carry-over from the last injection. This was corrected for by assuming a linear increasing background. However, it shows that a fraction of the tracer deposited inside the pipeline, leading to an underestimation of the carry-over. Thus, only a lower limit of the liquid carry-over was obtained.

The cause for such deposit is not quite evident. However, two possible explanations have been proposed: the heavy $[^{82}\text{Br}]1,3,5$ -tribromobenzene molecules settle on a film of heavy components on the wall inside the pipe, or some $[^{82}\text{Br}]1,3,5$ -tribromobenzene molecules are destroyed during neutron activation (Szilard-Chalmers process [1]) resulting in ^{82}Br containing compounds which adsorbs to the wall of the pipeline.

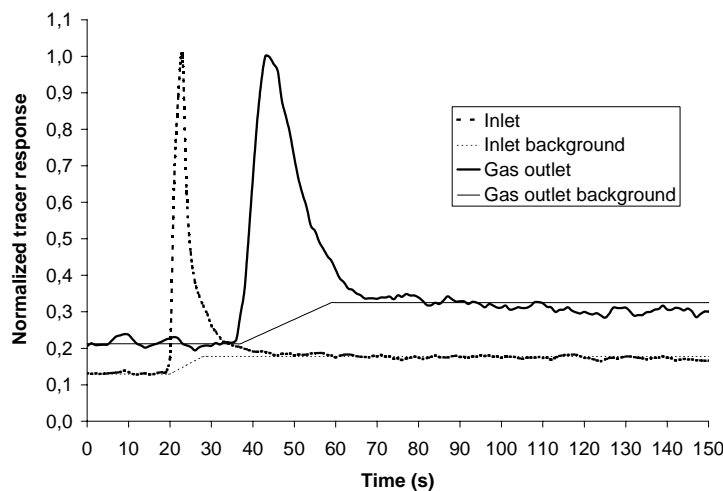


Fig. 2. Normalized tracer response curves from the last injection of $[^{82}\text{Br}]1,3,5$ -tribromobenzene into scrubber A.

The liquid residence time equalled the gas residence time in the pipeline upstream of the scrubber for the two highest flow velocities (see Table 1), indicating that the liquid moved as small droplets in the gas phase. However, for the lowest flow velocity the liquid residence time was considerable higher than the gas residence time, indicating that the condensate moved as large droplets or as a continuous phase. This was confirmed with the second detector placed in a bend, resulting in tracer response's strongly dependant on the flow regime due to centrifugal forces. The tracer response was much higher in the first injection than the others, even though the velocity was lower. The consequence of such a flow regime may be an underestimation of the carry-over because large droplets and a continuous liquid phase is easier separated than small droplets, leading to higher tracer velocity at the gas outlet than at the inlet of the scrubber.

Table 1. Residence times in the pipe upstream scrubber A at different gas velocities.

Injection number	Gas velocity	Gas residence time between the first and second detector	Liquid residence time between the first and second detector
1	0.94 m ³ /s	18 s	23 s
2	1.23 m ³ /s	14 s	14.5 s
3	1.23 m ³ /s	14 s	14 s
4	1.43 m ³ /s	12 s	12 s
5	1.43 m ³ /s	12 s	12 s

4.2. [¹³¹I]iodobenzene as condensate tracer

[¹³¹I]iodobenzene was used as tracer to measure condensate carry-over from the scrubbers C and D. 100 GBq ¹³¹I as iodide in NaOH solution was added 2.5 mmol NaI and 1.0 mmol Na₂S₂O₃. [¹³¹I]iodobenzene was then synthesized through decomposition of a diazonium ion equivalent intermediate in aceton/water containing 70 GBq of the [¹³¹I]iodide. After product extraction with diethylether, NaCl/Carbonate wash, and evaporation of the ether, the product was diluted with 50 ml chlorobenzene to a 2 % (v/v) tracer solution, and dispensed in 10 ml portions into 20 ml vials. The 10 ml tracer solution was pumped into the pipeline with condensate taken from the process.

Three condensate tracer injections with 2-4 GBq were performed on scrubber C and two condensate tracer injections with 4-5 GBq were performed on scrubber D. Fig. 3 shows the tracer response curves from scrubber C after the first injection.

The measurements were repeatable, but the tracer method overestimated the carry-over significantly. Subsequent investigations showed the cause to be evaporation of tracer into the gas phase. Simplified calculations prior to the tests using the equation of state for an ideal gas, tabulated vapour pressures for iodobenzene [3] and the Clausius-Clapeyron equation [2], concluded that evaporation could be neglected. However, more realistic simulations using PVTsim [4] and HYSYS [5] showed that a large amount of the tracer evaporates at the given process conditions. The evaporation estimated with PVTsim and HYSYS did not fully account for the deviation between the measured carry-over and the documented carry-over. However, such simulations are connected with large uncertainties, especially with respect to the selection of equation of state as they can be very inaccurate, particularly when used in simulations of trace elements as in this case. Evaporation has, based on this, been concluded to be the cause to the given deviation.

It is impossible to obtain acceptable accuracy using a tracer with non-neglecting evaporation. However, simulations with PVTsim have shown that alternative condensate

tracer candidates have neglectable evaporation at the given conditions, i.e. are suitable for future test work.

The pipelines upstream and downstream the scrubbers C and D are insulated due to low temperature. In order to verify whether it was necessary to remove the insulation to improve the detection limit (shorter distance between the detector and the pipe) and the accuracy in measured carry-over (easier to control the distance between the detectors and the pipe), a Monte Carlo simulation with ECRIN2 was performed [6]. Insulation thickness at each detector position on scrubber D was used as input. The results showed that the effect of the insulation on the accuracy was neglectable, while the detection limit would have been reduced by 9 % if the insulation had been removed.

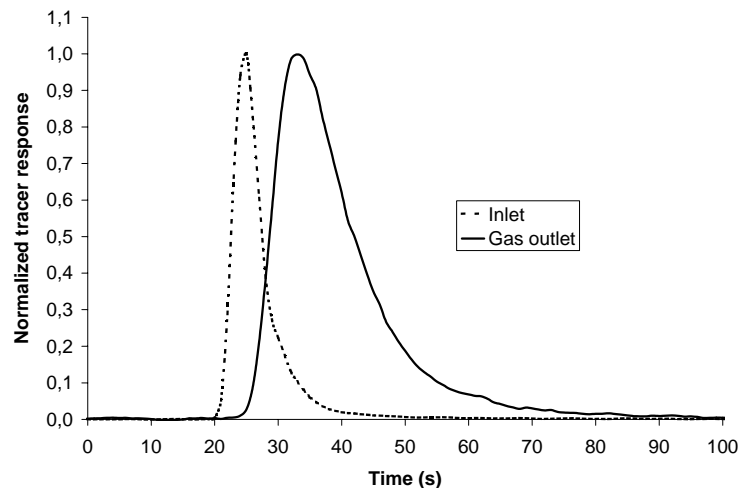


Fig. 3. Normalized tracer response curves from the first condensate injection in scrubber C.

4.3. ^{131}I iodide as MEG tracer

^{131}I iodide was used as water/MEG tracer. 30 GBq of the ^{131}I iodide solution described in Section 4.2 was diluted to 50 ml with a 5 % (v/v) water in MEG solution, and dispensed in 10 ml portions into 20 ml vials. The 10 ml tracer solution was pumped into the pipeline with water/MEG taken from the process.

Two injections with 2 GBq were performed on scrubber B and one injection with 2 GBq was performed on scrubber C. No carry-over was measured, even though the carry over was documented to be considerable.

This deviation has not yet been explained. However, two possible explanation have been proposed: the tracer settles out as particles due to low solubility in small droplets or the droplets of the injected fluid are larger than the process fluid.

The solubility of the tracer in the water/MEG is high. This has been verified with water/MEG from the process. However, the solubility decreases with the droplet size [7]. When the droplets become very small, the solubility may become so low that the tracer settle out as particles and thus are easily separated.

If the injected fluid does not mix properly with the process fluid and the droplet size distribution differs from the droplet size distribution of the process fluid, erroneous results may be the consequence. If the droplets of the injected fluid are too large they are easily separated, if they are too small the tracer may settle out as particles due to reduced solubility.

5. DISCUSSION AND CONCLUSIONS

None of the tracers included in the presented tests gave acceptable results. [^{82}Br]1,3,5-tribromobenzene deposited to some extent inside the pipeline, [^{131}I]iodobenzene overestimated the carry-over due to high vapour pressure, and [^{131}I]iodide indicated no carry-over while the carry-over was documented to be considerable. However, the tests have shown that the method is fully acceptable if suitable tracers are available. The carry-over measurements were repeatable and the counting statistics were very good. The detection limit is dependant on the counting statistics, and in the presented tests the detection limit for carry-over of tracer was typically 1 %. The uncertainties in the measured tracer carry-over have been estimated to vary between 4 and 14 %. These estimations are based on counting statistics, repeatability of the experiments, accuracy of the distance between the detectors and the pipe, accuracy of the thickness of the pipe wall, and information on skewed tracer distribution inside the pipe obtained by the different detectors in a detector ring.

The tracer should be as representative as possible for the liquid it is going to trace. It is therefore recommended to dissolve and inject the tracer with the same liquid, taken from the process, as it is going to trace. Use of a jet to control the droplet size of the injected tracer and simulation to check the degree of tracer evaporation should be considered.

The detectors should be placed on straight pipelines to avoid skewed liquid distributions, and a ring of detectors should be used both at the inlet and gas outlet to verify whether the liquid distribution is skewed or not. Valuable information on the flow conditions is obtained by measuring the tracer velocity inside the pipeline. It is not necessary to remove the insulation from the pipeline, neither due to accuracy nor due to detection limit. However, the thickness of the insulation should be measured at each detector position to confirm this in each case.

With suitable tracers this method has the potential to become a powerful tool for liquid carry-over measurements from scrubbers.

Acknowledgements

We thank Lars Henrik Gjertsen and Nichlas Marheim from Statoil for practical help and discussions of the results. Statoil is acknowledged for the permission to publish these data.

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