IFE Gas Tracer Technology

1 Brief introduction to Institute for Energy Technology (IFE), Norway

IFE was established in 1948 as an independent research foundation. The main activity during the first 20 years was the construction of two nuclear reactors for research purposes only. These reactors have later been upgraded and they still serve as one of IFE's main research instruments. Along with basic nuclear physics research, several other topics have grown to be important for IFE:

- Fluid flow mechanics
- Corrosion engineering
- Materials technology
- Process simulation
- Reservoir and exploration technology
- Energy systems

where the first four topics originally were derived from running of the nuclear reactors.

IFE later on developed numeric methods for better design of two- and three-phase flow transport systems for hydrocarbons, a technology of immense importance for the oil industry.

IFE is organised into 5 sectors where one is the Sector for Petroleum Technology. This sector is again divided into 3 Departments. One of these departments is "Reservoir and Exploration Technology".

The Department of Reservoir and Exploration Technology is again divided into 4 Sections:

- Geophysics
- Reservoir modelling
- Tracer technology
- Tracer analysis

The Section for Tracer technology has during the last 10 to 15 years developed today's industrial standards for reservoir tracer technology, and several of the major oil companies recognise IFE's tracer technology to be world leading. IFE has top qualified personnel to inject and analyse radioactive and non-radioactive water and gas tracers. IFE has state-of-the-art analytical equipment and the lowest detection limits for most tracer compounds.

IFE is perhaps the only company that continuously develops tracers for reservoir applications.

IFE is involved in tracer technology both for industry and environmental studies. In oil industry the main focus has been on interwell tracer tests. IFE, however, also applies tracers in single well operations, process equipment studies and general flow studies.

Presented below are general information related to interwell tracer technology. The topics addressed are:

- Types of tracers
- Analysis
- Temperature stability
- Calculation of tracer amounts
- Health, environment and safety.
- Injection of tracers
- Sampling of traced gas
- Evaluation of results from tracer test
- Performance of work

2 Gas tracers for interwell examinations

The most ideal gas tracer for methane is tritiated methane. Tritium is radioactive, but the emitted particles have very low energy and virtually no penetration power. The performance/cost ratio of tritiated methane is very good.

IFE has through the last 10 years significantly improved the use of chemical gas tracers. Perfluorinated carbons, PFCs, which are non-radioactive, have shown to be excellent tracers. The PFCs, which are most common as gas tracers for reservoir applications are perfluoro-dimethyl-cyclobutane (PDMCB), perfluoro-methyl-cyclopentane (PMCP) perfluoro-methyl-cyclohexane (PMCH) and several of the isomers of perfluoro-di-methyl-cyclohexane (PDMCH)

A good gas tracer for reservoir gas must behave similar to the gas components with the highest concentrations, normally methane and ethane. Like all hydrocarbons the PFCs will have a partitioning between gas and oil. For the most frequently applied PFC tracers the partitioning to the oil phase is in the same order as that of methane and ethane.

During the tracer development and qualification phase IFE has carried out numerous batch experiments aimed at measuring the degree of gas/oil partitioning expressed by the partition coefficient $D = C_{Tr,\ oil}/C_{Tr,\ gas}$ for the perfluorinated gas tracers at different pressures and temperatures.

All the PFC gas tracers resist temperatures of up to at least 400 ^{o}C.

In field examination, typical amounts for injection per well of the non-radioactive PFC-tracers using the CATS sampling technology (see next chapter) is 1 to 10 kg.

3 Gas Tracer Analysis

Tritiated hydrocarbon gases are analysed by combustion and LSC counting of the produced water. Detection limit is, like for tritiated water HTO, limited by the background of tritium in nature.

Chemical gas tracers are analysed using GC/MS (Gas Chromatography/Mass Spectroscopy) or GC/ECD (Electron Capture Detector). GC/ECD is very sensitive, offering detection limits of $\sim 1 \bullet 10^{-11}$ litres/litre for the lighter PFCs and $\sim 1 \bullet 10^{-12}$ litres/litre for SF_6. GC/MS allows detection of PFCs in sub $1 \bullet 10^{-12}$ litres/litre amounts. IFE offers analysis on GC/MS using the Capillary Absorption Tube System (CATS), which removes the need of shipping gas samples in pressurised cylinders. A Capillary Absorption Tube (CAT) is a small, lightweight, non-pressurised and non-flammable tube filled with an absorption material, which absorbs PFCs.

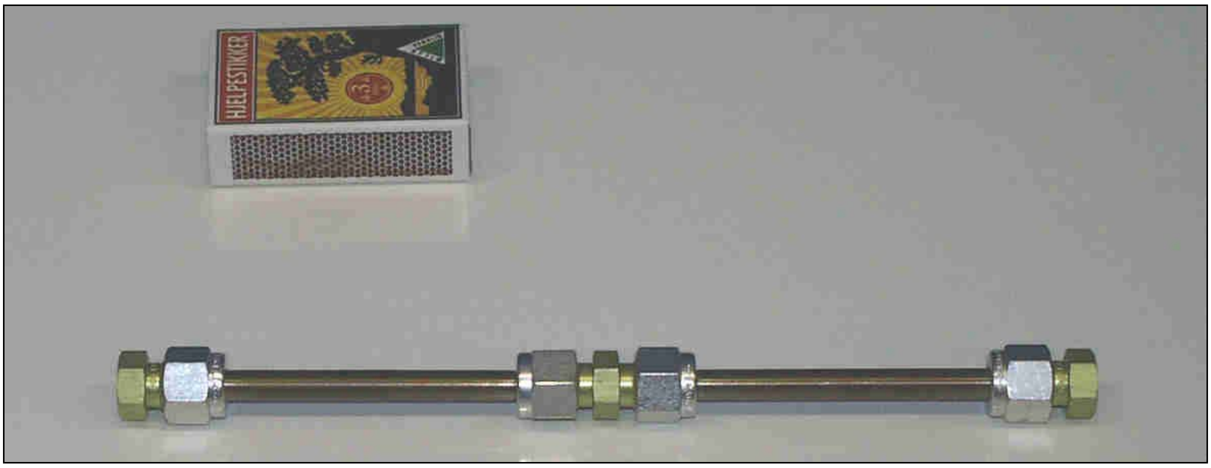

Figure 1. CAT with matchbox as reference scale.

4 Calculation of tracer amount

Several factors are important when performing an analytical calculation of the amount of tracer needed for a successful tracer field examination. First of all, the objectives with the tracer test have to be defined. Normally, the amount of tracer to be injected is designed to give a concentration in the top of the production profile that is 100 X the lower limit of detection. If the test is aiming at covering several injection and production wells, the expected dilution volume to the most remote well will be decisive for the amount to be injected. If it is satisfactory to simply get an answer on whether there is fluid communication or not, the needed amount of tracer is less than if a full tracer production curve is wanted. If a full tracer production curve is obtained a lot more information can be extracted from the test.

To perform a calculation of tracer amount the following data are needed:

- Dilution volume (height of zone, distance from injector to producer)
- Flow regimes (patterns, preferred flow directions, fractures, earlier experience)
- Temperature and pressure
- Fluid saturation and matrix porosity
- Detection limit of the tracer

Normally, there will be uncertainties in estimated dilution volumes because of uncertain reservoir description. The calculated amount of needed tracers normally contains a safety factor. Due to the latest years' improvements in detection techniques and corresponding lowering of detection limits, the amount of tracer needed is reduced. This implies that the cost of the tracer itself, in most cases, is relatively low and constitute only a minor part of the total cost of the tracer test. If, however, really large volumes are considered, the cost of the tracer may be the major factor in the cost of the tracer test. In such cases there is potential for reducing the total costs by reducing the safety factor. This evaluation has to be based on a discussion between the Company and IFE.

5 Health, environment and safety

IFE provides background documentation and data sheets for the actual tracers.

Normally the local authorities demand applications sent by the operating Oil Company for the use of chemicals and radioactive material. IFE will assist in preparing such applications. On the Norwegian sector IFE has a general license to apply radioactive material.

6 Injection of tracers

Since the PFC tracers are liquids at normal temperatue and pressure (NTP), they are easily injected using a pneumatically driven pump, which delivers about 200 ml/minute of PFC-tracer at pressures up to 800 bars. No pressurized gas containers are needed. The pump is complete with tracer reservoir, injection line (1/8" steel tubing) and a one-way valve (check-valve).

The injection equipment is operated by “instrument air” at a pressure of 7 bar.
The following items are needed to perform gas tracer injection:

- Tracer injection pump with injection tubing (1/8” steel tubing)
- Tracer(s)
- N-hexane for post-wash of equipment after tracer injection

IFE provides all items for performance of the work except the “instrument air” at 7-10 bar pressure (plant air) for the pneumatically operated pump. If tracer injection is performed at a platform, compressed air is normally present at the site.
Therefore, several gas tracer injections may be performed in the course of one day.

The needed amount of gas tracer is small. 1 kg is generally enough to cover a dilution volume of 10^{11} std litres (= 2,77 billion scf) of free gas at NTP. Some reservoir parameters like temperature, pressure, saturation pressure, well patterns, dilution from other wells etc must be taken into account when making a closer estimate on the tracer amount to be injected.

Shipment of tracers and equipment is always invoiced according the original receipts, as are local customs and VAT.

7 Collection of tracer samples

Sampling of produced gas can be done in the above-mentioned CATs or in pressure cylinders. IFE has designed a CAT-sampling-kit to ensure a reproducible sampling procedure. Statoil, BP and PDVSA are at the moment using several kits. Our non-Norwegian customers ship CATs effectively usingworld-wide mail delivering companies, e.g. DHL, Fedex or UPS. In Europe the CATS may be put in ordinary padded envelopes and sent using standard postal services.

8 Evaluation of results

In order to obtain maximum information from a tracer test it is important to follow up the test and ensure that a sufficient number of samples is collected. Interpretation of tracer results is an integrated process where primary fluid production data, knowledge about the reservoir geology and wells and understanding of fluid behaviour are crucial factors. The objective is to obtain an improved reservoir description that can be applied to correct the reservoir model to enable optimization of the production from the reservoir. IFE can, through its large variety in activities, offer such services.

IFE has developed a numerical module (ITRC tracer module) especially for the simulation of tracers. At present, is coupled to the CMG-STARS reservoir simulator, but may in principle be integrated in or attached to any reservoir simulator with some extra effort. The module is able to handle the partition of the tracers between phases and the possible adsorption of the tracers to the reservoir rock. Also, the module can handle a large number of tracers and uses advanced numerical methods, e.g. 2^{nd} order numerical scheme and separate grid refinement, for the reduction of the numerical dispersion, without increasing the computing cost. These features are necessary in order to obtain reliable simulation results of tracers in complex reservoirs. The tracer module is presently used very successfully to analyse the flow of gas and water tracers in Snorre field in the North Sea. The major objective here is to obtain a better understanding of the WAG process applied in Snorre and in particular to monitor the three-phase zones and the degree of gas-oil contact.

In addition, IFE has developed considerable experience in tracer simulation using the ECLIPSE reservoir simulator, but this is recommended only for simple reservoirs and for passive tracers only. Presently, we use ECLIPSE for the simulation of passive water tracers in Gullfaks field, in the North Sea, in order to improve the reservoir model. The tracer simulation can be used, not only for interpreting the tracer data, but also for the design of a tracer job. This is recommended particularly for the cases where partitioning water or gas tracers are planned to be injected. The tracer simulation, even with a partially reliable reservoir model, can help in the selection of the tracers with the appropriate partitioning coefficients, so that the optimum time delay between the partitioning tracers can be achieved.

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