FINAL PUBLISHABLE REPORT

CONTRACT N°: ENK6-CT-2001-00501

ACRONYM: AEOLOS

TITLE : ASSESSMENT OF IMPACT OF SF_6 AND PFCs RESERVOIR TRACERS ON GLOBAL WARMING"

PROJECT CO-ORDINATOR: NCSR DEMOKRITOS (NCSRD, HE)

PARTNERS:

STATOIL (Norway)
IFE (Institute for Energy Technology, Norway)
ICSTM (Imperial College of Science, Technology and Medicine, London, UK)
SFT (Norwegian Pollution Control Authority/Statens forurensningstilsyn)
MOL (MOL Hungarian Oil and Gas PLC, HU)

REPORTING PERIOD: FROM 1/11/2001 TO 30/10/2004

PROJECT START DATE: 1/11/2001 DURATION: 36 MONTHS

Project funded by the European Community under the EESD Programme (1998-2002)

CONTENTS

1. PUBLISHABLE FINAL REPORT

1.1. Executive Publishable Summary

For several purposes related to reservoir characterisation and enhanced oil recovery, the oil production industry on the Norwegian Continental Shelf uses extensively and depends heavily on non-radioactive tracing substances like SF_6 (sulphur hexafluoride) and PFCs (perfluorocarbons). However, these compounds, SF_6 and PFCs, are potent greenhouse gases with very high global warming potential (GWP) and extremely long atmospheric lifetimes, resulting in their essentially irreversible accumulation in the atmosphere. Given (i) the current pressure of the environmental authorities on the oil industry to reduce and even ban the use of such chemicals and (ii) the proven usefulness of employing these substances in the oil exploration and production operations, the AEOLOS major objectives were as follows:

- Specify sources of leakage and quantify emission levels of SF_6 and PFCs during standard tracer reservoir technology programmes on the Norwegian Continental Shelf. Both SF_6 and PFCs might leak to the atmosphere directly from platforms during straight gas burning and hydrocarbon combustion at platforms as well as on-shore processing facilities. Thus, identify and quantify the products of SF_6 and PFCs combustion in realistic flame and temperature conditions (corresponding to operations in platforms, vehicle engines, households, power stations, refineries).
- Evaluate the effect on global warming and atmospheric quality due to these emissions. Here one should account for the very high GWP and long atmospheric lifetimes of the substances under consideration.
- Formulate recommendations and guidelines to the oil industry regarding the use of the currently employed tracers.

The main results achieved include the following:

- Compilation of database with emission values of SF_6 and PFCs leaking to the atmosphere from all possible sources during oil activities on the Norwegian Continental Shelf and following refining and usage in Norway.
- Establishment of methodology for the calculation of emitted tracers to the atmosphere from production wells and during offshore loading, using the ECLIPSE Reservoir Simulator and appropriate data from in-situ measurements.
- During laboratory controlled combustion of PFC-tracers only minute fractions remain as uncombusted. No combustion products other than fluoride and CO_2 were detected in the laboratory.
- Field experiments were performed offshore, on the Gullfaks-C platform (STATOIL operated field). The tracers were found to be distributed to both oil and gas phases in the separation process on an offshore oil producing installation. Although problems with the mass balance were observed during analysis, it could be concluded that nearly 100% of the SF_6 would end up in the gas phase while almost 70% of the PMCP, 30% of the PMCH and 8% of the 1,3-PDMCH would end up in the gas phase. The higher the boiling point of the PFC compound is, the more it would partition to the oil phase.
- Experiments performed on an offshore gas turbine (General Electric Energy) showed that the tracers contained in the gas are almost completely combusted. Such turbines are used for power generation offshore (~100%, on the Norwegian Continental Shelf).
- A combustion experiment with a real car engine showed only low amounts of un-combusted PFC tracers in the exhaust. Moreover, no differences were found in the results using different speeds on the engine.

- A new methodology has been established for processing large meteorological data sets and determining representative weather types for an area of interest.
- A thorough investigation of the effects of different weather conditions combined with various possibilities of emissions was carried out in the distribution of SF_6 and PFCs and consequently in the radiative patterns of the atmosphere, applying appropriate atmospheric modelling tools over the area of interest. In all cases studied, the emissions of SF_6 and PFCs from oil activities were found to affect large areas of the computational domains. In addition, in most cases SF_6 and PFCs concentrations were transported by the air masses towards the land of Norway.
- Absolute absorption cross sections of perfluoromethylcyclopentane (PMCP, $CF_3C_5F_9$), perfluoromethylcyclohexane (PMCH, $CF_3C_6F_{11}$), and 1,2-perfluorodimethylcyclohexane (1,2-PDMCH, $(CF_3)_2C_6F_{10}$) have been obtained of the pure vapours in the infrared region. Moreover, Global Warming Potential values have been calculated for those gases studied.
- Although significant efforts were made in AEOLOS in calculating absorption data for PFCs and SF_6, spectral data for SF_6 covering the existing spectral gaps are still needed. Once new data is obtained, the estimate will be updated and the uncertainty reduced.
- Realistic scenarios concluded that the current emitted quantities of PFCs and SF_6 do not cause any detectable impact to the atmosphere.
- Even with an unrealistic onshore scenario, the radiative forcing due to SF_6 and PFCs produced by the Norwegian Continental Shelf oil activities can be considered to be negligible.

The results from the AEOLOS project are new coming and of significant value particularly to the oil companies. This project has improved our knowledge about the gas tracer's fate from injection in a field to the distribution into different fractions in a refinery, the combustion products and the amount of the components that are released to the atmosphere. The developed method is a management tool for the oil companies regarding the environment. Therefore, the project outcome is also of importance to the environmental authorities. Taking into account the difficulty of developing environmentally friendly gas tracers, the results from AEOLOS are important for the oil companies' further use of tracers. Moreover, the results from the AEOLOS study are of great importance to the scientific community involved in studies of the effects of greenhouse gases in climate change.

1.2. Publishable Synthesis Report

1.2.1. Objectives

SF_6 (sulphur hexafluoride) and PFCs (perfluorocarbons) are gas molecules, which are being used as the state-of-the-art tracers in tracer technology programmes aimed at hydrocarbon reservoir characterisation and efficient oil recovery. Despite the term "tracers", these chemicals are employed for the above purposes in quantities that are significant enough to represent e.g. in the case of Norway less than 0.5% of the total annual SF_6 emissions. Although SF_6 and PFCs are anthropogenic compounds originally used as substitutes for ozone depleting substances, their high Global Warming Potential (GWP) and extremely long lifetimes in the atmosphere constitute them very potent greenhouse gases (GHG). Since these compounds are very useful to the oil industry, the AEOLOS project aspired to assess and quantify the environmental impact of the use of SF_6 and PFCs in oil activities. More specifically, the major objectives were as follows:

- Estimation of injected/released SF_6 and PFCs amounts as reservoir tracers; Development of reliable database for corresponding sources & rates of emissions including combustion by-products; Quantification of potential savings in GHG emissions (e.g. in the case of Norway they may represent <0.5% of the total annual SF_6 emissions).
- Qualitative and quantitative laboratory analysis of SF_6 and PFCs combustion products under specific operational conditions (corresponding to engines, platforms, power plant, households, refineries).
- Field scale characterization of SF_6, PFCs and combustion by-products.
- Modelling and assessment of the effects of SF_6, PFCs reservoir tracers and their combustion products on global warming and atmospheric quality.
- Evaluation of the results, integration into recommendations and guidelines of industrial relevance.
- Dissemination and exploitation of the results in the oil and other industrial and service sectors and through environmental authorities; Final aim is to contribute to the coordination of national and international activities and policies on the issue.

1.2.2. Description of the scientific and technical work

At this stage of reporting period, only the results given in section 1.1 (Executive Publishable Summary) can be released because the consortium wish to withhold the detailed information regarding the methodology of work and quantitative discussion of the results. Such information will be released with the respective publication in a scientific journal in a few months time. In the meantime, members of the public could access the project website (http://milos.ipta.demokritos.gr/aeolos/, public area only) or could contact the project coordinator (mandy@ipta.demokritos.gr).

1.2.3. Acknowledgements

This project was partly funded the European Commission under the contract number ENK6-CT2001-00501. The consortium would like to acknowledge:

- ***General Electric Energy*** for showing such interest to the project and providing their facilities and personnel to carry out the experiments.
- ***Øyvind Bakke at Sogn Upper Secondary Vocational School*** in Oslo (car mechanics) for his significant help in carrying out the experiments with the car engine.
- The ***production managenent*** at Gulfaks C (platform) and Kårstø (gas refinery) for their participation in carrying out the tests.
- ***DNMI*** (Norwegian Meteorological Office) for supplying the meteorological data sets.
- ***University of Oslo*** for carrying out spectroscopic measurements of the three PFCs.
- ***University of the Aegean*** for performing the chemical modelling calculations.
- ***Prof. Lancome (University of Paris)*** and ***Dr. Boudon, (Université de Bourgogue)*** for supplying new spectral data on SF_6.

Last but not least, the consortium wishes to thank the Scientific Officer of the project Dr. Jeroen Schuppers for his kind help and guidance throughout the duration of the project.