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IOR Review of experimental data and building a prototype IRIS-lab database

Report IRIS - 2016/142

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Summary

The purposes of this project were to review previous IRIS projects, related to IOR/EOR (with focus on experimental data) and look upon opportunities of using them in NIORC activities, including building a laboratory database prototype.

More than 800 project reports and publications were selected and briefly described in an inventory which gives an overview of all activities which could be of a value for further IOR-related research. The confidentiality status was verified for each inventory entry. Suggestions are given on possible use of previous project reports.

Main findings:

- Existing experimental data is of a great value for future studies. The possibilities to utilize the data are presented, but not limited in chapter 3.
- The potential use of many projects (especially, SCAL studies) is limited due to confidentiality;
- The project types and, therefore, the data available are quite miscellaneous, therefore it appears illogical to combine everything in a single database. Though other options such as building up small fit-for-purpose databases may be discussed.

Introduction

A significant number of laboratory experiments have been carried out at IRIS during last four decades. These experiments cover the considerable part of reservoir on the Norwegian Continental Shelf (NCS) and majority of known IOR methods. The results of these experiments were partly published, while the rest of the data is stored internally and may still be confidential. These data may and should be systemized and collected in an IRIS internal database.

In general this database may significantly improve IRIS competence and capability to address industry oriented as well as generalized research projects. The data, obtained during the previous research projects, is likely to be of great added value for upcoming IOR activities such as:

1. Reservoir simulation;
2. IOR/EOR screening;
3. Field studies;
4. Consistency check of laboratory experiments
5. Serve as a starting point for developing “numerical lab”
6. Continuity of research

This project aims at filling the following knowledge gaps:

1. Which types of experimental data are available at IRIS?
2. What project results are free from confidentiality restrictions?
3. How could they be potentially used?

1 Initial plan

The initial project plan as of Q4 2014 was as follows:

1. Feasibility study (Q4 2014 – Q1 2015). Budget: 200 kNOK
   1.1. Making an inventory of experimental studies carried out in IRIS. For instance, the data may be classified by:
      a) Experiment type;
      b) Field/formation/company;
      c) Reservoir and core properties (e.g. porosity, permeability etc.);
      d) Results of the experiments (e.g. relative permeability curves, oil recovery curve etc.)
      e) Confidentiality
   1.2. Detailed discussion of possible future usage of the data:
      a) Confidentiality issues and ways to deal with them;
      b) Creating and analyzing the database;
      c) Which experiments may be of use;
      d) Possible ways to use the database and the analysis results.
2. Data collecting (Q1 2015 – Q3 2015). Budget: 600 kNOK
   Excel or structured text files may be considered at the first stage.
3. Database creation (Q3 – Q4 2015). Budget: 200 kNOK

2 Description of project activities

2.1 Overview of previous IOR/EOR activities

Previous research projects which results may be of interest for future IOR/EOR studies can be roughly split into the following categories:

1. Projects within big research programs;
2. Stand-alone projects with industry partners co-funded by RCN;
3. Services on performing petrophysical, SCAL or EOR studies for industrial clients;
4. Internal projects;

The timeline of the most prominent IOR-related research programs that IRIS was involved in, is shown at Figure 1. The short descriptions are summarized in table 1.

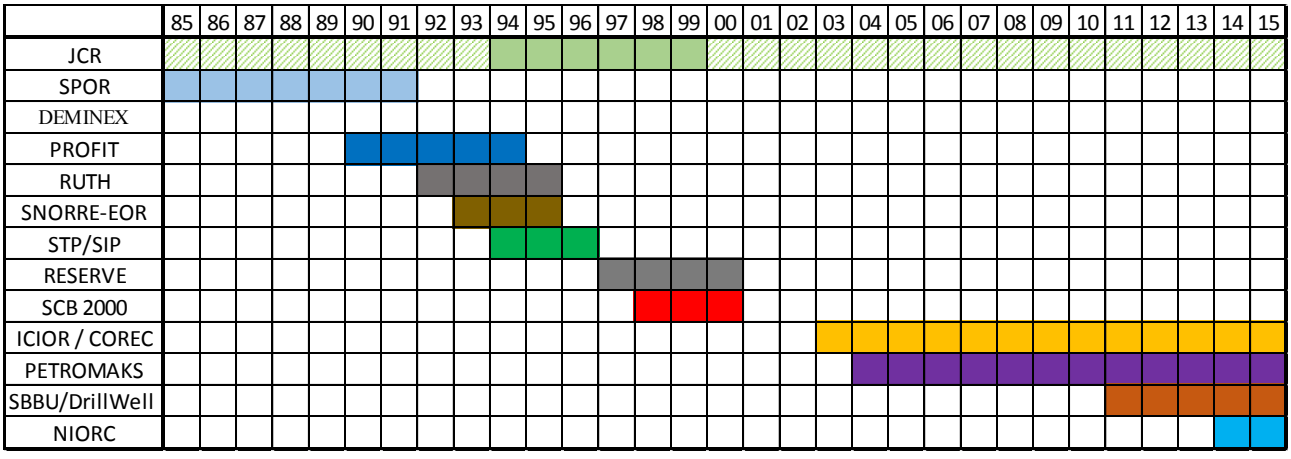


Figure 1. Timeline of research programs carried out at IRIS

Table 1. Research programs

Program	Years	Short description/ Topics/Scope/link	Participants
JCR (Joint **C**halk **R**esearch Program)	1980 -	North sea carbonate reservoirs http://jointchalkresearch.org/	Total, Statoil Petroleum, Shell, Nordsøfonden, Mærsk Oil, Hess, Dong Energy, ConocoPhillips, BP Norge , NPD and Energistyrelsen
SPOR (State R&D **P**rogram For Improved **O**il Recovery and **R**eservoir Technology)	1985 - 1991	- Reservoir Characterization - Water Injection including the use of chemicals - Gas Injection techniques	Statoil, Hydro, Saga, IFP, IKU, IFE
PROFIT (Program for **R**esearch **O**n **F**ield Oriented **I**mproved Recovery **T**echnology)	1990 - 1994	Reservior characterization and near well flow http://www.npd.no/engelsk/news/ior3/ior-3.htm	Amoco, BP, Conoco, Deminex, Elf, Fina, Agip, Hydro, NPD, Petrobras, Phillips, Saga, and Statoil. + Total
RUTH (Reservoir **U**tilization **T**hrough Advanced Technological **H**elp)	1992 - 1995	- Gas Flooding - Combined Gas/Water Injection (WAG) - Foam - Polymer Gels - Surfactants - Microbial Method http://www.npd.no/engelsk/projects/ruth/contents.htm	Amerada Hess, Amoco, BP, Conoco, Elf, Enterprise Oil, Idemitsu Petroleum, Mobil Exploration, Neste Petroleum, Norsk Agip, Norsk Hydro, Norske Shell, Pelican, Phillips Petroleum, Saga Petroleum, Statoil, Svenska Petroleum, Total Norge
SNORRE-EOR	1993 - 1995	- SAGA (surfactant-alternating-gas-ameliorated injection), - Foam assisted WAG - Water shut-off by gels	Saga Petroleum AS
STP/SIP (Krittreservoar EOR)	1993 - 1996	Chalk reservoir related research	NFR
RESERVE	1997 - …	- Disproportionate Permeability Reduction (DPR) - Polymer gels for improved oil recovery - Foam treatment - Surfactant alternating gas injection - WAG	Amoco, BP, Conoco, Elf, IFP, Hydro, Phillips, Saga, Sintef, Statoil, Total
SCB (Scale **C**ontrol **B**eyond 2000)	1998 - 2000	scale squeeze treatment improved design	Amerada Hess, BP, Conoco, Statoil, Elf, Phillips, Saga, Shell, Total, Baker Petrolite, Champion Blacksmith, Dyno Industrier ASA, Halliburton, Nalco/Exxon Energy Chemicals, TR Oil Services Ltd"
COREC / ICIOR (**C**enter for **O**il **Rec**overy / **I**nternational **C**enter for **I**mproved **O**il **R**ecovery)	2003 - …	enhanced oil recovery in general, including multiphase flow, gas and liquid injection, reservoir description and modeling with focus on carbonate reservoirs http://www.corec.no/	ConocoPhillips, BP, Ekofisk license and others
SBBU/DrillWell	2011 - …	- Safe and efficient drilling process - Drilling solutions for improved recovery - Well solutions for improved recovery http://drillwell.no/research-	Statoil, ConocoPhillips, Det Norske, Wintershall

NIORC -National **I**OR **C**entre of **N**orway	2013 - …	- IOR/EOR - Robust upscaling of recovery mechanism observed on pore and core scale to field scale - Optimal injection strategies based on total oil recovered, economic and environmental impact http://www.uis.no/research-and-phd-studies/research-centres/national-ior-centre-of-norway/	BP Norge AS, ConocoPhillips Skandinavia AS, Det norske oljeselskap AS, DONG Energy AS, Eni Norge AS, GDF Suez E&P Norge AS, Lundin Norway AS, Maersk Oil Norway AS, Statoil Petroleum AS, Wintershall Norge, Schlumberger Norge AS, Halliburton

2.2 Preparation of project inventory

As said above, preparation of the project inventory was the first step. In the process it became clear that this step is likely to take more time than it had been initially planned due to the following circumstances:

- Lack of descriptors and keywords, often missed descriptions, difficulties with the search engine in the Lotus project database;
- Incorrect confidentiality status. Quite a few projects are marked as confidential, though contract terms allow for using of project results after confidentiality period has expired (for instance, the standard COREC contract set it of 2 years after project completion date).
- IRIS's contract database covers only projects delivered approximately after 2000. The earlier contracts are not available electronically and may be found only as paper copies in the storage.

Significant amount of project time was allocated for checking the old contracts in order to correctly access confidentiality status.

The project inventory has been compiled as an Excel spreadsheet organized in order to allow quick filtering of the projects that meet certain criteria and to give brief overview of their scope, confidentiality status, experiments performed, core materials used etc. Structure of the inventory is summarized in table 2.

The examples of possible future use were added in the separate column for some projects.

Table 2. Structure of the inventory

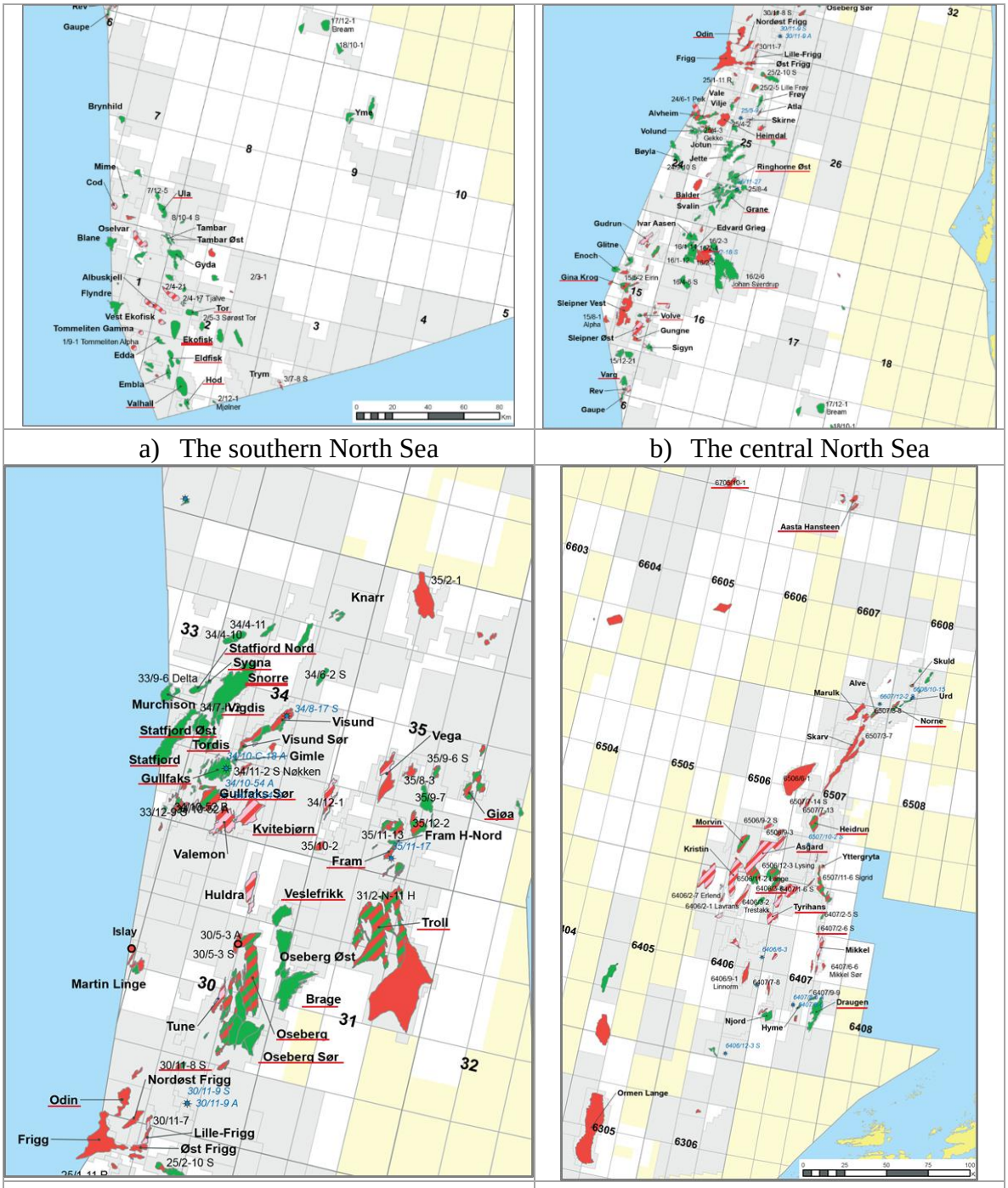
#	Column	Comments
	I. General information	
1	Publication number in Lotus database	
2	Project number	
3	Project title	
4	Research program	
5	Date	
6	Clients	
7	Status of confidentiality	
	II. Porous media	
8	Field, reservoir	

9	Rock type	Lithology (sandstone, carbonates)
10	Number samples	The field refers to number of cores or core plugs used. It also applies to polymer, gel, foam and other samples
11	Reservoir	marks that reservoir cores were used
12	Outcrop	marks that outcrop cores were used
13	Artificial	Glass beads, sand packs etc.
	III. Scope descriptors:	
14	Geology	Descriptive geology, geochemistry
15	Petrophysics	
16	Wettability	
17	Relative Permeability	Refers to all projects having relative permeabilities as a part of the scope, including, aside from SCAL studies, developing new procedures for experiments, upscaling etc.
18	Bulk (rheology) studies	
19	PVT or phase studies	
20	IOR/EOR	Type of IOR/EOR method
21	Geomechanical studies	
22	Scale inhibitors	
23	Modelling, screening, field studies	Miscellaneous activities related to modelling such as upscaling, numerical interpretation of the experiment, IOR screening etc.
24	Other	Additional descriptor which aims to mark document as a literature survey, progress report, SCAL etc.
25	Short description	Information about the scope
26	Additional comments on possible use	The recommendation for further use are given for some reports
27	Keywords	

2.3 Brief overview of inventory content

The inventory covers all found reports, publications etc. potentially relevant for IOR from 1986 to 2014. The short list of the most common project scopes is given below:

- Routine core analysis;
- SCAL (2,3-phase relative permeabilities, wettability, Pc);
- EOR:
    - Gas methods (air, miscible injection, nitrogen, WAG, CO_2, carbonized water)
    - WAG - Water-Alternating-Gas injection (WAG)
    - Surfactant flooding, including adsorption studies
    - SAG – surfactant altering gas injection (SAG)
    - SAGA – surfactant-alternating-gas-ameliorated injection
    - polymer flooding;
    - LTPF - low tension polymer water flooding;
    - Cyclic flooding;
    - “Smart water” (imbibition and forced imbibition profiles), LSWF - low salinity water flooding;;
    - MEOR – microbial enhanced oil recovery;



a) The southern North Sea

b) The central North Sea

c) The northern North Sea

d) The Norwegian sea

Figure 2. NPD maps with reservoirs studied by RF and IRIS

› IOR:
  - Water/gas shut-off: gels, foams;
  - acid treatments
  - rheology studies: foams, gels, polymers
  - adsorption of surfactant;
  - phase studies (for instance, for surfactant flooding), PVT;
› Chalk mechanical properties;
› Experimental set-up, developing and testing new experimental procedures
› Other:
  - Outcrop geological studies;

- Scale inhibitor experiments;
- Cores descriptions;
- Field simulation studies IOR/EOR, CCS;
- Models of processes (gelation, polymer, foam aging etc.);

Various types of porous media were in use for said experiments:

- Reservoir cores;
- Outcrop cores;
- Sand packs;
- Glass beads;
- Physical models (1D, 2D, 3D);

NCS reservoirs studies by IRIS are marked by the red underline on the maps (figure 2 a,b,c,d). The most of studies were carried out on Snorre and Ekofisk fields.

The inventory includes in total 840 entries of which:

- 103 SCAL studies
- Around 40 field simulation studies
- 229 publications and monographs

It's hard to give an estimate for number of corefloods carried out at IRIS/RF, but it's safe to say that at least 500 core plugs (most likely, much more) have been used for experiments, not including artificial media.

Around 85 reservoirs have been studied by IRIS/RF. The rough geographical split is given in figure. 3. The list of fields is given in table 3.

Figure. 3. Percentages of fields studied by IRIS in Norway and internationally

Table 3. Fields studied by IRIS/RF in alphabetical order

#	Field	Location	#	Field	Location
1	35/10-1	NCS	44	Mariner	international
2	6306/6-1	NCS	45	Mittelplate	international
3	6505/10-1	NCS	46	Morvin	NCS
4	7120/10-2	NCS	47	Njord	NCS
5	Aasta Hansteen	NCS	48	Norne	NCS
6	Al Ghubar	international	49	Novogodneye	international
7	Asab Thamama	international	50	Odin	NCS
8	Åsgard	NCS	51	Oseberg	NCS
9	Asterix	NCS	52	Oseberg Sør	NCS
10	Bab Thamama B	international	53	Peregrino	international
11	Balder	NCS	54	Rabi	international
12	Biotitt	NCS	55	Ragnarrock	international
13	Brage	NCS	56	Rima	international
14	Bressay	international	57	Ringhorne	NCS
15	Brynhild	NCS	58	Salah	international
16	Champion	international	59	Siri	international
17	Dan	international	60	Skarfjell	NCS
18	Draugen	NCS	61	Sleipner	NCS
19	Ebba	NCS	62	Snøhvit	NCS
20	Ekofisk	NCS	63	Snorre	NCS
21	Eldfisk	international	64	South Arne	NCS
22	Fahud	NCS	65	Stafjord Nord	NCS
23	Fram	NCS	66	Statfjord	NCS
24	Gannet	international	67	Svale	NCS
25	Gina Krog	NCS	68	Sygna	NCS
26	Gjøa	NCS	69	Thistle	international
27	Grane	NCS	70	Tor	NCS
28	Gudrun	NCS	71	Tordis	NCS
29	Gullfaks	NCS	72	Troll	NCS
30	Gullfaks Sør	NCS	73	Tyra	NCS
31	Guntong	international	74	Tyrihans	NCS
32	Gyda	NCS	75	Ula	NCS
33	Heather	international	76	Urd	NCS
34	Heidrun	NCS	77	Valhall	NCS
35	Hod	NCS	78	Varg	NCS
36	Johan Castberg	NCS	79	Velsefrikk	NCS
37	Johan Sverdrup	NCS	80	Vigdis	NCS
38	Kamennoye	international	81	Vilje	NCS
39	Krafla	NCS	82	Volve	NCS
40	Kristin	NCS	83	Yu.Korchagin	international
41	Kvitebjørn	NCS	84	Yuzhno Khylchuyu	international
42	Logocinoco	international	85	Zafarani	international
43	Maria	NCS			

2.4 Confidentiality

As it was mentioned before, the inaccurate information on confidentiality status given in the project description led to the time-consuming checking of the project contracts. The results of confidentiality study are shown at figure 4.

As a rule, contract terms of any research project co-funded by NFR imply that the results are to be opened on expiration of confidentiality period. This was the case of a few research programs such as: RUTH, PROFIT, RESERVE, Krittreservoir/EOR (STP/SIP), etc. Similar rules are included in COREC research program sponsored by PLO18. 15% of project results are open due to expiration of the confidentiality period. Some research programs, such as SPOR, had been opened from the very beginning.

However, in the course of the project, all doubts regarding confidentiality status were interpreted in favour of the former, i.e. if a project is marked as confidential, then its status remains unchanged in absence of contract terms implying the opposite.

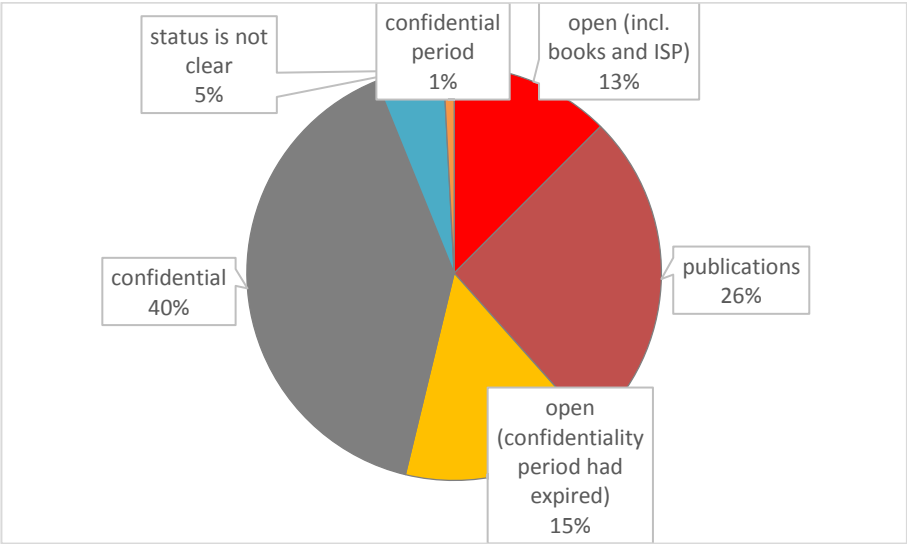


Figure 4. Pie-chart showing confidentiality status of projects summarized in inventory

40% of projects are strictly confidential and must not be used for research purposes and disclosed by IRIS in any way. However, the project results may still be used for in-house activities aiming, for instance, to improve experimental procedures or research activities with the same clients.

5% of projects, for which confidential status is not clear, including the cases when reports are missing from the database or storage should be treated as confidential.

2.5 JCR library

Additional data (not included into the main inventory) is available in the Joint Chalk Research Library (briefly, mentioned above as one of research programs IRIS contributed in). This library comprises all reports carried out within JCR research project which are older than 5 years and, therefore, are in public domain. JCR library is mentioned in this report because of two reasons:

1. This library contains reports that are likely to be of great value for IOR center, for instance:
    a. Blowdown Performance and Gas Saturation in Water Flooded Chalk;

   b. Wettability and Imbibition in Chalk, WIC Database;
   c. Many experimental studies on carbonate outcrops and reservoirs, including Ekofisk, Eldfisk, Valhall, Hod and so forth;
2. The library itself can serve as an example of how large volume of miscellaneous results can be classified, organized and represented.

JCR library may be accessed upon completing a simple registration procedure. The content of JCR library was briefly summarized on in the inventory. The project 1995/197 (monograph "Petroleum Research in North Sea Chalk") missed in IRIS project database was found in JCR library and copied into the report folder.

3 Conclusions on Feasibility Study

1. The inventory, comprising more than 800 reports and publications, has been compiled.
2. The initial goal to build a unified database of the experiments does not seem to be feasible due to quite miscellaneous nature of the investigations which would make such a database very expensive in terms of the required work hours and efforts and very complicated to use.
3. The inventory may further be used, for instance:
   a. To filter all studies carried out for a particular IOR method;
   b. To find analogues, examples, extend data availability for potential or on-going projects in terms of scope, materials used etc.;
   c. To find the studies carried out for a reservoir in question;
   d. To update IRIS project database with more relevant keywords, descriptions and correct confidentiality imprints;
   e. To maintain an easy to access track record of IOR related projects;
   f. To develop specific databases of experiments on polymers, polymer gels, foam, scale squeeze treatments, etc.;
4. More specifically the inventory may be used for the following activities in the IOR centre:
   a. **Task 1. EOR potential at NCS**. The previous studies can be used to get necessary data for IOR screening. Previous field and EOR screening studies can be used for benchmarking.
   b. **Task 1. Core plugs preparation procedures.** The previous SCAL studies may be used for the benchmarking;
   c. **Task 1. Displacement mechanisms in heterogeneous reservoirs with CO2-foam for mobility control; upscaling for field application:** a lot of experimental and simulation studies on the subject are available in the database
   d. **Task 2. Further evaluation of IOR mechanisms on outcrop and reservoir rocks.**
   e. **Task 2. Understanding mechanism of mineral alteration. Screening of outcrop and reservoir chalks.** Some previous wettability studies may be of use
   f. **Task 3. Upscaling from pore to core -** A lot of studies available for upscaling of (2-3 phase) relative permeability for field-scale simulations.

g. **Task 4. IORsim/OPM development.** Previous studies may be of a great value for development of an OPM and IORSim simulators:
    i. Previous numerical and experimental studies may be used for verification and benchmarking of OPM polymer, gel, surfactants and foam models;
    ii. Existing process models and correlations may updated or the new ones could be developed based on the large volume of data available and could be implemented in OPM and /or IORSim
h. **Task 5. Reservoir simulation tools. Modelling of near well zone scenarios**. A lot of studies have been carried out previously on modelling foams and gels on single well models, including field-cases.

5. The list of activities that can be supported with inventory is not full and may be continued.

Abbreviations

JCR – Joint Chalk Research
NFR/RCN – Noregs forskingsråd / Research Council of Norway
OPM – Open Porous Media simulator;
PROFIT – Program for Research On Field Oriented Improved Recovery Technology
RUTH – Reservoir Utilization through Advanced Technological Help
SPOR – State R&D Program for Improved Oil Recovery and Reservoir Technology

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APPENDIX. Content of the inventory file

Due to large volume it is not possible to include the inventory spreadsheet in this document. So it has been attached to the report ("inventory final.xlsx"). Here is the short description of the content:

1. "Inventory" – inventory itself as it was described above in 2.3
2. "relevant research programs" – short description of previous research programmes (table 1 from 2.1).
3. "IRIS research timeline" – figure 1 from 2.1.
4. "JCR inventory" – inventory of Joint Chalk Research programme.
5. "statistic – confidentiality" – master data for figure 3.
6. "statistic-NCS vs. International" – master data for figure 4.