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Comparative Analysis of Successful Application of EOR in Russia and CIS

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ABSTRACT

The oil industry of the former Soviet Union (FSU) has extensive experience in enhanced oil recovery (EOR) methods. Variety of conditions, both geological and geographical, require systematic analysis of the applicability of EOR methods under different reservoir conditions.

Fuzzy logic comparative analysis enabled the identification of the main reservoir/fluid parameters that have an impact on the success of EOR methods. Analysis was done on EOR methods such as steam injection, polymer flooding, surfactant flooding, group of the gas injection methods, and CO_2-flooding. The data base created by the authors includes more than 800 EOR projects with a substantial part of them carried in the FSU. Several examples of the EOR feasibility study are discussed in the paper.

The approach described in this paper allows the selection of secondary/tertiary oil recovery methods which are most promising for the given geological conditions. This reduces the number of diverse field performances and, hence, shortens the risk and uncertainty in the decision making.

References and illustrations at end of paper

INTRODUCTION

Conventional (primary and secondary) methods of oil recovery usually result in less than 45% of the recoverable resources. The major portion of petroleum remains in place. This unrecovered quantity depends on the complexity of reservoir conditions, field development strategi, and is greatly affected by economics. EOR/IOR methods are effective in upgrading reserves which can be economically recovered beyond conventional recovery methods by augmenting a volumetric sweep (macroscopic) efficiency and/or by enhancement of the displacement (microscopic) efficiency.

During the last 30 years the FSU underwent a considerable change in the reserves replacement mainly due to the gradual depletion of giant fields coupled with their increased waterflooding and new discoveries associated with "hard-to-produce" reserves (formations with low permeability and high heterogeneity, extensive wedge zones, high-viscosity oil, etc.). During this period the "hard to recover" reserves in the overall reserves estimates were raised from 10% to 45%. This change in the reserve structure resulted in the gradual drop in the oil recovery from nearly 50% in 1960 to 40% in 1993 [1]. This was despite the fact that many oil fields had already experienced the application of EOR methods. The current problems in Russia and CIS dictate even more intensive application of those EOR/IOR techniques which can provide more ultimate oil recovery with better or, at least, the same economics as compared to conventional recovery methods [2].

APPLICATION OF EOR IN THE FSU

At present enhanced oil recovery methods are carried out on 237 blocks of 122 oil fields in the FSU. Regionally their application is generally as follows (see also Fig. 1):

Thermal methods	Kazakhstan, Volga-Ural, Komi region, Ukraine
Chemical flooding	Volga-Ural, Bashkortostan, Tatarstan, West Siberia
Gas flooding	West Siberia

Despite the abrupt recent and still continuing drop in oil recovery caused by the gradual collapse of the FSU the total number of EOR projects is growing proving their effectiveness and competitiveness with conventional methods of oil recovery (Fig. 2).

Thermal Methods

Cumulative production of oil in the FSU by thermal recovery methods reached 40.8 mln t (million metric tons) by the end of 1992. Nearly 50% were recovered by steam injection (20.3 mln t), 16.9 mln t – by hot water injection, and 3.6 mln t – by in-situ combustion.

The main region of thermal methods implementation in the FSU is Kazakhstan. The biggest EOR-pilot is in the Uzen oil field (350 injection and 980 production wells) where seawater from the Caspian sea heated up to 90°C is injected.

Two pilots are in the Karazhanbas oil field (Kazakhstan) where in-situ combustion and steam injection recoveries reached 1.5 and 2.5 mln t of oil, respectively.

Other thermal pilots are in the Komi region (Usa and Yarega oil fields), Volga-Ural (Mishkinskoye and Gremihinskoye oil fields), and in the South-European part of Russia (Staro-Groznenskoye oil field).

Chemical Flooding

Chemical flooding is carried out mainly in Tatarstan, Western Siberia, and the Volga-Ural yielding an incremental cumulative production of 39.2 mln t. In 1992 alone the amount of oil recovered by chemical flooding reached 6.7 mln t.

The most cost-effective polymer flooding experiment was carried out in the Orlyanskoye oil field (Volga-Ural). During the experiment a slug of 2.83 mln Sm^3 of polymer solution with polymer-gel concentration of approximately 130 ppm was injected and was followed by water injection. The amount of extra oil produced during the experiment was 0.78 mln t which was about 2111 t of oil per ton of polymer gel. By using new technologies of polymer gel injection this ratio can be augmented up to 400,000 t of extra oil per t of polymer gel injected [1].

Several field experiments with surfactant flooding are still undergoing in West Siberia (Samotlor, Mamontovskoye, Zapadno-Surgutskoye oil fields), Bashkortostan (Arlanskoye oil filed), and Tatarstan (Romashkino, Novo-Elhovskoye oil fields). Obsolete equipment and often mismanagement coupled with high costs for surfactants make most of these pilots economically inefficient.

Gas flooding

Cumulative oil production by gas and water alternating with gas (WAG) injection in the CIS reached 6.7 mln t by the end of 1992 (0.7 mln t in 1992 alone).

These methods are used widely in Western Siberia since 1984 when gas flooding was initiated in the Samotlor oil field. Gas flooding is mostly used in low-permeability formations while WAG injection is used in high-permeability heterogeneous reservoirs. Cumulative incremental recovery from the Samotlor alone reached 1.24 mln t by the end of 1992.

The FSU has little experience in CO_2 flooding. The only pilot was initiated in the Radaevskoye oil field in 1984 and ended up soon after because of numerous problems with pipeline explosions and contamination of the area.

EOR Potentials in Russia and CIS

Tremendous amount of hard to recover reserves, hundreds of billions barrels of oil left in flooded reservoirs [3] advocate extensive application of EOR/IOR methods in the FSU. Under favorable economic and political conditions the incremental oil that can be produced by EOR techniques can reach 0.2 – 0.4 mln barrels/day by the year 2000, and 0.4 – 0.8 mln barrels/day by 2010 [3]. According to another estimate [4] production of the incremental oil associated with EOR methods can be within the range of 0.8 – 1.3 mln barrels/day by the year 2010.

SCREENING FOR THE APPLICABILITY OF EOR METHODS

Different approaches to the selection of EOR techniques based on screening THE reservoir and operating parameters have been introduced recently [5-12]. Analysis of implementation of EOR methods under different reservoir conditions allows the determination of target criteria (usually reservoir parameters) and a range of their variation for the successful implementation of EOR methods. This information combined with operating parameters [4, 9] and economic analyses form the basis for a relational tree-structured database for decision support.

Database Description

The database contains information on more than 800 EOR projects with a substantial part of them carried out in the FSU. The database has an incorporated glossary and maintains variety of outputs from simple histograms to sophisticated multi-dimensional distributions showing the applicability level of different EOR methods under the given geological conditions.

The database has the following built-in information which can be obtained/added at a random access:

General Information	Country, Field Name, Company-Operator, Cost-effectiveness of EOR Process
Reservoir/Fluid Parameters	Reservoir, Lithology, Reservoir Depth, Reservoir Temperature, Reservoir Pressure, Permeability, Porosity, Initial Oil Saturation, Current Oil Saturation, Oil Gravity, Oil Viscosity
Pilot Characteristics	Process Start-Up Time, Area, Number of Injection Wells, Number of Production Wells, Drive Mechanism Prior to EOR, EOR Method, Cumulative Oil Recovery, Tertiary Oil Recovery, Project Stage

Selection of EOR method is based on combination of multi-criterion approach [13] and a fuzzy logic technique [14]. Statistical analysis of successful and promising EOR-pilots contained in the database provides a multi-dimensional function belonging to a fuzzy set *"Successful Application of EOR Methods"* [9]. A multi-dimensional function is simply an intersection of several one-dimensional functions reflecting the applicability level of a given EOR for a specified reservoir/fluid/operating parameter. Such an intersection can be obtained by implementing different principles of fuzzy logic [15]. As it has been done for reserve estimates [16] the following classification of EOR methods applicability is suggested:

Value of Function	EOR Method Applicability Level
1.0 – 0.8	Successful
0.8 – 0.6	Promising
0.6 – 0.4	Probable
0.4 – 0.2	Possible
0.2 – 0.0	Can not be applied

This information yields an estimate of reserves which can be developed by EOR methods with different levels of certainty. This statement is illustrated on Fig. 3 where favorable (*a*) and unfavorable (*b*) conditions for EOR application are shown. This type of screening analysis can be performed for reservoirs exhibiting later stages of exploitation as well as for incoming candidates waiting to be developed. In both cases, such an analysis provides the petroleum engineer with a knowledge of where, when and what type of EOR technique should be applied for best performance.

FIELD EXAMPLES

Based on the information furnished by the database, EOR methods have been clustered according to their successful applicability under different geologic conditions. Such a clusterization allows the determination of a range of main reservoir/fluid/operating parameters for the best EOR performance. This approach is especially fruitful when applied for screening EOR methods for a candidate field. It allows the selection of an appropriate method of enhanced recovery at any earlier phase of project design and improves the timing of important planning decisions, reducing the number of possible alternatives.

Romashkinskoye Oil Field, Minninbaevo Exploitation Pay

Minninbaevo is one of the 24 exploitation pays of the giant Romashkinskoye oil field located in Tatarstan, and contains two major productive horizons, namely D_0 and D_1. Both horizons belong to the same devonian formation and have the same lithology. However, D_0 is a non-stratified reservoir while D_1 consists of 8 layers. Main characteristics of both horizons are shown below:

Parameter	Value
Reservoir depth, m	1750
Reservoir temperature, ^{0}C	40
Reservoir pressure, MPa	17.5
Initial oil saturation, %	84.3
Oil viscosity, cp	3.55
Oil density, g/cm^3	0.80
Mineralization of formation water, g/l	260

The permeability of horizon D_0 varies from 100 to 300 md with porosity and net pay thickness variations from 16 to 21% and from 1.8 to 7.1 m, respectively. The corresponding characteristics of horizon D_1 are shown below:

Layer	Pay thickness m	Absolute permeability md	Porosity %
A	1.8 – 7.1	157 – 589	14.3 – 22.9
B_1	2.8	541	21.8
B_2	2.2	317	18.8
B_3	2.9	411	22.4
V	1.9 – 3.2	142 – 731	13.3 – 23.6
G	2.9	300 – 400	20.0
G_{2+3}	6.6	824	21.2
D	2.0 – 3.7	156 – 553	14.2 – 21.8

Screening analysis applied to both horizons of the Minnibaevo exploitation pay provides an estimate in the applicability level of different EOR methods. Fig. 4 illustrates such an estimate for polymer flooding. As follows from the Fig. 4, *a)* polymer flooding in horizon D_0 involves high risk and uncertainty in the reservoir performance (possible and not acceptable levels of applicability) while its implementation in horizon D_1 (Fig. 4, *b)*) is quite promising.

Comparative Analysis of EOR Application in USA and FSU

The database enables to perform comparative analysis of successfully completed or still ongoing EOR projects under different reservoir conditions. Because the number of reservoir parameters affecting EOR performance exceeds three these results can be represented graphically only as [2D] projections of a multi-dimensional figure. However, such cross-sections of multi-dimensional space clearly exhibit area(s) of successfully carried out EOR-pilots and provide information on favorable [reservoir] conditions for their performance. Figs. 5 and 6 show some statistics on successful application of EOR methods in the USA and FSU. As can be seen from those Figures, EOR projects carried out in the USA have more diverse reservoir conditions. On the other hand, enhanced oil recovery in Russia and CIS experiences more difficult conditions for its implementation which can affect the economics of oil recovery.

CONCLUSIONS

- Comparative analysis made on a basis of multi-criterion analysis and fuzzy approach allows the identification of the main reservoir/fluid parameters controlled the successful application of EOR methods. This knowledge combined with operating parameters and economics of enhanced oil recovery form the basis for creating a relational tree-structured decision support database.
- The database including more than 800 completed or still ongoing EOR-projects is an effective tool for screening reservoir conditions for the best performance of EOR methods.
- The database allows to identify a candidate field and provides the petroleum engineer with a knowledge of where, when and what type of EOR technique should be applied for the best reservoir performance.

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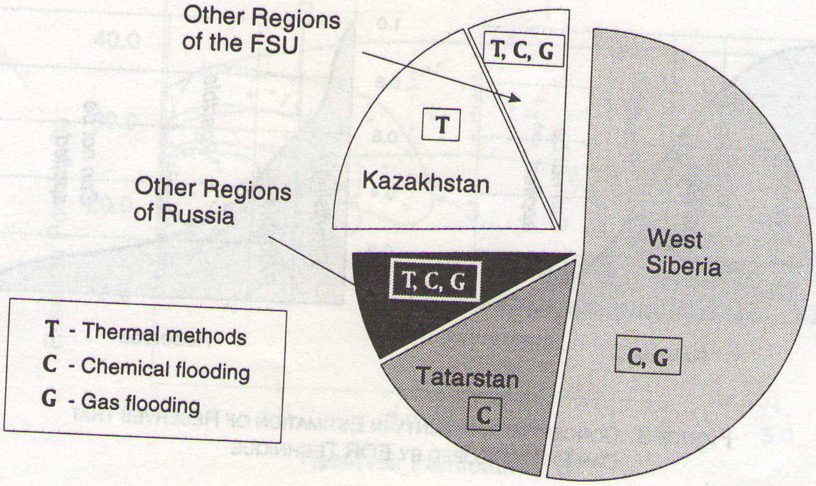

Figure 1: MAP OF EOR METHODS APPLICATION IN THE FSU (ADAPTED FROM [1])

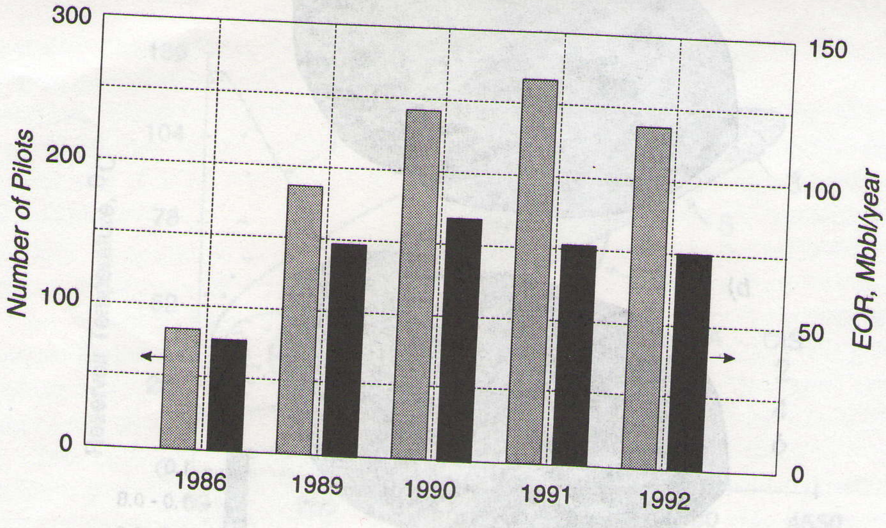

Figure 2: NUMBER OF PILOTS AND EOR IN RUSSIA AND CIS

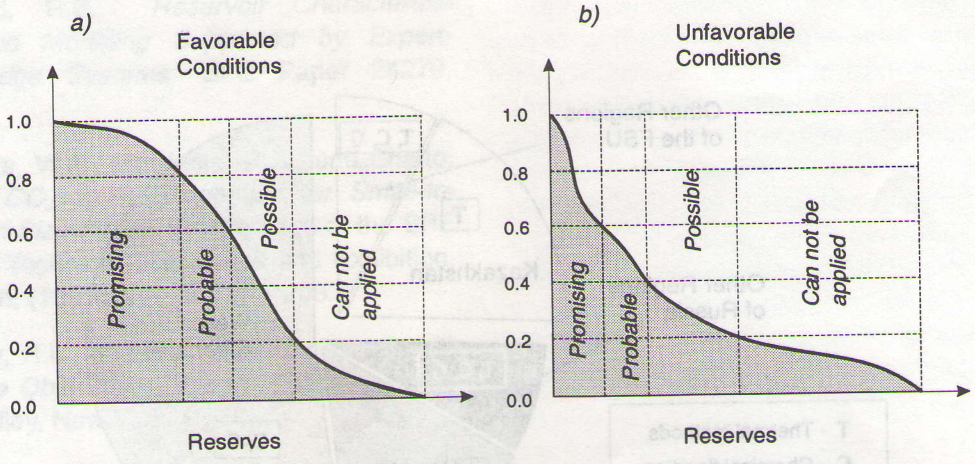

Figure 3: CONCEPT OF CERTAINTY IN ESTIMATION OF RESERVES THAT CAN BE DEVELOPED BY EOR TECHNIQUE

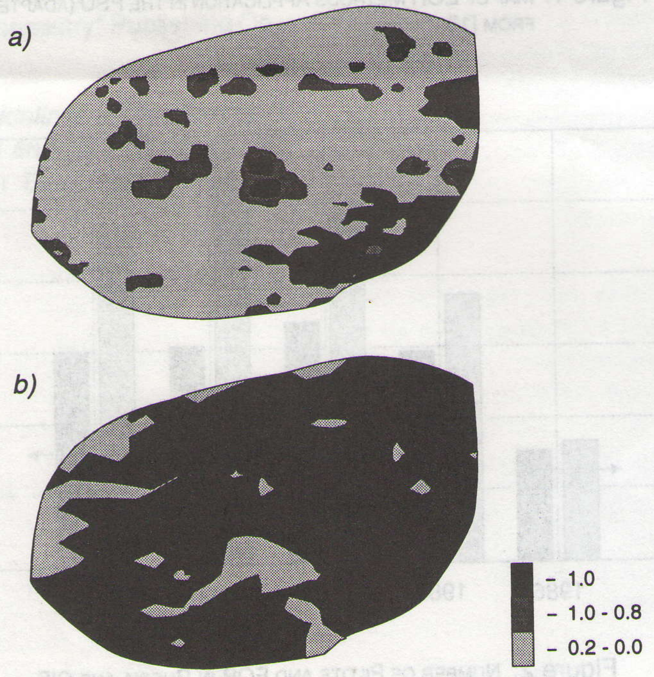

Figure 4: MAPS OF APPLICABILITY LEVEL OF POLYMER FLOODING IN HORIZONS D_0 (*a*) AND D_1 (*b*) OF THE MINNIBAEVO EXPLOITATION PAY (ROMASHKINSKOYE OIL FILED, TATARSTAN)

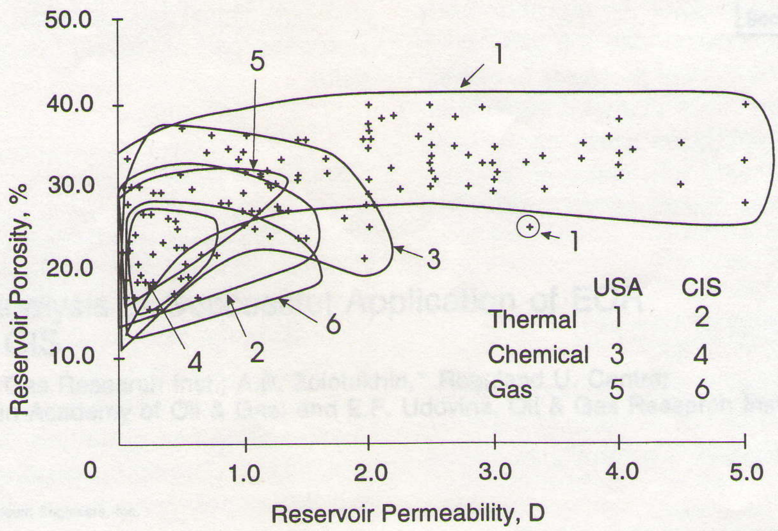

Figure 5: ALLOCATION OF COMMERCIALLY SUCCESSFUL EOR PROJECTS IN DOMAIN OF RESERVOIR PARAMETERS (RESERVOIR PERMEABILITY – RESERVOIR POROSITY)

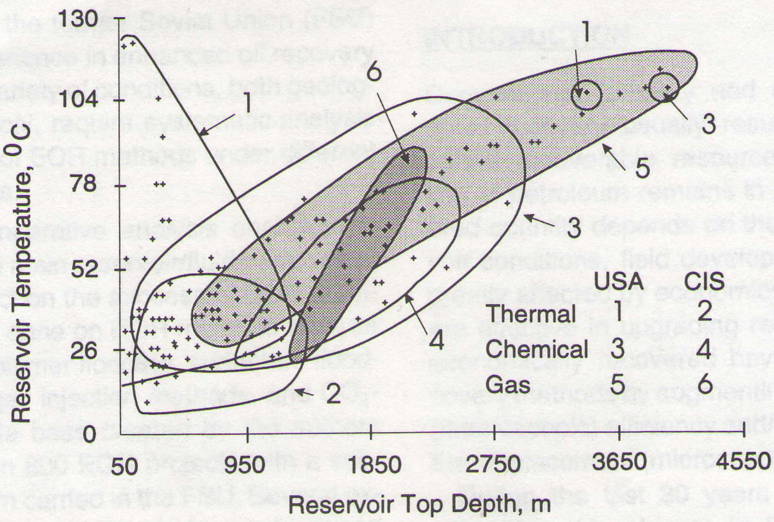

Figure 6: ALLOCATION OF COMMERCIALLY SUCCESSFUL EOR PROJECTS IN DOMAIN OF RESERVOIR PARAMETERS (RESERVOIR TOP DEPTH – RESERVOIR TEMPERATURE)