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Potential for increasing oil recovery from Polish oil-fields by applying EOR methods

Introduction

The constant increase in the scale of global exploitation of mature oil fields is noticeable. In the long run, this may result in declining production of this energy source and necessitate a search for alternative energy sources, including renewables (Bujakowski et al. 2008). Increasing the efficiency of extraction in already discovered fields seems to be a simpler solution. In a number of cases, maintaining production in partly depleted fields can be achieved through the use of advanced, specialized methods categorized as EOR (Enhanced Oil Recovery). The traditional, primary exploitation methods involve natural field energy, and secondary methods rely on maintaining natural processes in the field and enabling the oil to flow. Unlike these, in advanced methods the emphasis is on applying additional energy sources to the field to enhance, or as a substitute for, natural processes and to modify the composition and physical properties of formation fluids in order to minimize flow resistance in the field (Rychlicki et al. 2010). This should result in an increase in production by raising the recovery factor (the ratio of oil produced to total geological reserves). An analysis of global statistics reveals that for light and medium oils, the end recovery factors obtained through the use of primary and secondary methods may reach a level of 25–30%. For heavy oils, the coefficient totals about 10%. Thus, considerable amounts of oil remain in the field, and EOR methods can be used to recover them.

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Depending on the technology used and techniques applied in the field, the methods can be divided into the categories of thermal (the most common), gas injection in mixing conditions, and chemical (Stosur 2003). The popularity of these methods is more sensitive to oil prices than classic methods. Despite periodic fluctuations in oil prices, recently these methods have become more widely used mainly in the USA (Manrique et al. 2010). The increasing interest in advanced methods is also due to advances in technology resulting in a decrease in the cost of using these methods. Figures 1 and 2 illustrate how the number of EOR projects in the USA is changing in relation to average oil prices.

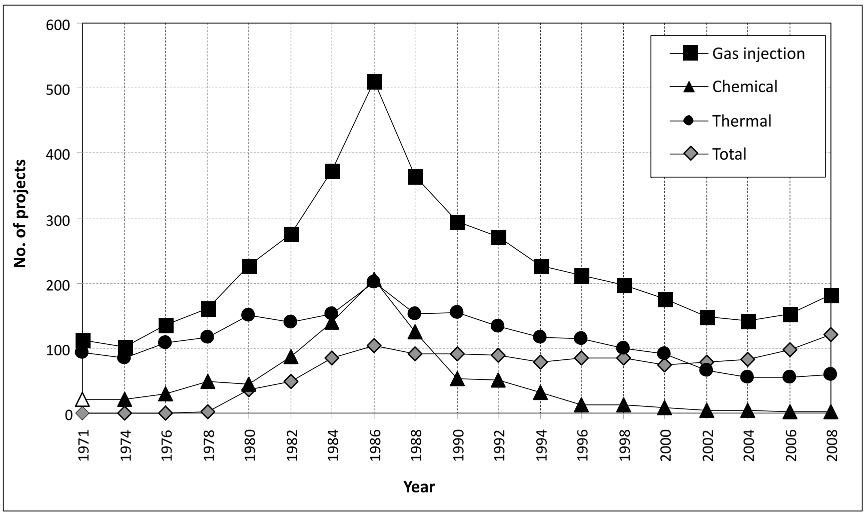

Fig. 1. Evolution of EOR Projects in the USA (Manrique et al. 2010)

Rys. 1. Zmiany ilości realizowanych projektów EOR w USA (Manrique i in. 2010)

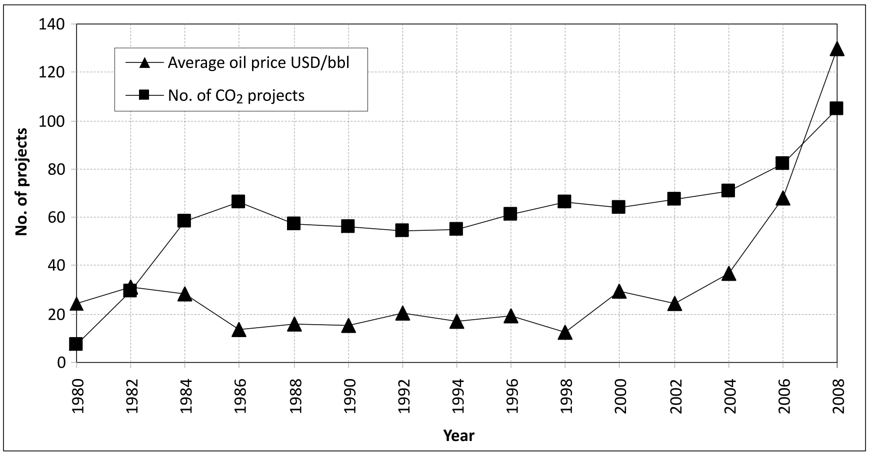

Fig. 2. Trend of CO_2 projects and oil prices in the USA (Manrique et al. 2010)

Rys. 2. Projekty zatłaczania CO_2 na tle ceny za ropę (Manrique i in. 2010)

The CO_2 injection method is very popular in the USA. The production of cheap gas from natural sources (0.035–0.071 USD/m^3 (1–2 USD/Mscf)) and availability of pipelines connecting gas sources make this process economically attractive even if oil prices remain at a level of 126 USD/m^3 (20 USD/bbl) (Manrique et al. 2007; Moritis 2001).

In Poland there were 84 documented oil fields in 2009 (Bilans zasobów kopalin… 2010). Most of them have been exploited for many years with a relatively low recovery factor when compared to the available geological reserves. This implies a considerable exploitable potential even if no new, larger fields were to be found. At present, advanced recovery methods are not used in Poland; only secondary methods are employed in several fields. This means that much can still be done in this area. However, the American experience cannot be directly transferred to Poland because of significant differences in geological, infrastructure, and economic conditions. Therefore, the implementation stage should be preceded by a feasibility study of methods which could be used in Poland.

1. Applicability criteria and selection of EOR methods

The appropriate EOR technique is selected on the basis of geological conditions of the field as well as properties of the formation and field fluids. Owing to their different mechanisms, the methods usually cannot be used interchangeably.

The basic criteria of applied methods are presented in Table 1 (Rychlicki et al. 2011; Taber et al. 1997).

The selection of the optimum method for a given field is a complex procedure consisting of many stages, from collecting data about the field, through more advanced data-interpretation, to working out a detailed proposal for the most efficient method of extraction. The process of EOR screening and implementation processes is presented in Figure 3.

The preselection stage is dependent upon excluding methods which, owing to their specific mechanisms, cannot be used for a particular field without prior detailed analysis – e.g. thermal methods in light oil fields or nitrogen injection into shallow reservoirs. An economic assessment based on general information about the cost of the specific methods compared to expected profits is another factor affecting decision-making at this stage.

Four basic groups of methods are used in the analysis (Trujillo et al. 2010):
- binary technical screening,
- analogy method,
- benchmarking,
- analytical models.

Binary technical screening is based on the use of EOR applicability criteria (*screening criteria*, e.g. Tab. 1). Physical properties of the formation and field fluids are compared with the applicability range based on laboratory experiments and field experience. The value 1 is given when the field factor is congruent with screening criteria for particular methods, or 0 when no such congruence is observed. Various modifications of this method are also used.

TABLE 1

EOR screening criteria

TABELA 1

Podstawowe kryteria stosowania metod EOR

Method	Oil properties				Field characteristic					
	density [kg/m³]	viscosity [mPas]	composition	oil saturation	reservoir rock type	effective thickness [m]	average permeability [mD]	depth [m]	temperature [°C]	porosity [%]
Gas injection methods										
Hydrocarbons	< 850	< 10	high % content C_2–C_7	> 30% PV	sandstone or limestone	low, unless the field is inclined	negligible	< 608 (LPG) do <1520	negligible	negligible
Nitrogen + exhaust gas	< 910 < 850 (N_2)	< 10	high % content C_1–C_7					> 1 368		
CO_2	< 898	< 15	high % content C_5–C_{12}					> 608		
Chemical injection										
SPC / polymer	< 904	< 30	desired presence of light components	> 30% PV	sandstone preferred	> 3	> 20	< 2 433	< 79	≥ 20
Polymer	< 904	< 150	negligible	> 10% PV moving oil		negligible	> 10	< 2 737	< 93	
Alkaline compounds	850–979	< 200	present organic acids		carbonate admissible	negligible	> 20	< 2 737	< 93	
Thermal methods										
In Situ Combustion	> 825 (usually 904 + 1000)	< 1 000	present asphalt components	> 40–50% PV	sand or sandstone	> 3	> 100	preferred > 46	preferred > 66	≥ 20
Steam injection	> 904	> 20	negligible	> 40–50% PV		> 6	> 200	91–1 520	negligible	≥ 20

Rychlicki et al. 2011; Taber et al. 1997

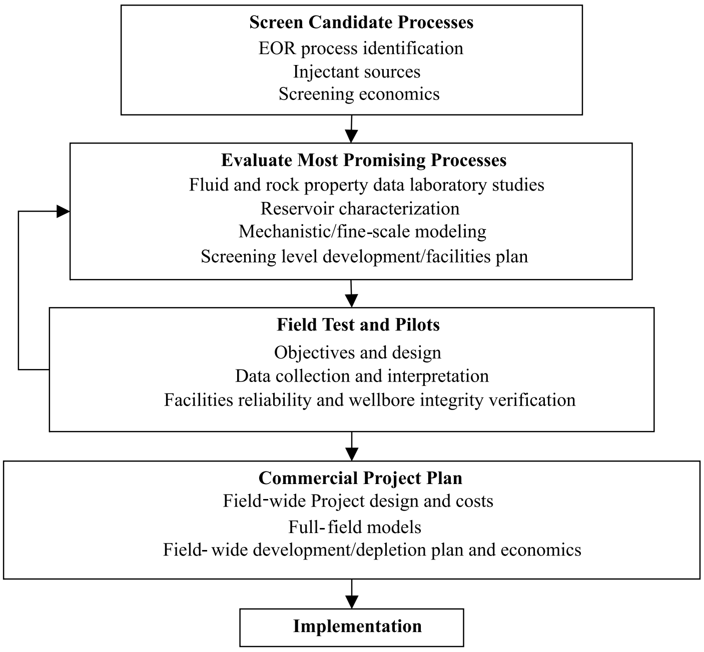

Fig. 3. Staged process of EOR Project evaluation and development (Teletzke et al. 2010)

Rys. 3. Etapy doboru metod EOR (Teletzke i in. 2010)

For example, values between 0 and 1 are ascribed in a situation of a partial convergence of the parameter with an assumed criterion (Trujillo et al. 2010). This method can also be extended by analysis based on fuzzy logic (Rychlicki et al. 2010). Fuzzy logic is based on the concept of a fuzzy set, being an extension of a classic set. Fuzzy sets do not have a clearly defined boundary and the members belong to a set "to some extent". They are defined as figures by the so-called membership function, which can assume arbitrary values from the interval [0, 1] (Rychlicki et al. 2010). The comparison of the results for specific methods reveals which of them fits a given field and which methods should be excluded from further analysis.

The analogy method lies in finding similarities between the analyzed field and other fields where EOR methods were implemented (Trujillo et al. 2010). Therefore, databases containing information about all projects undertaken in similar geological, technological, and economic conditions have to be created. Owing to the fact that such methods have not been used in Poland so far, at present no such database can be created. Consequently, transferring American experience directly to Poland might result in incorrect or poor decisions. Initially, the benchmarking method was applied to steam injection projects. Now, it also relies on the experience from ongoing projects. The main parameters deciding the applicability of the method are selected on this basis. Each parameter is ascribed a weight and "variation coefficient" a measure of "relative dispersion" of analyzed data in reference to the pre-determined average. In practice, this is a standard deviation from the arithmetic mean ratio (Perez et al. 2001). Using this principle, specific methods are ranked from 0 to 100. The analytical models assume a simplified field model for which phenomena taking place during advanced extraction methods are analyzed, employing analytical models such as the Marx–Langenheim model for stem injection. Under Polish conditions where no experience in EOR projects is available for the entire field, at the initial stage of screening, binary technical screening is available. Such screening does not require detailed data, and reduces the area needed for detailed analysis by making use of field simulation models.

2. Applicability of EOR methods on Polish oil fields

Forty-nine oil fields were analyzed based on generally available and published data (Karnkowski 1993; Bilans zasobów kopalin… 2010). These are fields dispersed throughout Poland which have been managed and exploited for years. Twenty-five are in sandstone, and 24 in carbonate rocks. Apart from the rock type, the following parameters were also taken into account in the analysis: oil density and viscosity, average porosity, permeability and thickness of the reservoir, and also depth of deposit. The variability of those parameters is presented in Figures 4–9.

Among the fields analyzed, oil fields of an average density to 850 kg/m^3 (65%) and viscosity below 15 mPas (86%) prevail. In 78% of analyzed fields, the average porosity is up to 15%. Permeability of 5 mD is typical of 50% of the fields, whereas permeability of over 100 mD is 32% and predominates in shallow fields. In most of the analyzed fields, the average thickness is over 10 meters (88%). Two ranges of reservoir depth dominate – below

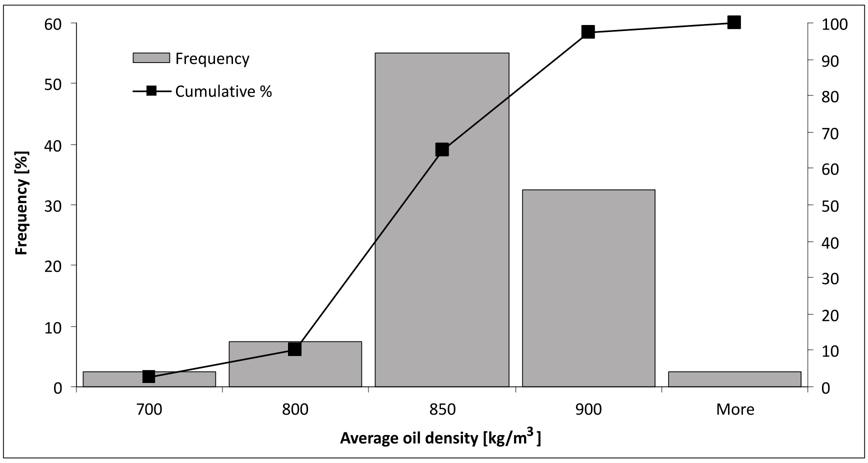

Fig. 4. Average oil density distribution for analyzed oil fields

Rys. 4. Rozkład średniej gęstości ropy z analizowanych złóż

600 meters (25%, Carpathian fields) and in the range from 1300 to 2000 meters (23%). Thus, from the perspective of the criteria for applied EOR methods, the analyzed objects are oil fields with medium density and viscosity, low permeability (double porosity in carbonate rocks), and are relatively shallow or at medium reservoir depth.

The applicability criteria presented in Table 1 aid in the preparation of a preliminary feasibility evaluation of particular EOR methods in the studied fields. The results are presented in Figure 10. A few different methods can be applied in some fields.

The results of analysis reveal that, in practice, thermal methods cannot be widely used under Polish conditions mainly due to the scarcity of heavy oil fields. It is technically

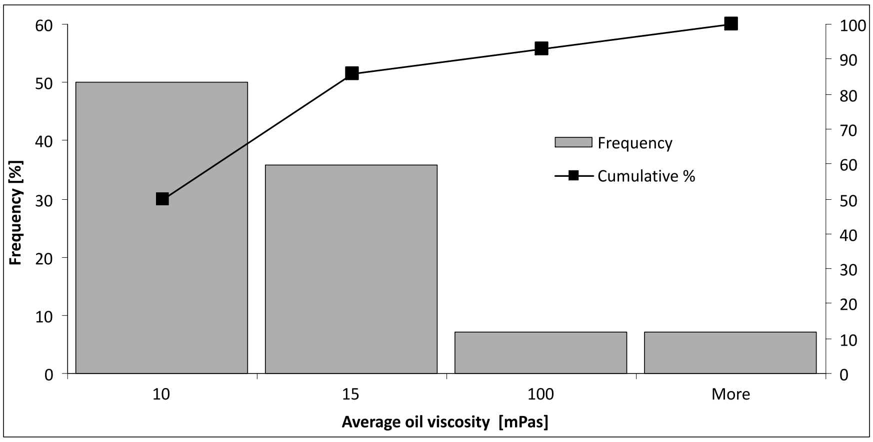

Fig. 5. Average oil viscosity distribution for analyzed oil fields

Rys. 5. Rozkład średniej lepkości ropy z analizowanych złóż

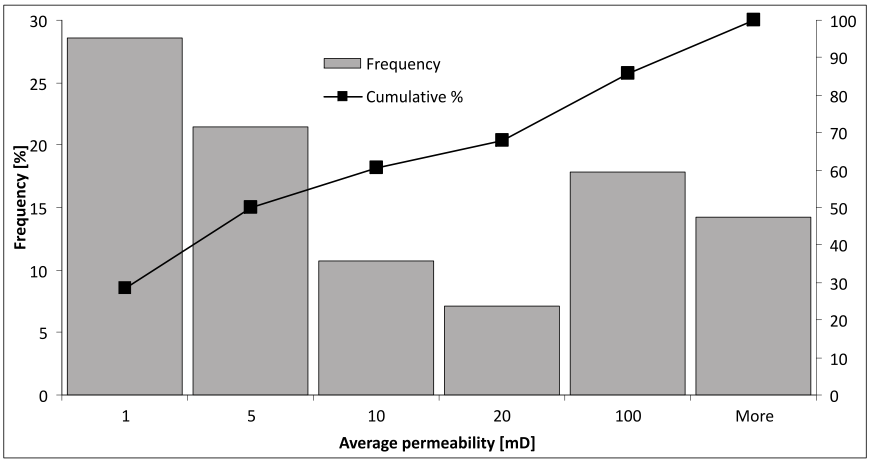

Fig. 6. Average permeability distribution for analyzed oil fields

Rys. 6. Rozkład średniej przepuszczalności skały z analizowanych złóż possible to use the steam injection method in one case, but the analyzed field coincides with double porosity rocks which would certainly affect the efficiency of the process. Nor do chemical methods have any significant potential, mainly due to the requirement for high porosity and permeability of the field. The use of these methods also entails high costs, which further reduces the appeal of these methods in the case of small fields. Only polymer injection, being an "improved waterflooding" method, may be applicable in a few cases. Most promising are gas injection methods under mixing conditions, CO_2 injection among them, which is in line with global trends in this regard. This leading EOR method is the only

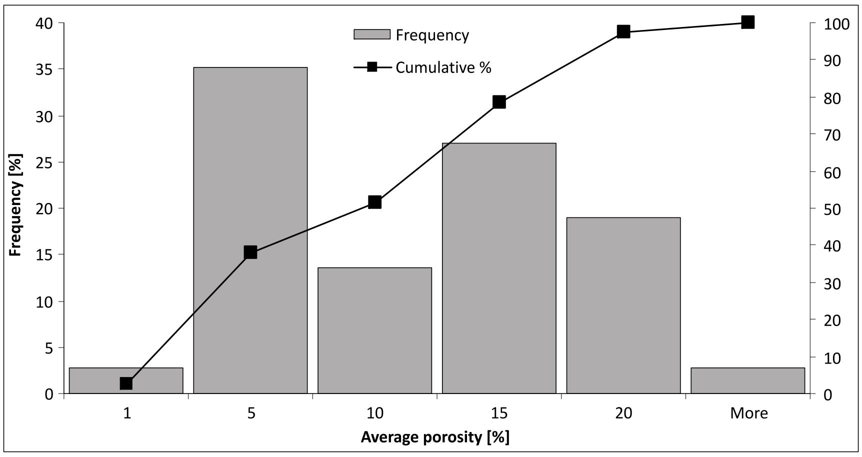

Fig. 7. Average porosity distribution for analyzed oil fields

Rys. 7. Rozkład średniej porowatości skały z analizowanych złóż

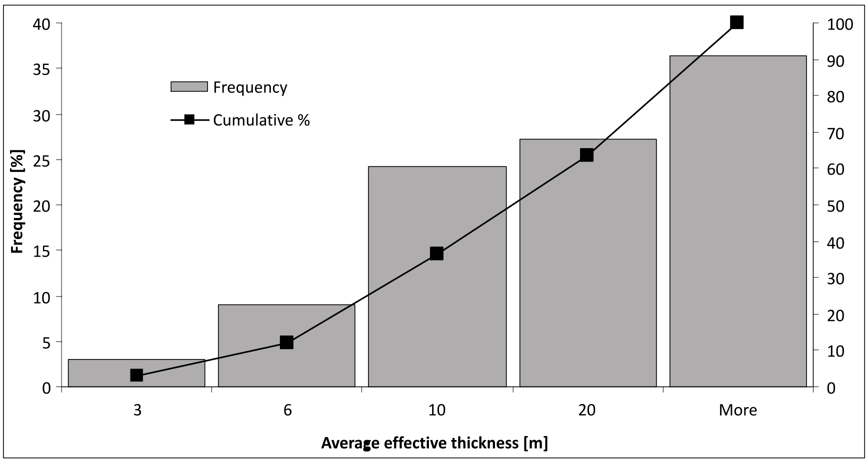

Fig. 8. Average thickness distribution for analyzed oil fields

Rys. 8. Rozkład średniej miąższości efektywnej analizowanych złóż

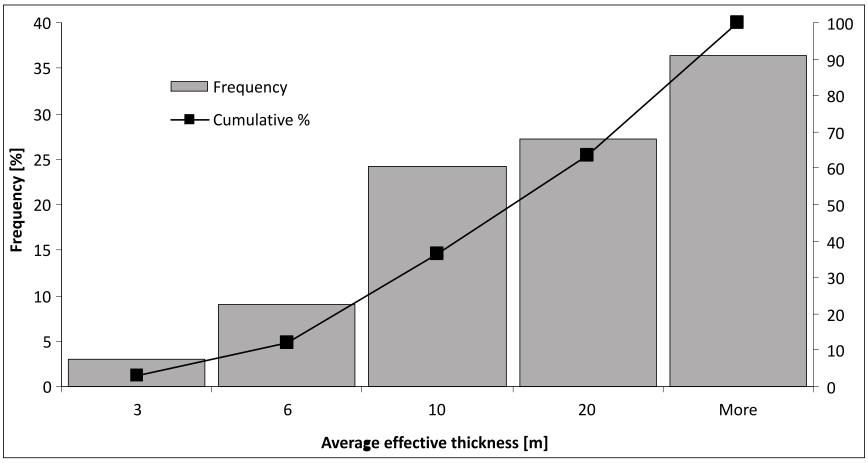

Fig. 9. Average reservoir depth distribution for analyzed oil fields

Rys. 9. Rozkład średniej głębokości zalegania analizowanych złóż

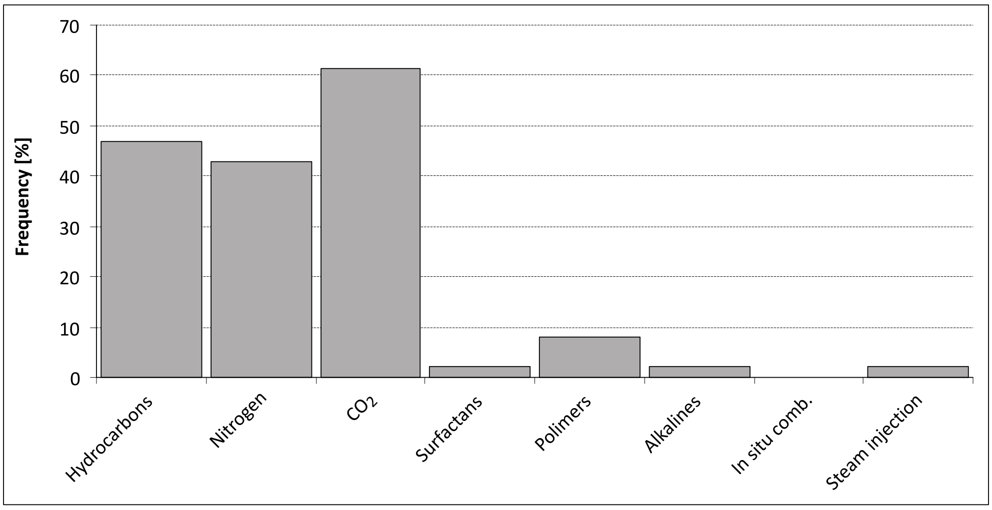

Fig. 10. Possibilities for selected EOR method application on analyzed oil fields

Rys. 10. Możliwości zastosowania wybranych metod EOR na analizowanych złożach

one to be used in carbonate rocks, provided the remaining criteria are met (oil viscosity and density, depth of reservoir) (Manrique et al. 2007). It should be kept in mind that American experience is mainly connected with large fields and cannot be directly applied to the conditions in Poland. Such solutions can be used in the Polish fields only after detailed research, analysis, and pilot tests. Advantageously, this method can be associated with the sequestration of carbon dioxide (Stopa et al. 2009). Nitrogen injection may be an alternative to CO_2 in the case of deeper fields. The high rating of hydrocarbon gas injection is related to shallow fields. However, the applicability of the method is limited mainly due to the high cost of the injected medium and the fact that shallow Polish fields are Carpathian fields, which have a very complex geological makeup and are to a large extent non-homogeneous. There is a real risk of using considerable quantities of the injected gases without any significant influence on production.

Conclusions

The focus on more efficient oil production has resulted in the considerable development of enhanced oil recovery methods. Among them, gas injection methods have started to play the most important role. Using these methods for carbonate fields increases the recovery factor.

To date, Polish fields have been exploited using conventional methods, so considerable potential exists for enhancing oil production through EOR methods.

The analysis of the study reveals that gas injection methods (including CO_2 injection) are the most widely applicable for Polish conditions.

Owing to different geological-and-field, technical, and economic conditions, the American experiences cannot be directly applied to Poland; implementation must be preceded by a number of studies and pilot tests.

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ANALIZA MOŻLIWOŚCI ZWIĘKSZENIA EFEKTYWNOŚCI WYDOBYCIA ROPY NAFTOWEJ Z POLSKICH ZŁÓŻ W OPARCIU METODY EOR

Słowa kluczowe

Zaawansowane metody wydobycia, zatłaczanie CO_2, efektywność wydobycia

Streszczenie

Jednym ze sposobów zwiększenia efektywności wydobycia ropy naftowej jest zastosowanie zaawansowanych metod wydobycia (EOR – *Enhanced Oil Recovery*). W odróżnieniu od pierwotnych i wtórnych metod wydobycia, celem metod zaawansowanych jest dostarczenie do złoża dodatkowego źródła energii wspomagającego naturalne procesy lub je zastępującego, a także modyfikacja składu i właściwości fizycznych płynów złożowych w celu minimalizacji oporów przepływu w złożu. Metody te znajdują szczególnie zastosowanie w przypadku złóż w znacznym stopniu sczerpanych. Znaczenie tych metod w światowym wydobyciu rośnie, a dominującą rolę zaczynają odgrywać metody zatłaczania gazów w tym dwutlenku węgla. Polskie złoża ropy naftowej są obecnie eksploatowane z wykorzystaniem metod konwencjonalnych, co stwarza możliwości podniesienia efektywności wydobycia przez zastosowanie metod zaawansowanych. Proces doboru optymalnej metody do złoża jest złożony i wieloetapowy. W fazie wstępnej opiera się na podstawowych informacjach o złożu i stopniowo przechodzi do etapów zaawansowanych, kończących się opracowaniem szczegółowego projektu najefektywniejszej metody. W pracy przeanalizowano możliwości zastosowania tych metod na polskich złożach wykorzystując technikę opartą na podstawowych kryteriach ich stosowalności i logikę dwuwartościową. Przeanalizowano 49 złóż ropy naftowej z całego obszaru Polski występujących zarówno w skałach węglanowych jak i piaskowcowych. Z punktu widzenia kryteriów stosowania metod EOR, analizowane obiekty to złoża ropy o średniej gęstości i lepkości, niskiej przepuszczalności (w przypadku skał węglanowych podwójna porowatość), zalegające stosunkowo płytko lub na średniej głębokości. Uzyskane wyniki wskazują, że najszersze zastosowanie w warunkach polskich znaleźć mogą metody zatłaczania gazów, w tym dwutlenku węgla lub azotu. Wymaga to jednak przeprowadzenia szeregu badań i testów pilotażowych, gdyż doświadczenia amerykańskie nie mogą być bezpośrednio przenoszone ze względu na odmienne warunki złożowe, technologiczne i ekonomiczne.

POTENTIAL FOR INCREASING OIL RECOVERY FROM POLISH OIL-FIELDS BY APPLYING EOR METHODS

Key words

Enhanced oil recovery, CO_2 injection, recovery efficiency

Abstract

The application of enhanced oil recovery processes (EOR – Enhanced Oil Recovery) on oil fields increases recovery efficiency. This is especially important in depleted and mature fields. This should result in an increase in production by raising the recovery factor (the ratio of oil produced to total geological reserves). This review presents the growing trend of gas injection (particularly carbon dioxide). In Polish oil fields, conventional methods are currently used. This means that much can still be done in this area. The selection of the optimum method for a given field is a complex procedure consisting of many stages, from collecting data about the field, through more advanced data interpretation, to working out a detailed proposal for the most efficient method of extraction. The pre-selection stage involves excluding methods which, owing to their specific mechanisms, cannot be used for a particular field – e.g. thermal methods in light oil fields or nitrogen injection into shallow reservoirs. This paper analyzes the potential for the application of EOR methods in Poland using a binary technical screening method. Forty-nine, mature Polish oil fields were analyzed. Apart from the rock type, other parameters were also taken into account in the analysis as follows: oil density and viscosity, average porosity, permeability and thickness of the reservoir, and also depth of deposit. In regard to the criteria for the EOR methods applied, the subjects of analysis are oil fields with medium density and viscosity and low permeability (double porosity in carbonate rocks), which are at a relatively shallow or medium depth of deposit. The results of analysis show that gas injection methods, especially carbon dioxide or nitrogen, have the highest potential. Application of this method must be preceded by detailed research and field pilot tests. International experience cannot be applied directly to Poland because of different field characteristics as well as technological and economic conditions.