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KVANTIFIKACIJA VARIJABLI PROIZVODNJE U PJEŠČENJAČKIM LEŽIŠTIMA U ODNOSU NA DRUGE TIPOVE LEŽIŠTA U HRVATSKOJ *QUANTIFICATION OF PRODUCTION VARIABLES IN SANDSTONE HYDROCARBON RESERVOIRS VERSUS OTHER LITHOLOGIES IN CROATIA*

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Ključne riječi: ležišni litofacijesi, srednji miocen, gornji miocen, rezerve ugljikovodika, iscrpak, Panonski bazen, Hrvatska

Key words: *reservoir lithofacies, Middle Miocene, Late Miocene, hydrocarbon reserves, recovery, Pannonian Basin, Croatia*

Sažetak

Najveći dio rezervi ugljikovodika u hrvatskom dijelu Panonskog bazena pripadaju pješčenjačkim ležištima gornjeg panona i donjeg ponta (gornji miocen) te predstavljaju 1. ležišni litofacijesi. Druga dva ležišna litofacijesa pripadaju krupnoklastičnim sedimentima badena (2. ležišni litofacijesi) i predneogenskim karbonatima, magmatitima i metamorfitima (3. ležišni litofacijesi). Količina utvrđenih rezervi ugljikovodika smanjuje se prema starijim ležišnim litofacijesima. Geološke rezerve prvog ležišnog litofacijesa, popraćene s udjelom u cjelokupnim rezervama, su sljedeće:

- nafta 217.316.037 m³ (68,63 % ukupnih geoloških rezervi),
- plin otopljen u nafti i plinska kapa 24.391,95 x10⁶ m³ (79,08 % ukupnih geoloških rezervi),
- plin 27.199,47x10⁶ m³ (22,80 % ukupnih geoloških rezervi),
- kondenzat 2.637.147 m³ (12,90 % ukupnih geoloških rezervi).

Iz pregleda rezervi jasno se može vidjeti da se u pješčenjačkim ležištima nalazi glavnina rezervi (oko 70 % ukupnih) nafte i plina otopljenog u nafti ili iz plinske kape. Najveći iscrpak pak ima 2. ležišni litofacijesi (38,74 %) kojeg slijedi 1. ležišni litofacijesi s 29,96 % te na kraju 3. ležišni litofacijesi s 26,2 % iscrpka. Pješčenjačka ležišta pretežno se nalaze u strukturnim i strukturno-stratigrafskim zamkama. Otkriveno je preko 200 ležišta s prosječnom poroznošću 21 % i propusnošću u rasponu od 3,73 do 384x10⁻¹⁵ m². Također, u prvom ležišnom litofacijesu najveća je vjerojatnost pronalaska novih **satelitskih ležišta** na već otkrivenim poljima kao i povećanje iscrpka utiskivanjem vode ili plina.

Abstract

The main hydrocarbon reservoirs in the Croatian part of the Pannonian Basin (CPBS) are discovered in sandstones of Upper Pannonian and Lower Pontian (i.e. Upper Miocene)

ages (1st reservoir lithofacies). **The other two reservoir lithofacies are Badenian coarse-grained clastites (2nd lithofacies) and Pre-Neogene carbonates, magmatites and metamorphites (3rd lithofacies). The discovered hydrocarbon reserves are consequently lesser toward older lithofacies. Amount of geological reserves of hydrocarbons discovered in 1st reservoir type (sandstone) are:**

- oil 217,316,037 m³ (68.63% of total reserves in all lithofacies),
- gas dissolved in oil and gas cap 24,391.95 x10⁶ m³ (79.08% of total reserves),
- gas 27,199.47x10⁶ m³ (22.80% of total reserves),
- condensate 2,637,147 m³ (12.90% of total reserves).

It is clear that sandstone reservoirs are the main reservoir types (about 70% of total reserves) for oil as well as for gas (recovered from oil or gas cap). However, reached recovery is the maximal in breccia reservoirs (38.74% in 2nd, 29.96% in 1st and 26.2% in 3rd reservoir type). Sandstone reservoirs are mostly found in structural and structural-stratigraphic traps. There are more than 200 separate reservoirs bodies, with average porosity about 21% and permeability in range from 3.73 to 384.00x10⁻¹⁵ m². This lithology is the most probable for discovering new, satellite reservoirs on existing fields or the application of water or gas injection for reaching additional recovery.

1. Introduction

The Croatian part of Pannonian Basin System (abbr. CPBS) is divided in four larger depressions, i.e. hydrocarbon provinces of Neogene age. Those are the Mura, Drava, Sava and Slavonija-Srijem depressions (Figure 1.). The depression margins are generally located along several mountains and massifs in the Northern Croatia or their subsurface extensions (Velić, 2007; Velić et al., 2002).

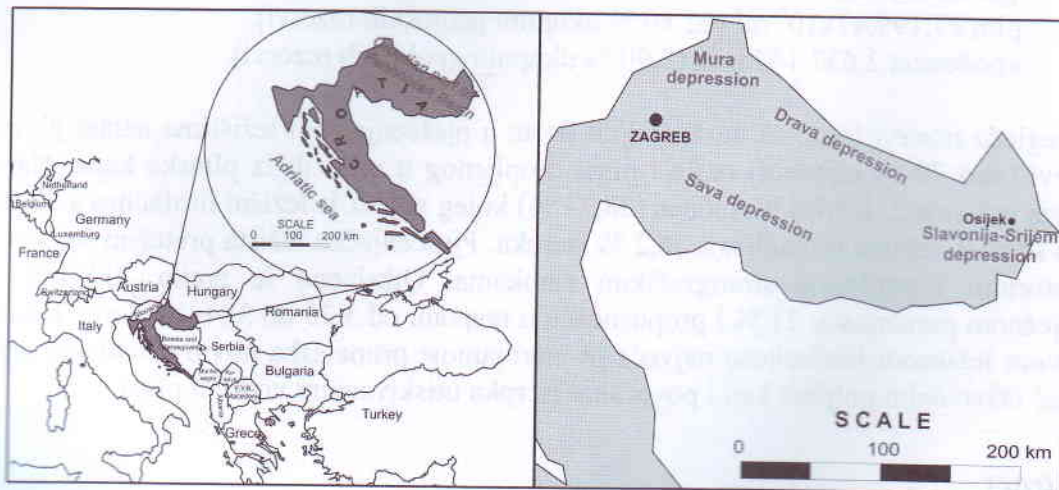


Figure 1. Croatia and its Croatian geotectonical regions
(from: Velić et al., 2008)

In the last 50 years 40 oil and 25 gas fields had been discovered and exploited in CPBS. The estimated geological reserves are $450 \times 10^6 \text{ m}^3$ of equivalent oil. INA Plc. performed exploration and development of more than 60 hydrocarbon fields in Croatia, of which is 15 not in production. The recovered hydrocarbon volumes between 1940-2005 is shown in Figure 2. The annual production of oil reached 3.14×10^6 tons in periods 1979-1982 and 1985-1988, and gas more than $2 \times 10^9 \text{ m}^3$ between 1987-1990 and $2.05 \times 10^9 \text{ m}^3$ in 1993 (Velić et al., 2008).

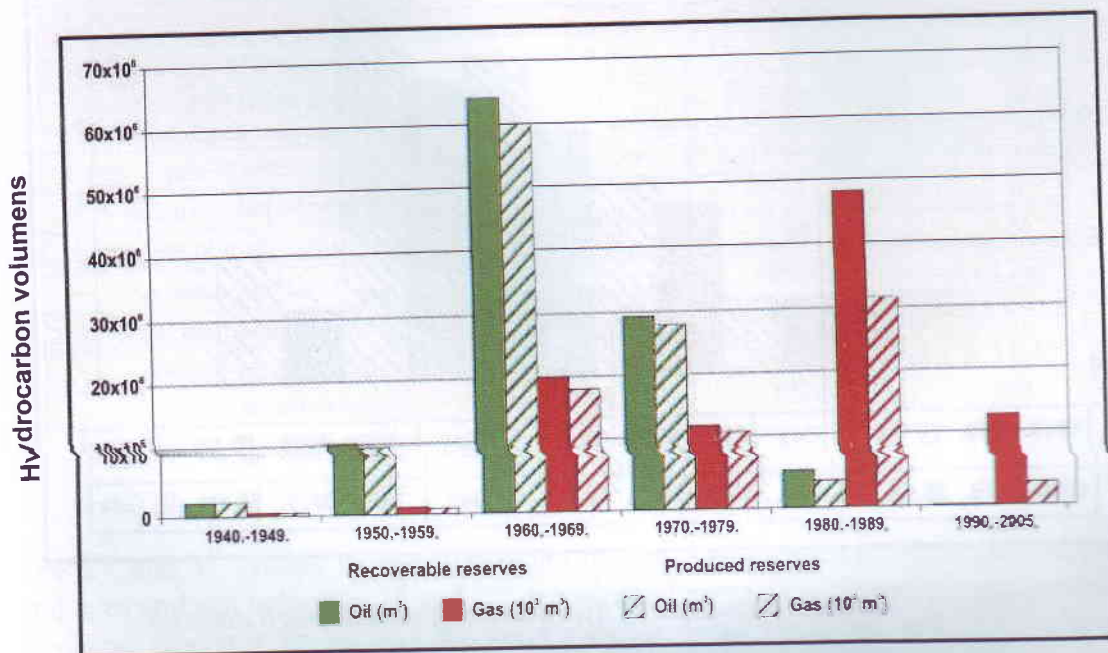


Figure 2. Relation between recoverable and produced reserves of oil and gas through decades (from: Velić et al., 2010)

At the end of the sixties average recovery was 25%. Later, it was improved using wider spectrum of recovery methods for different fields. So in the seventies had been used several production regimes reaching recovery of: (a) 30-50% with water injection, (b) 20-25% using gas cap and (c) 16-20 for soluble gas. Generally, water injection is still the most used secondary recovery methods in the CPBS, and about half of present production comes from water flooded reservoirs (especially sandstones), reaching recovery 40-54% thanks to production favourable oil viscosities. The total recovery does not depend on reservoir size, but on reservoir lithofacies.

So, the some largest Croatian fields reached recovery from only 16% (Žutica Field), then 31% (Kloštar Field), Stružec Field (39%) and even 51% (Beničanci Field). The contemporary production declining is results of lacking of new hydrocarbon discovering and depletion of the most fields, which were mostly discovered from 1959 to 1989 (Figure 3.).

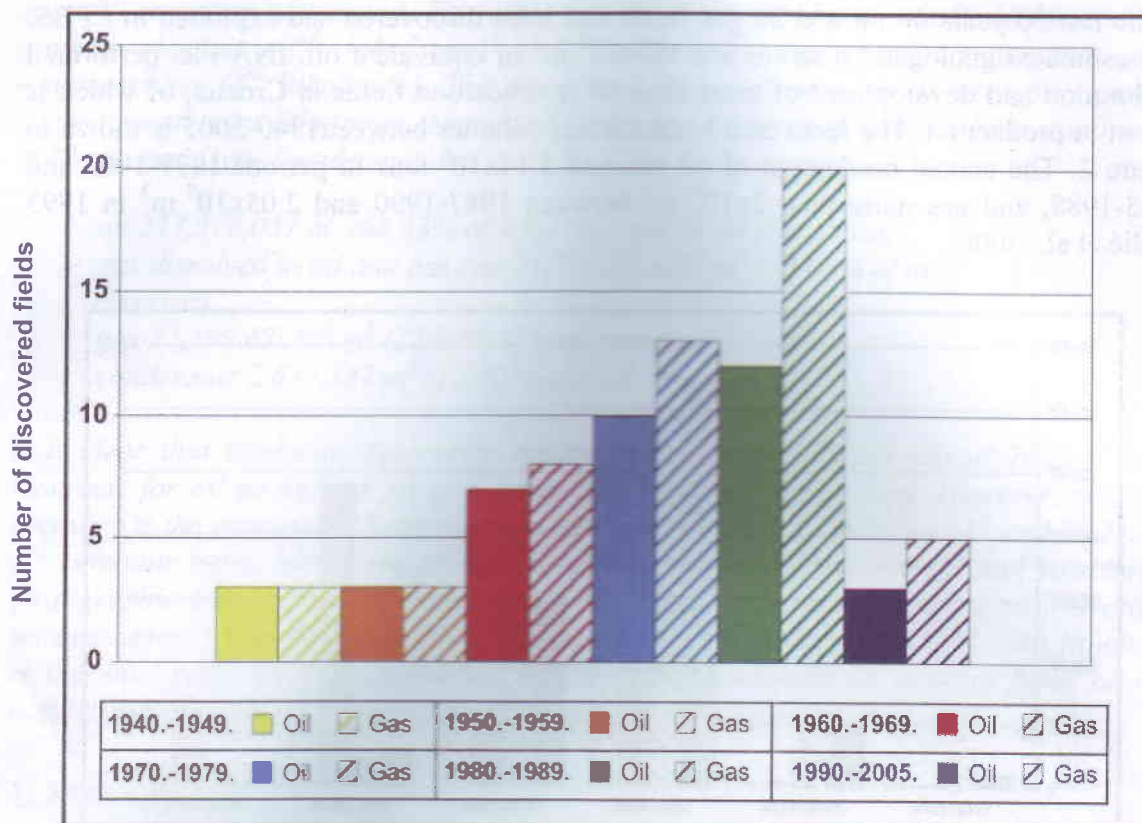


Figure 3. Number of discovered hydrocarbon fields through decades
(from: Velić et al., 2010)

2. Reservoir properties

In CPBS about 3300 wells had been drilled. It offered a lot of data for defining properties of hydrocarbon reservoirs. Regarding statistical analysis of those properties reservoirs are divided in three groups (Velić et al., 2008), as it is shown for oil fields and reservoirs in Table 1 (main data are derived from Velić et al., 2008).

Those groups (Table 1) can be often accompanied with three reservoir lithofacies. It means that properties and group selection is significantly dependant about reservoir belonging to particular sediments of three Neogene depositional megacycles, how it is defined in Velić et al. (2002). The largest and the most productive reservoirs from the 1st group mostly belong to 2nd depositional megacycle (Upper Miocene), i.e. to sandstones of Pannonian and Pontian age (1st reservoir lithofacies). One, but significant, exception is the Beničanci Field, where breccia reservoir is part of the 1st megacycle (Badenian), i.e. 2nd reservoir lithofacies.

Table 1. Grouping of oil reservoirs based on depositional, structural, petrophysical, production and fluid properties

Basic characteristics	1 st group	2 nd group	3 rd group
Neogene megacycle which the most of reservoirs belong	2 nd (rarely 1 st)	1 st and 2 nd (+ Ng basement)	1 st and 2 nd (+ Ng basement)
Dominant reservoir lithofacies	1 st (Upper Miocene)	1 st , 2 nd , 3 rd (U. Mioc., Baden., Pz-Mz basement)	1 st , 2 nd , 3 rd (U. Mioc., Baden., Pz-Mz basement)
Portion of total production (%)	84.8	12.3	2.9
Number of oil fields that mostly product from group	8	11	18
Abs. depths to reservoir top (m)	-570 to -1700	-310 to -2280	-790 to -2350
Average number of reservoirs	16	9	4
Prognosis of exploitation (years)	55	46	36
Average porosity (%)	21.08	15.62	12.65
Average permeability ($10^{-3} \mu\text{m}^2$)	3.73-384.00	8.16-196.60	2.9-92.3
Average recovery (%)	33.87	24.73	14.27
Average oil density (kg/m^3)	847.6	873.6	869.5

The 2nd and 3rd groups include reservoirs of very heterogeneous lithologic composition and ages and can belong to 1st and 2nd depositional megacycle. Some of them include pre-Neogene reservoir rocks, like in the Đeletovec Field (granites, gneisses, schists and diabases of Palaeozoic), Kučanci-Kapelna Field (Triassic dolomitic breccia), Obod-Lacići (Cretaceous carbonates) etc.

There is only a few reservoir in CPBS which are discovered in the sediments of 3rd megacycles up to now (Pliocene sandstones), and they are still considered as potential play that need to be evaluated numerically with Probability Of Success (abbr. POS) regionally.

Reservoir lithology, age, depth, porosity and recoveries are generally correlative with predicted and reached recoveries (e.g. in Velić, 2007; Velić et al., 2002; Malvić et al., 2005; Saftić et al., 2001). So, average porosity decreases from 1st group toward 3rd group, as well as the maximal permeability (Table 1).

The entire remaining recoverable reserves in the CPBS are shown on Figure 4 fir the beginning of, and updated (Table 2) for the end of 1st decade of the 21th century. in fact, there are several newer sources for hydrocarbon reserves in the CPBS published in the last decade like Dobrova et al. (2003) and Velić et al. (2008, 2010).

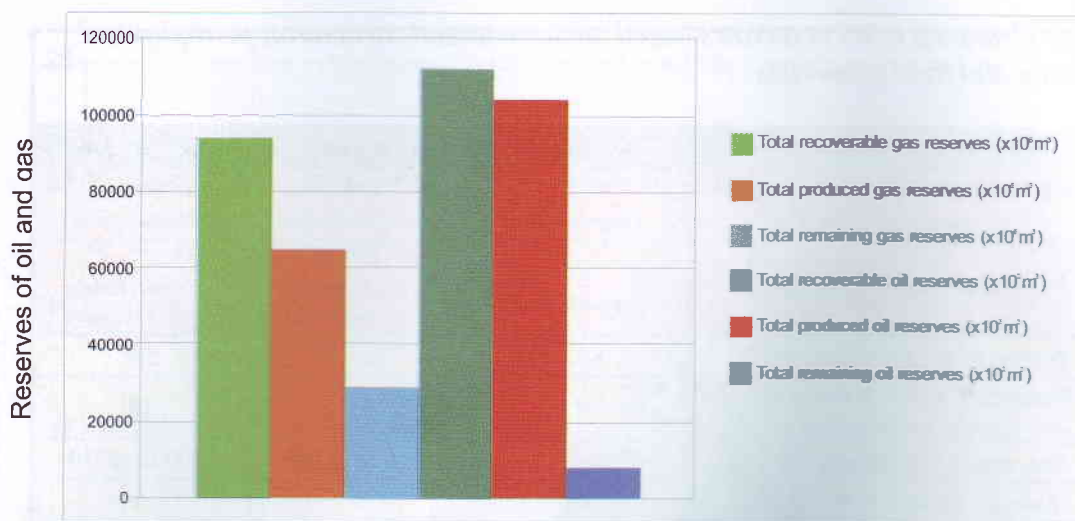


Figure 4. Recoverable (+ produced + remaining) reserves of oil and gas in the CPBS (from: Velić et al., 2008)

Table 2. Croatian recoverable (+ produced + remaining) hydrocarbon (*reserves given in brackets are condensate volumes) reserves

Dobrova et al., 2003						Velić et al., 2010					
Recoverable reserves		Cumulative Production		Remaining Reserves		Recoverable reserves		Cumulative Production		Remaining Reserves	
Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas	Oil	Gas
141.18	108.11	109.70	26.16	31.48	81.95	112.06 (10.73)	100.67	104.05 (6.93)	64.91	8.01 (3.80)	35.76
Oil in 10 ⁶ m ³ ; Gas in 10 ⁹ m ³ .											

3. Conclusions

Some studies for the CPBS stated that that there is 2-4 times more oil had been generated than it was proven in existing reservoirs. Although it can be overestimated value, there is for sure some significant part of hydrocarbon reserves that could be:

- (a) Producing with increased maximal estimated recovery from existing fields, especially from the reservoir belonging to 2nd depositional megacycle, i.e. in Pannonian and Pontian sediments (1st reservoir lithofacies);

- (b) Discovering the new ones reservoirs as satellite to existing fields or maybe in the pre-Neogene basement or 1st Neogene megacycle (Badenian);
- (c) Estimation of gas potential for the youngest part of 2nd and the oldest of 3rd Neogene megacycle (Upper Pontian and Pliocene sediments).

Potential reservoirs can be discovered using different geological models, especially models of regional and local hydrocarbon systems in the CPBS. In any case, the further exploration need to be oriented to regionally weaker explored chronostratigraphic units, like Badenian, Upper Pontian or Pliocene sediments. Stratigraphic traps in the sandstones of 2nd Neogene megacycle, located in the margins of larger anticlines with smaller closure, maybe can be primary goal for exploration of existing hydrocarbon fields.

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