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Review paper

Hydrocarbon Reserves Replacement - Methods and Expenditures

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Key words: Hydrocarbon reserves replacement, Classification of hydrocarbon reserves, Acquisition of reserves, Reserve management, Development expenditure, Production cost, Finding cost, Net present value, Reservoir management.

Ključne riječi: obnavljanje zaliha ugljikovodika, klasifikacija zaliha ugljikovodika, kupnja zaliha, upravljanje zalihama, ulaganja u razradu, troškovi proizvodnje, troškovi pronalaženja, netto sadašnja vrijednost, upravljanje ležištima.

Abstract

Results of INA-Naftaplin's activity in replacement of oil and gas reserves are compared to those of western oil companies. The reserve replacement ratio for the 20-year period from 1975-1994 is approximately 90%, but it averaged only 43% in the last 5 years when exploration results in our domestic area were poor. Exploration and development costs, which have also been analysed, indicate a higher cost per barrel discovered in the last 5-year period. Acquisition of reserves as a method of reserve replacement is still unknown in Croatia, but precisely this method should provide a solution to the current situation.

Remaining oil reserves are to be found in old fields in their final development phase and only selective introduction of new technologies and EOR processes, as well as the lowering of production costs, can guarantee their rational production. Full introduction of the reserve management concept is a guarantee that such activity will proceed in a manner customary for western oil companies. Results achieved to date on concessions abroad indicate considerably higher efficiency and lower oil costs, justifying our growing orientation towards exploration of foreign concessions.

Sažetak

U radu se analiziraju načini i rezultati aktivnosti INA-Naftaplina u obnavljanju rezervi nafte i plina. Ti rezultati usporedeni su s aktivnostima zapadnih naftnih tvrtki. Koeficijent obnove rezervi za dvadesetogodišnje razdoblje 1975-1994 je oko 90%, a prosjek posljednjih pet godina je 43% sa skromnim rezultatima u istraživanju na domaćem prostoru. Analiziraju se i ulaganja u istraživanje i razradu, iz čega se može zaključiti da ulaganja po jedinici otkrivenih rezervi također rastu u posljednjem petogodišnjem razdoblju. Kupnja rezervi kao način nadomještavanja rezervi kod nas je nepoznat, a upravo to bi trebao biti izlaz iz situacije u kojoj se sada nalazimo.

Preostale rezerve nafte su na starim poljima u završnoj fazi razrade, te samo selektivna primjena novih tehnologija i EOR procesa kao i sniženje troškova proizvodnje mogu osigurati njihovo ekonomično crpljenje. Potpuno uvođenje koncepta upravljanja ležištima pretpostavka je da će se ta aktivnost odvijati na način kako je to organizirano u zapadnim naftnim tvrtkama. Dosadašnji rezultati aktivnosti na koncesijama u inozemstvu ukazuju na znatno veću efikasnost i nižu cijenu koštanja nafte, što opravdava sve značajniju orijentaciju tvrtke na istraživanja na inozemnim koncesijama.

1. INTRODUCTION

The primary task of every oil company is the rational exploitation of the discovered reserves of hydrocarbons, the most important activity being the replacement of oil reserves at least equivalent to the quantities produced in a given period. Oil companies which fail to replace the produced quantities of oil and gas are essentially self-liquidating.

Reserves can be replaced by several methods, and such activity is known as **reserve management**. The most important of these methods is the discovery of new reserves as a result of exploration for oil and gas. Development operations leading to the increase of recoverable reserves in certain phases of the field's productive life are almost equally important. Due to the fact that determination of hydrocarbon reserves within a reservoir is a complex process repeated several times during the productive life of a field, the influence of reserve revision on the total volume and quality of reserves is significant. The Rules on Categorization and Classification of Hydrocarbon Reserves in the Republic of Croatia include the term "balance reserves". They represent the fraction of the discovered oil and gas in place, which can be economically produced using existing technology.

During the long productive life of a field considerable technological advances in the development and production of oil and gas are to be expected, and the economic conditions such as price of hydrocarbon's products also change. These two groups of factors have an effect on the revision of reserves. Since Rules on Reserves Categorization in the Republic of Croatia differ from corresponding western standards, for the purposes of this paper reserves of A, B and C_1 category are identified as: proven "developed and undeveloped" reserves, according to the Society of Petroleum Engi-

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Year	Proved reserve changes 10^3 TOE				Production 10^3 TOE	Reserve replacement ratio		
	Discoveries	Extensions & sec. recov.	Revisions +/-	Total		(1):(5) %	((1)+(2)):(5) %	(4):(5) %
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
1975	73	8338		8411	3654	2.0	230.2	230.2
1976			4470	4470	3875	0.0	0.0	115.4
1977		2100	-3315	-1215	4078	0.0	51.5	-29.8
1978	18550	2995	1250	22795	5194	357.1	414.8	438.9
1979			-1068	-1068	4122	0.0	0.0	-25.9
75.-79.	**18623**	**13433**	**1337**	**33393**	**20923**	**89.0**	**153.2**	**159.6**
1980	500		-1875	-1375	4226	11.8	11.8	-32.5
1981		1240	937	2177	4524	0.0	27.4	48.1
1982	510	594	72	1176	4576	11.1	24.1	25.7
1983	385		-3106	-2721	4277	9.0	9.0	-63.6
1984	2311			2311	4341	53.2	53.2	53.2
80.-84.	**3706**	**1834**	**-3972**	**1568**	**21944**	**16.9**	**25.2**	**7.1**
1985			132	132	4735	0	0.0	2.8
1986	6879	80	792	7751	4846	142.0	143.6	159.9
1987	6897	8694	7132	22723	5200	132.6	299.8	437.0
1988	2611		58	2669	5038	51.8	51.8	53.0
1989		1173	1277	2450	4957	0.0	23.7	49.4
85.-89.	**16387**	**9947**	**9391**	**35725**	**24776**	**66.1**	**106.3**	**144.2**
domest. & intern. **85.-89.**				**37306**	**25450**			**146.5**
1990		733	-693	40	4633	0.0	15.8	0.9
1991		505	-1071	-566	4171	0.0	12.1	-13.6
1992		204	1558	1762	3457	0.0	5.9	51.0
1993		513	6614	7127	3890	0.0	13.2	183.2
1994	1589		-1539	50	3510	45.3	45.3	1.4
90.-94.	**1589**	**1955**	**4869**	**8413**	**19661**	**8.1**	**18.0**	**42.8**
domest. & intern. **90.-94.**	**3274**	**1955**	**5530**	**10759**	**20691**	**15.8**	**25.3**	**51.9**
TOTAL	**40305**	**27169**	**11625**	**79099**	**87304**	**46.2**	**77.3**	**90.6**
TOTAL domest. & intern.				**83026**	**89008**			**93.3**

Table 1 INA-Naftaplin's Replacement of Proved Hydrocarbon Reserves for the Period 1975-1994.

neers methodology (S.P.E., 1987). The volume of reserves and production of oil and gas is expressed in tons of equivalent oil (TOE: 1000 m^3 of gas = 1 t of oil).

Through the activity of every oil company there are certain periods when the produced quantities cannot be replaced by any of the described methods and in such cases oil companies usually resort to acquisition of reserves from already discovered fields or from fields in development. In such a manner stabilization of business operations is achieved and the basis formed for the new cycle of exploration and other activities. Financial investments into the replacement of reserves by each of the mentioned methods are naturally of primary importance.

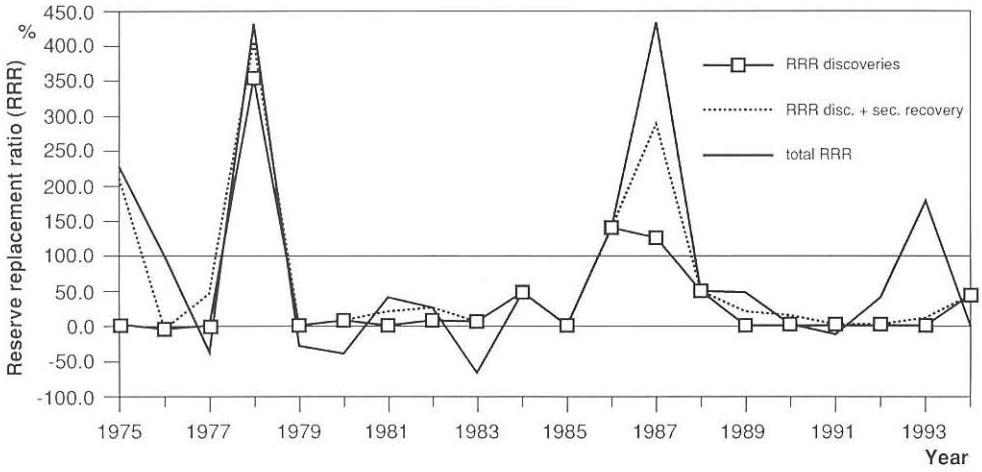

Fig. 1 Reserve replacement ratio for INA-Naftaplin domestic.

The analysis of activities related to the reserves replacement on a year to year basis will not give realistic results, since they can be altered by unexpected successes or failures. Instead, the results and expenses for the replacement of reserves over a longer period - at least 5 years - should be reviewed. The paper will analyse the activity of INA-Naftaplin during the preceeding 20-year period and compare it with the results of well-known western companies. This paper is the first attempt to analyse reservoir exploration and development results and expenditures in INA-Naftaplin beyond those intended for internal use.

The data on reserves have been taken from the so-called Book of Reserves, with approval of the authorized Committee of the Ministry of Economic Affairs. The Company's Financial Department provided the data on exploration and development investments.

2. METHODS AND RESULTS OF RESERVE REPLACEMENT

Table 1 and Fig. 1 show the results of reserve replacement by INA-Naftaplin in the 20-year period from 1975 to 1994. During this period 72% of the cumulative production of INA-Naftaplin has been realized and reserves have increased by 44% in comparison with those registered at the beginning of that period. The analysis was prepared to establish the reserve replacement ratios (RRR). This ratio is a relationship between the volume of replaced reserves and realized production in a certain period.

The paper analyses three methods of reserve replacement: discovery, field extension and introduction of secondary methods during the development of a field, as well as the revision of reserves upwards or downwards. Since the data have been taken from the Book of Reserves, there's a certain lag, especially between the discovery and booking of proven reserves, which in our case may range from 2 to 12 years. The average lag is 8 years for the 22 newly discovered and analysed fields (for the group of companies from Table 2 that average is 5 years). During the analysed period 8 new fields have been discovered in this period and out of the 22 new fields 18 can be classified as oil and 4 as gas fields. The ratio of discovered reserves is 90:10% in favour of gas and gas-condensate fields. Total reserve

Oil Company	Expl. spend $/BOE produced	Total spend $/BOE produced	Finding expend. $/BOE*	Acquisit. expend. $/BOE	Develop. expend. $/BOE**	Total RR. expend. $/BOE	RRR expl.+revis %	Total RRR %
Majors	1.63	4.98	3.31	3.91	3.59	7.24	68	100
US independ.	2.76	7.68	2.82	3.99	1.77	4.25	99	149
8Europeans	3.64	14.8	3.1	3.33	1.72	5.4	128	310
INA (86.-90.)	5.4	8.89	5.34	-	2.41	6.16	101	144
INA (90.-94.)	2.83	3.91	8.63	-	3.80	9.12	32.8	42.8
INA (85.-94.)	4.21	7.04	5.81	-	2.85	7.09	72.5	99.3
INA domest. & intern. 90.-94	3.1	4.58	4.8	-	3.67	8.36	42.5	52.0

Table 2 Reserve Replacement Expenditure - 5-year average 1986-1990. Legend: *BOE - discovered+revision; **devel.expend. / Total reserve increased.

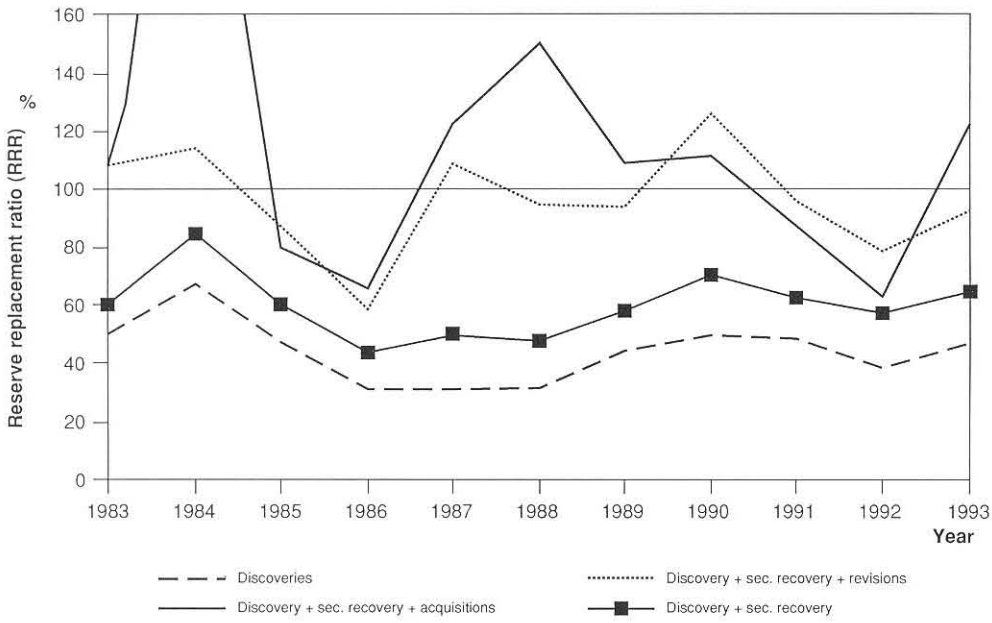

Fig. 2 Reserve replacement ratio for major companies.

replacement ratio for the 20 year period of activity in the Republic of Croatia is 90.6%, 50% of which are newly discovered reserves, and the remainder is the result of field extension and introduction of secondary oil recovery methods (31%) and revision of reserves (14%). Analysing the 5-year periods, the replacement of reserves was successful in the periods from 1975-1979 and 1980-1984. In the former the results can be mainly attributed to the discovery of the Molve gas field and the introduction of secondary oil recovery methods at the Beničanci and Žutica fields. In the later period the reserves of Kalinovac, Stari Gradec and Ivana gas and gas-condensate fields have been taken into account, together with those related to the extension of the Molve and Đeletovci fields, as well as the results of several successful revisions of reserves.

The average reserve replacement ratio based on exploration, which exceeds the balanced average achieved by the group of large oil companies in exploration over a several-year period (Fig. 2), can be attributed to three significant gas discoveries (Molve, Kalinovac, Ivana).

The results of the last 5-year period 1989-1994 (with RRR at 8.1%) are disappointing, especially in view of the fact that unrecorded but discovered reserves will not significantly change the situation. The results of the period from 1980-1984 are similar, in fact the overall results of reserve replacement by all methods are the lowest - only 7.1%.

Extension of reservoirs in the existing fields and the introduction of secondary methods to increase the recovery ratio is an important method for the replacement of reserves. For the group of major companies (Fig. 2) it amounts to approx. 20% and for INA-Naftaplin about 31%. It needs to be stressed that the most significant additional reserves acquired by this method have been recorded in the same period as the discoveries, resulting in two pronounced peaks in 1978 and 1987. Since we have no major oil fields as candidates for the introduction of secondary methods, this method cannot be expected to significantly increase our reserves. This paper particularly focuses on the rational utilization of remaining reserves. Activities involving the reinterpretation of geological models of reservoirs are ongoing and are expected to yield some positive results. The difference between the extension of reservoirs and revision of reserves has to be explained.

Extension of reservoirs results in new reserves based on the increase of reservoir volume defined after the completion of geological, geophysical analyses and after drilling. There is a term "reserves determined by bit", which are the result of operations conducted during field development.

Revision of reserves is also a continuous activity of field development which consists of the revision of all parameters for reserves calculation, including recovery factor prediction. Revisions were carried out at 5 year intervals. The basis for every revision is the monitoring of field production performance and results of calculations or numerical simulation of the reservoir depletion process. Revisions can be optimistic or pessimistic, the average for the 20-year period from Table 1 is +14%. Pessimistic revision of reserves (-18%) is evident in one 5-year period (1980-1984) and for other such periods revisions differ by +6% to +38% in comparison with the total change of reserves. The size of change in reserves based on revisions also reflects company policy, i.e. is it more or less careful in the definition of reserves. Depending on the year the growth of reserves based on revision ranges from 20-50% for the group of large companies (Fig. 2).

Results of revision are often added to the initial reserves of the discovered fields, as in this paper in the analysis of funds spent in exploration activities (Table 2).

Results related to reserve replacement mentioned so far refer to the activity of INA-Naftaplin in our national exploration area. Effects of activities on concessions abroad are presented in Table 1. Detailed data are given only for the 1990-1994 period, together with the overall effects for the two 5-year periods when we recorded production abroad (mostly from Block 3 in Angola).

Contribution of our expenditure into exploration and development abroad is evident. The reserve replacement ratio for foreign fields for the period 1990-1994 amounted to 228% and reached 235% in the period from 1985-1990.

3. RATIONAL EXPLOITATION OF INA-NAFTAPLIN'S REMAINING RESERVES

Out of the predicted recovery ratio of 36%, 30% of the discovered reserves of oil have been produced by the end of 1995. The realized recovery ratio for free gas amounts to 30% of the predicted 72%. Only the exploitation of the remaining oil reserves will be dealt with in this short analysis, since major gas fields are in the stable development phase and incorporation of new reserves into production is to follow.

Based on the current data, about 5 x 10^6 m^3 of oil or about 25% of the remaining recoverable oil reserves have been categorized as uncommercial reserves, primarily in view of high production costs, particularly in the final phase of exploitation. By lowering exploitation costs and increasing well productivity part of those reserves could turn into commercial reserves.

Economic criteria will be decisive in the introduction of new technologies applicable to additional development of old reservoirs with reservoir pressures considerably below hydrostatic pressure and with high water content. Secondary methods are being applied in 15 major fields with over 80% of initial reserves, or where we have an efficient natural water drive.

The greatest attention should be focused on this group of fields, since the remaining 27 fields account only for 3 x 10^6 t of unrecovered reserves, and only 0.6 x 10^6 t of reserves that have not already been placed into production. The expected recovery rate for the first group of fields is estimated at 38%, which means that 62% of the discovered (geological) reserves would remain in the reservoir. According to the analyses, 22% is the so-called mobile oil in those zones of the reservoir with poor reservoir characteristics which have not been swept by water encroachment. A part of those reserves can be activated by in-fill drilling, application of intensive stimulation (hydraulic fracturing), drilling of horizontal well bores in old wells (re-entry), or by horizontal drilling. These operations are already in progress. The second part of remaining oil amounting to some 40% (90 x 10^6 t) is the so-called immobile oil, which remains in pore spaces behind the water front. Under our reservoir conditions, some of this oil can be recovered by the injection of CO_2 into the reservoir under miscible conditions. Laboratory research and numerical simulations have indicated that some 9-24 x 10^6 m^3 of oil could be recovered from the Ivanić Grad, Žutica and Stružec fields in this way. The projects are economically sensitive and only pilot-projects in the field could provide the data for business decisions related to their full-scale implementation.

Possibilities previously considered by Naftaplin's experts (BAUK et al., 1988) have only been briefly mentioned here. Other EOR processes would be hardly applicable in our conditions. In such ambitious projects it is important to apply the **reservoir management** concept, which is defined as: *increasing the economic value of oil and gas reservoir to the maximum by optimizing recovery and production, and by reducing expenditures and production costs to the minimum rates.*

This definition implies a continuous team effort of experts, including geophysicists, geologists, geostatisticians, reservoir engineers, production engineers and economic-analysts from the discovery of the field to its abandonment. This concept has been applied only partially and without continuity.

4. RESERVE REPLACEMENT EXPENDITURES

Analysis of expenditures into the exploration, development and acquisition of reserves on global, regional and company level is certainly the most important activity in directing **hydrocarbon reserve management** strategy.

Table 2 shows the data for groups of western companies (JOHNS & GAILEY, 1992) and for INA-Naftaplin for different time periods. INA-Naftaplin financial data were often inconsistent due to the nature of the former economic and political system. Exploration and development expenditures were often burdened with irrelevant items, while some expenditures which, according to current practice should have been incorporated were omitted.

Since the process of intensive analysis of all expenditures involved in the process of exploration, development and production of oil and gas is relatively new, it is to be expected that this pioneering work could experience some corrections. However, estimates derived on the basis of such data, in the author's opinion, should not undergo major changes. Table 2 lists the data related to overall spending per barrel produced, which is an indication of the intensity of spending during certain periods. A drop in investment by INA is evident in the period 1990-1994, but over a longer period investments are at par or higher than in certain groups of western companies. The effects of this can be seen in the last two columns.

Spending during a particular period (especially in exploration) has a greater effect on reserves in the following period than in the one when they were invested. Negative consequences of lower investments in the

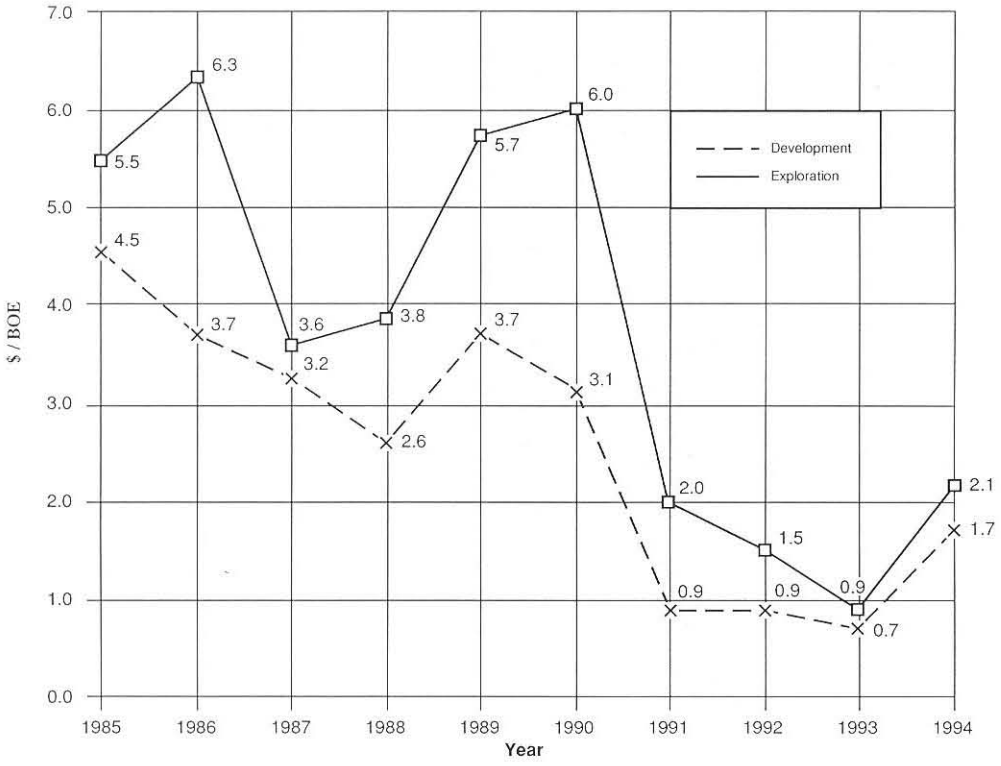

Fig. 3 Exploration and development expenditures per BOE produced in INA-Naftaplin.

period from 1991-1994 (Fig. 3) remain to be identified. Spending per barrel of discovered reserves is also listed in Table 2. Overall exploration costs refer to discovered reserves together with revisions made during the productive life of a field and considerably exceed the data for foreign companies. It also refers to development spending and particularly to the overall cost of reserve replacement, except possibly for the period from 1986-1990.

In business circles, the rule is that total costs of reserve replacement should not exceed 1/3 of product's selling price, if one is to achieve acceptable returns.

5. ACQUISITION OF RESERVES

We have already mentioned the importance of acquisition of reserves on the stabilisation of business operations. Table 2 shows expenditures of foreign companies for the acquisition of reserves. Such activities have not been previously recorded in INA- Naftaplin.

Companies are buying (or selling) reserves to stabilize the overall costs of reserve replacement. Figure 4 shows reserve replacement costs by all methods and participation of reserve acquisition.

We have already mentioned that initial estimates of discoveries based on exploration are considerably upwardly revised (in INA by 6-38% and in the group of western companies by an average of 40%) (Fig. 2). Oil companies which buy reserves on the market try to make reserve estimates as reliable as possible and expect significant increases during development. Some analyses indicate a 15% improvement in comparison with the initial estimates. One such analysis (JOHNS & GAILEY, 1992) indicates a great dispersion of acquisition estimates.

The Net Present Value $(NPV)_{10}$ of future production estimated at the time of purchase and compared to the acquisition price, differs from the re-estimated $(NPV)_{10}$ and paid price for acquisition updated to reflect the time value of money at the time of revision of these transactions.

The data indicate that some companies have overestimated purchased acquisitions by as much as three times, but some can expect 2-4 times greater profits on their investments. Discovered fields, fields in development or those in full production are being purchased.

INA-Naftaplin has made some attempts in that respect, but without success.

An analysis of indicators showing effects of reserve replacement (Fig. 1) should lead to the strategic conclusion that acquisition of reserves can reliably increase reserves at present and provide an impetus for the new cycle of reserve management based on modern concepts which this paper tried to outline.

6. CONCLUSION

The primary task of every oil company engaged in exploration and production of oil and gas is to increase reserves of hydrocarbons. In the preceeding 20-year period INA-Naftaplin has, by exploration and development activities, succesfully replaced almost all produced quantities. It has also maintained the stability of hydrocarbon production in the process, but with a considerable drop in oil production.

This can mostly be attributed to the discovery of gas and gas-condensate fields and to the introduction of

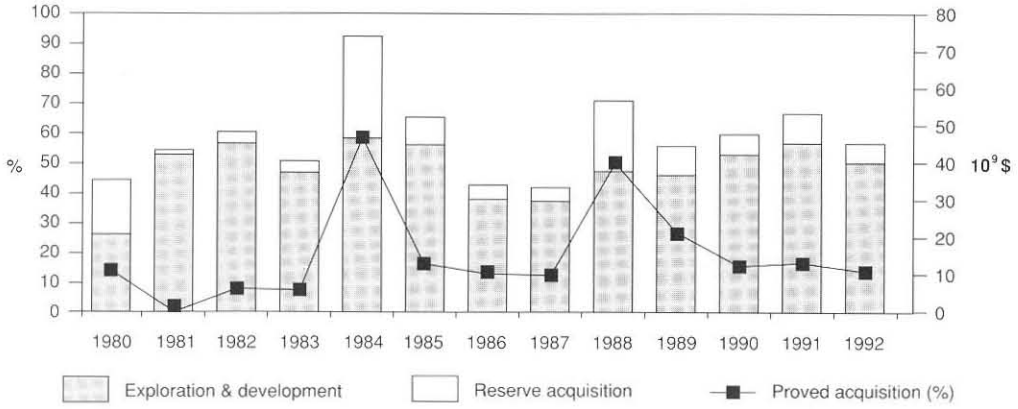

Fig. 4 Worldwide capital expenditures for exploration and development and proved reserve acquisitions.

secondary recovery methods in some fields. The reserve replacement ratio in the last 5 years is below 50%, partly caused by lower investment in explorations, and partly because the remaining potential of our domestic exploration area has not been able to provide new reserves sufficient to replace the quantities produced, particularly where oil is concerned. Therefore our reserve replacement costs are somewhat higher than the average for western companies. Remaining reserves of oil are mostly to be found in very old fields and the selective introduction of new technologies and EOR processes could raise their production economics. Results of exploration activities abroad to date only stress the necessity for its further intensification. In the next several years results which would stabilize the reserves of oil and prevent further drop in production are unlikely. Acquisition of reserves would be a proper strategic decision at present. It would employ the considerable human potential of the company and provide an impetus for the new cycle of reserve management based on principles used in modern western oil companies.

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