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The analysis of water injection systems in sandstone hydrocarbon reservoirs, case study from the western part of the Sava Depression

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Preliminary communication

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Abstract
Formation water injection is one of the constituent parts of the hydrocarbon production cycle in the secondary exploitation oil recovery phase. The formation water injection system can be divided the into single and central injection systems. The formation water injection costs have been described in this paper using the examples of field A (central injection system) and field B (single injection system). These are located in the western part of the Sava Depression. The reservoir rocks regarding the oil and gas fields A and B are fine to middle grained sands and quartz micaceous sandstones that belong to the geological age of Lower Pontian. The average porosity (intergranular) in field A is 15–35% and in field B it is 10-31%, depending on the depth and cementation percentage. Regarding the oil and gas fields described in this paper, a cost comparison has been made and an injection system sensitivity analysis as well as an analysis of possible injection systems' costs for optimization and rationalization.

Keywords
Water injection system; sensitivity analysis; economics of injection system; Sava Depression; sandstone

1. Introduction

Formation water injection is one of the constituent parts of the hydrocarbon production cycle. The economics of formation water disposal becomes essentially important in the production of oil and gas originating from mature oil and gas fields. The share of formation water regarding these fields in the overall amounts of the fluid gained is increased (see **Fig. 1**).

Figure 1 shows an increase in the amount of extracted formation water. From an economic point of view, this fact represents a relatively large load regarding the hydrocarbon production. Due to the increase in the quantity of the produced formation water, the cost of its disposal becomes increasingly important in the economics of oil and gas fields. This article will be dealing with the injection systems applicable to the oil and gas fields situated in the western part of the Sava depression in the Croatian part of the Pannonian Basin System. Moreover, a comparison between the central and single water injection systems will be made using the example of real oil and gas fields that will in this paper be referred to as A and B and their possible optimization with the goal of achieving larger profitability of hydrocarbon production.

2. The formation water injection in oil and gas fields

Formation water has a complex composition, but its constituents can be broadly classified into organic and inorganic compounds, including formation solids, salts, scale products, waxes, etc. (**Ignunnu & Chen 2012**). The separated formation water has to be properly disposed and the different possibilities of formation water disposal are (**Pedenaud 2006**):

- Re-injection into the reservoir,
- Relocated to other adequate geological formations,
- Treatment and discharge in the natural environment.

The formation water separated from the dehydration process is most frequently injected due to the reservoir pressure maintenance. Other means of formation water disposal (purification and disposal) ensure the unobstructed work of oil and gas fields, but have no results when it comes to the recovery increase. Different factors that affect the formation water injection during the life of oil and gas fields are shown in **Fig. 2**.

The top triangle presents the factors affecting the well injectivity while the lower triangle represents the waterflood factors that may be affected by the well injectivity (**Pallson et al 2003**). The formation water injection system can be divided into single and central injection systems (see **Fig. 3**).

In the central injection system (**Fig 3-A**), formation water is gathered in the central station for formation water injection. The central station for formation water injection contains centrifugal and reciprocating pumps. The centrifugal pumps ensure a constant formation water supply for the reciprocating pumps. The function of reciprocating pumps is to achieve the pressure of formation water injection regarding the selected pumps. Poste-

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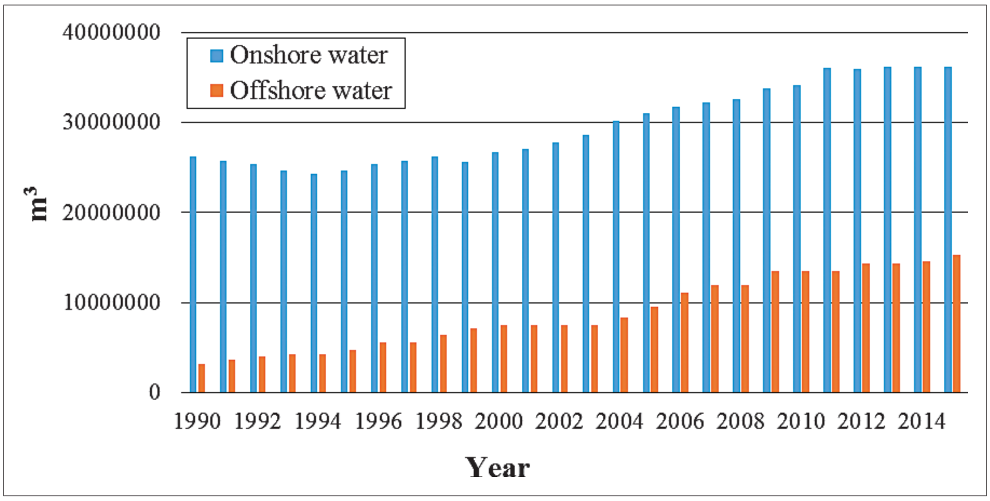

Fig. 1. The annual global water production (units on ordinate axis are changed into SI, from **Fakhru'l-Razi et al. 2009**)

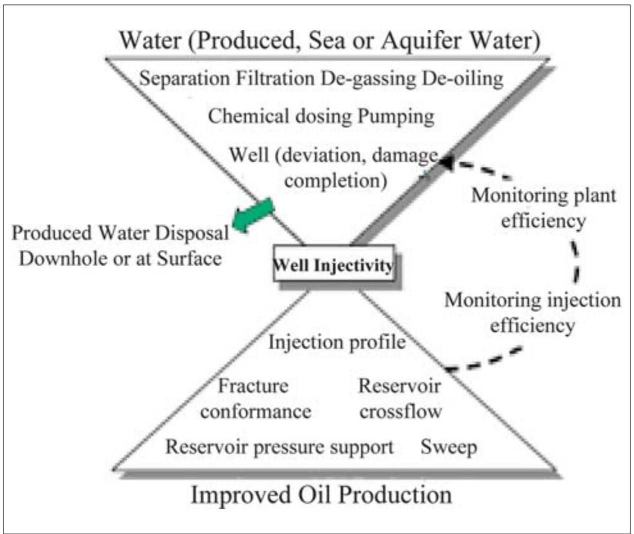

Figure 2. Factors that influence the well injectivity (**Pallson et al 2003**)

rior to achieving this pressure, the formation water is distributed by the pipeline to the injection wells. In the single injection system, (**Fig 3-B**) the formation water in the formation water pump station is distributed by a low pressure pipeline to the injection wells with centrifugal pumps. The injection well is housed in the container in order to protect the surface injection equipment. Every injection place is equipped with a reciprocating pump that ensures the pressure of formation water injection into the reservoir.

3. Geological characteristics of oil and gas fields A and B

Oil and gas fields A and B are located in the Croatian part of the Pannonian Basin System, that is; the western part of the Sava Depression (see **Fig. 4**).

Reservoir rocks of oil and gas field A are fine to middle grained sands and quartz micaceous sandstones of

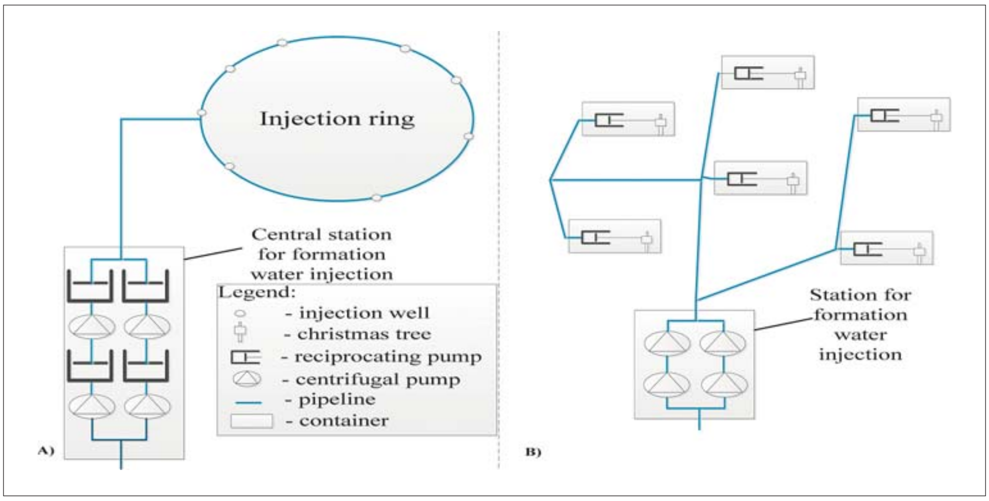

Figure 3. Central and single systems of formation water injection

Figure 4. Depressions located within the Croatian part of the **Pannonian Basin** System (**Velić et al., 2015**)

Lower Pontian age. Reservoir rocks are interlayered with marls and sandy marls. The reservoirs are tectonically or both tectonically and lithologically screened. The following chronostratigraphic units were determined on the field: Middle Miocene, Upper Miocene (Lower Pannonian, Upper Pannonian, Lower Pontian and Upper Pontian), Pliocene (Dacian and Romanian), Pleistocene and Holocene. The average porosity (intergranular) in the field is 15–35% depending on the depth and cementation percentage. Permeability is in the range from 2 to 200 mD (2 to $200 \cdot 10^{-15}$ m^2). The average net pay is 6 m.

Reservoir rocks of oil and gas field B are fine to middle grained sands and quartz micaceous sandstones. Reservoir rocks are interlayered with marls and sandy marls. Seal rocks are marls that turn into calcitic marls in the deeper reservoirs. The reservoirs are tectonically or both tectonically and lithologically screened. The following chronostratigraphic units were determined on the field: Middle Miocene, Upper Miocene (Lower Pannonian, Upper Pannonian, Lower Pontian and Upper Pontian), Pliocene (Dacian and Romanian), Pleistocene and Holocene. The average porosity (intergranular) in the field is 10–31% depending on the depth and cementation percentage. Permeability is in the range from 2 to 200 mD (2 to $200 \cdot 10^{-15}$ m^2). The average net pay is 15 m.

According to **Velić et al. 2012**, oil and gas fields are divided into: large fields, medium fields, small fields and very small fields. According to the above mentioned classification, small injection systems in this paper belong to medium fields, while the large injection systems belong to large fields. The possible ultimate recovery regarding large fields is 36.47% (103 216 280 m^3 oil) and, regarding medium fields, it equals 24.92% (8 290 547 m^3 oil) (**Velić et al., 2012**).

4. The formation water injection costs regarding the oil and gas fields A and B

An example of a single injection system is the oil and gas field B, while the A field is an example of a central injection system. Formation water is separated at one place into the oil and gas field B, while the formation water injection is performed on two fields. For practical reasons, this was named as the oil and gas field B, because it is a sole injection system. The formation water disposal is performed at the oil and gas field A, while the formation water at the oil and gas field B is injected with the purpose of supporting reservoir pressure. The oil and gas field A has a relatively large injection system, while

Table 1. The technical and geological characteristics of the oil and gas fields A and B

Oil and gas field A	Reservoir rock	Sandstone	**Oil and gas field B**	Reservoir rock	Sandstone
	Geological age	Lower Pontian		Geological age	Lower Pontian
	Depth (m)	807.5-1050.0		Depth (m)	1011.5-1593.5
	Number of injection wells	11		Number of injection wells	9
	Injection system	Central		Injection system	Single
	Injection pressure (bar)	40-62		Injection pressure (bar)	50-140
	Number of reciprocating pumps	5		Number of reciprocating pumps	9
	Number of centrifugal pumps	9		Number of centrifugal pumps	4
	Average power of injection pumps (kW)	52.50		Average power of injection pumps (kW)	37.66
	Quantity of injected brine water (m^3/year)	465 758		Quantity of injected brine water (m^3/year)	153 769

Table 2. Expenses of formation water injection in oil and gas fields A and B

Oil and gas field A									
The year	2009			2010			2011		
Quantity of injected brine water (m^3)	456 404			464 281			454 810		
Number of injection wells	11			11			11		
Description:	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%
Well maintenance	1 640 460	3.59	62.75	1 020 789	2.20	38.11	1 849 181	4.07	48.52
Maintenance of injection pumps	119 600	0.26	4.57	331 718	0.71	12.38	123 553	0.27	3.24
Electrical power	261 862	0.57	10.02	625 777	1.35	23.36	543 223	1.19	14.26
Chemicals	0	0.00	0.00	0	0.00	0.00	203 854	0.45	5.35
Staff costs and amortization	492 302	1.08	18.83	623 795	1.34	23.29	831 812	1.83	21.83
Construction work and other expenses	100 143	0.22	3.83	76 736	0.17	2.86	259 048	0.57	6.80
Total:	2 614 367	5.72	100.00	2 678 815	5.77	100.00	3 810 671	8.38	100.00
The year	2012			2013			2014		
Quantity of injected brine water (m^3)	472 073			479 280			467 698		
Number of injection wells	11			11			11		
Description:	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%
Well maintenance	284 625	0.60	14.02	0	0.00	0.00	0	0.00	0.00
Maintenance of injection pumps	730 227	1.55	35.95	131 403	0.27	6.42	736 973	1.58	22.31
Electrical power	586 563	1.24	28.89	293 687	0.61	14.35	248 253	0.53	7.51
Chemicals	163 454	0.35	8.05	226 424	0.47	11.06	248 620	0.53	7.53
Staff costs and amortization	210 000	0.44	10.34	144 000	0.30	7.03	144 000	0.31	4.35
Construction work and other expenses	55 790	0.12	2.75	1 251 781	2.61	61.14	1 925 958	4.12	58.30
Total:	2 030 659	4.30	100.00	2 678 815	4.27	100.00	3 303 804	7.06	100.00
Oil and gas field B									
The year	2009			2010			2011		
Quantity of injected brine water (m^3)	160 636			158 300			151 208		
Number of injection wells	9			9			11		
Description:	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%
Well maintenance	0	0.00	0.00	0	0.00	0.00	23 400	0.15	1.93
Maintenance of injection pumps	175 100	1.09	18.07	250 000	1.58	20.79	261 750	1.73	21.56
Electrical power	233 807	1.46	24.13	246 959	1.56	20.54	515 169	3.41	42.43
Chemicals	0	0.00	0.00	0	0.00	0.00	0	0.00	0.00
Staff costs and amortization	560 199	3.48	57.81	705 265	4.45	58.66	357 900	2.37	29.48
Construction work and other expenses	0	0.00	0.00	0	0.00	0.00	56 000	0.37	4.61
Total:	969 107	6.03	100.00	1 202 224	7.59	100.00	1 214 219	8.03	100.00
The year	2012			2013			2014		
Quantity of injected brine water (m^3)	153 939			152 015			146 514		
Number of injection wells	9			9			9		
Description:	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%	Amount (HRK)	Unit cost (HRK/m^3)	%
Well maintenance	128 311	0.83	7.15	0	0.00	0.00	0	0.00	0.00
Maintenance of injection pumps	721 379	4.69	40.20	212 484	1.40	16.38	343 133	2.34	22.84
Electrical power	650 980	4.23	36.27	887 609	5.84	68.41	985 959	6.73	65.62
Chemicals	0	0.00	0.00	8 434	0.06	0.65	9 437	0.06	0.63
Staff costs and amortization	238 000	1.55	13.26	144 000	0.94	11.10	144 000	0.98	9.58
Construction work and other expenses	56 000	0.36	3.12	45 000	0.30	3.47	19 909	0.14	1.33
Total:	1 794 670	11.66	100.00	1 297 527	8.54	100.00	1 502 438	10.25	100.00

the oil and gas field B has a relatively reduced injection system. The technological and economic characteristics of oil and gas fields A and B are shown in **Table 1**.

Table 1 contains all the elements crucial for the economic evaluation of the injection system. Based on the information in **Table 1**, the costs of formation water injection have been calculated according to **Ivšinović & Dekanić (2015)**. The calculated costs of formation water injection regarding the oil and gas fields A and B are shown in **Table 2**.

According to **Table 2**, the expenses that have the largest shares in the overall cost of formation water injection regarding the oil and gas field A are: well maintenance, electric power and injection pumps maintenance. These costs will be elaborated in the following chapters.

5. The main variables of sensitivity analysis regarding the single and central injection system cost using the example of the oil and gas fields A and B

The sensitivity analysis is done with the purpose of determining the positive or negative effect of the input variables on the output result of the overall costs. The chosen parameters are the critical ones and they are analysed for sensitivity. The interval for the possible values of critical parameters is defined as ±10-20% from the starting value of the critical parameter (**Bendeković et al. 2007**). The critical parameters in the costs of formation water injection according to **Table 2** for the oil and gas field A are the following expenses: injection pumps maintenance, electric power and well maintenance, and the costs regarding the oil and gas field B are: injection pumps maintenance and electric power. The well maintenance costs are not included in the field B analysis due to a small amount of data and a relatively small share in the total costs. The dependence of the changes in the principal expenses within the overall cost of formation water disposal for the oil and gas field A is shown in **Fig. 5.**

In the sensitivity analysis regarding the oil and gas field A the following mean values of the observed parameters have been taken into consideration: maintenance of injection pumps 1.74 HRK/m^3, electric power 0.92 HRK/m^3 and injection wells maintenance 1.74 HRK/m^3. The changes in the overall costs of formation water injection for the changes of the cost from 5% and 20% (see **Fig. 5**) for the above mentioned parameters are the following: injection pumps maintenance (0.65% and 2.61%), electric power (0.77% and 3.09%) and well maintenance (1.47% and 5.89%). According to this, the rationalisation and optimisation of the entire system of formation water injection on the oil and gas field A can

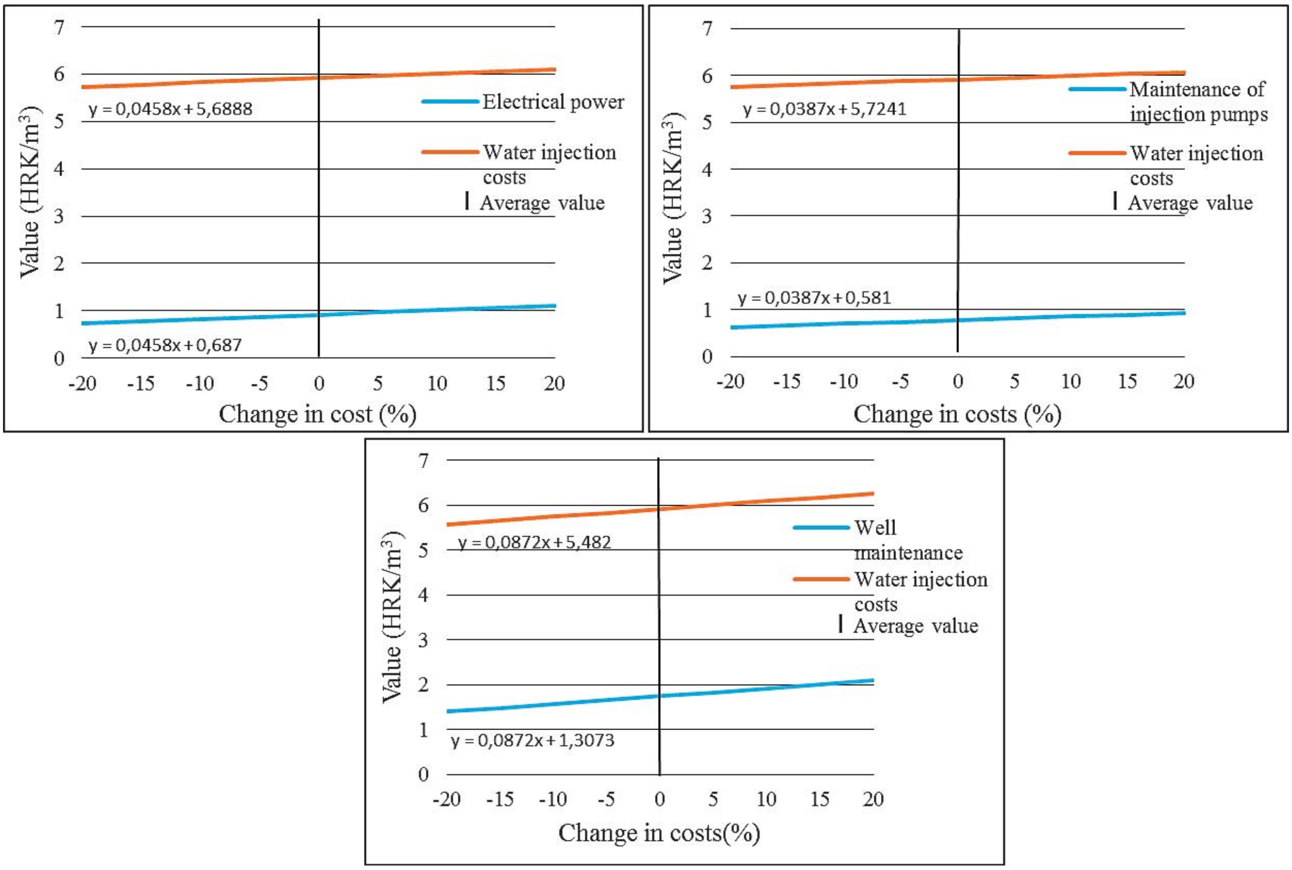

Figure 5. The influence of the cost change regarding electric power, injection pumps maintenance and well maintenance on the overall costs of formation water injection regarding the oil and gas field A.

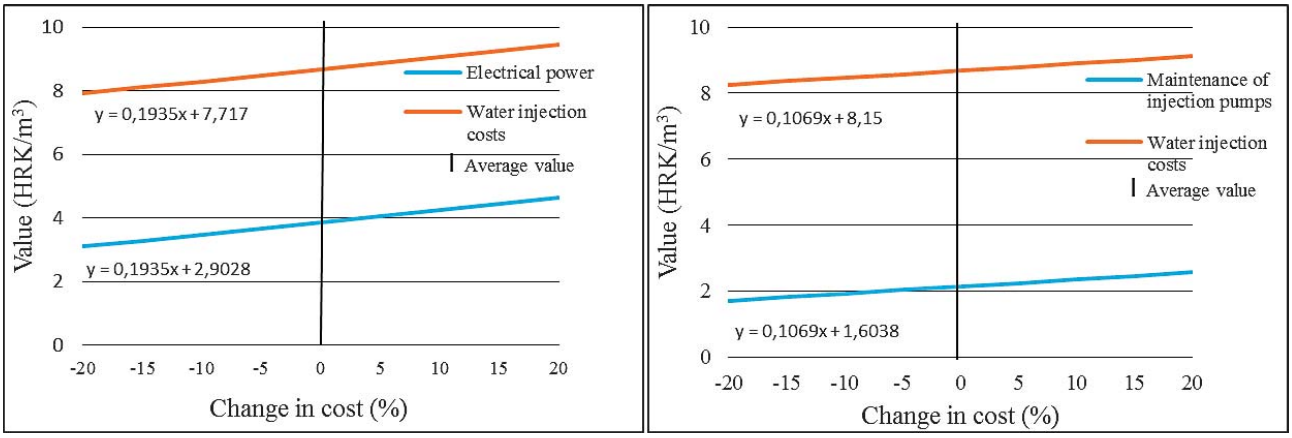

Figure 6. The effect of electric power and injection pumps maintenance cost changes on the overall cost of formation water injection regarding the oil and gas field B.

be achieved with the improvement of injection pumps (alteration of injection pumps, etc.), electric power (savings) and injection wells maintenance (formation water quality, workover, etc.) The dependence of capital costs within the overall cost of formation water injection is shown in **Fig. 6** regarding the oil and gas field B.

In the sensitivity analysis regarding the oil and gas field B, the following mean values regarding the observed parameters have been taken into consideration: injection pumps maintenance 2.14 HRK/m^3 and electric power 3.87 HRK/m^3. The changes in the overall expense of formation water injection regarding the cost changes of 5% and 20% (see **Fig. 6**) regarding the above mentioned parameters are the following: Injection pumps maintenance (1.23% and 4.92%) and electric power (2.23% and 8.91%). The rationalisation of the formation water injection on the oil and gas field B can be achieved according to **Fig. 6** with the improvement of injection pumps maintenance (replacement of pumps, etc.) and by savings in electric power (formation water quality, workover, etc.).

6. The optimization of the injection systems of oil and gas fields A and B considering the sensitivity analysis

The optimization of the above mentioned oil and gas fields in the sensitivity analysis in the previous chapter can be achieved in the following segments of the injection system:

a) The change of the reciprocating/ centrifugal pumps

b) The quality of formation water

c) The workover of injection wells

6.1. The change of reciprocating/centrifugal pumps

In the oil and gas fields considered in this paper, the reciprocating pumps are used to achieve the formation water injection pressure, while the centrifugal pumps are used to ensure constant supply for the reciprocating pumps. This chapter will consider the possibility of ensuring a constant supply for the reciprocating pumps. It will take into consideration the possibility of applying centrifugal pumps instead of the reciprocating ones during the formation water injection, with the purpose of decreasing operating costs regarding the injection system. The advantages of reciprocating pumps are (**Arnold 1987**): for a given speed, the rate of discharge is practical, the efficiency is high regardless of the head and speed, adapted to handling viscous fluids and they are usually self-priming. The most important deficiency is the often need for maintenance, especially during the injection of corrosive liquids and sand-polluted liquids. The reciprocating pumps can be constructed for working conditions under pressures higher than 200 bars and capacities up to 1 000 m^3/d (**Sečen 2006**). The advantages of centrifugal pumps are (**Arnold 1987**): simple construction, low prices, low maintenance, small space requirement in relation to their capacities, the capacity adjusts automatically to the changes in the head. Conventional centrifugal pumps operate at speeds between 1 200 and 8 000 rpm (126 rad/s – 838 rad/s), very high speed centrifugal pumps, which can operate up to 23 000 rpm (2 409 rad/s), and are used for low-capacity, high head applications (**GPSA 2004**). Centrifugal pumps are less efficient than the reciprocating ones, but have a higher work capacity and lower maintenance costs. They are used for satisfying the capacity of several thousand m^3/d under pressures lower than 100 bars. They can also be used under pressures lower than 20 bars, with the capacity of a several hundred m^3/d (**Sečen 2006**).Due to the characteristics of the injection systems according to **Table 1**, the horizontal multistage centrifugal pumps can be applied to the oil and gas field A, while the multicylinder plunger pumps are used on the oil and gas field B. The horizontal multistage centrifugal pumps can be applied on the oil and gas field A due to relatively large quantities of formation water and a lower injection pres-

Table 3. The performance of the horizontal multistage centrifugal pump and triplex pump (**Newman et al 2015**)

Parameters	Triplex pump	Horizontal multistage centrifugal pump
Max injection rate and pressure of slurry	3.4 bbl/min (0.01 m^3/s) @ 1000 psi (69 bars)	7.8 bbl/min (0.02 m^3/s) @ 2300 psi (159 bars)
Injection time for 600 bbl (95 m^3) of slurry	3 hours	1 hour 30 min
Max injection rate and pressure of sea water	3.3 bbl/min (0.01 m^3/s) @ 2000 psi (138 bars)	4.2 bbl/min (0.01 m^3/s) @ 2200 psi (152 bars)
Injection time for 1000 bbl (159 m^3) of sea water	5 hours	4 hours 40 min

sure, while this is not the case with the oil and gas field B due to higher injection pressures and relatively small quantities of formation water. The comparison between the pumping rate of the horizontal multistage centrifugal and triplex pump is shown in **Table 3**.

Table 3 shows how the horizontal multistage centrifugal pump can replace the triplex pump on the oil and gas field A according to the characteristics of the injection system in **Table 1**. Therefore, considering the maturity of the oil and gas field A, a further increase of the quantity of formation water can be expected. This fact favours the application of horizontal multistage centrifugal pump. The application of centrifugal pumps ensures the possibility of an increase in the production of formation water, lower maintenance and employees' costs, etc. The old reciprocating pumps can gradually be replaced by new ones with better effectiveness on the oil and gas field B due to the complex relief position of the injection wells. This will ensure lower operating costs.

6.2. Formation water quality

The objective of any water-injection operation is to inject water into reservoir rock without plugging or permeability reduction from particulates, dispersed oil, scale formation, bacterial growth, or clay swelling (**Patton 1990**). On the fields covered in this paper, there has been a dosing of scale and corrosion inhibitors while the formation water is not being filtered. Particles coated with oil may reduce permeability by as much as 50% (**Dunn-Norman & May 1997**). The installment of a formation water filter would ensure a reduction of the injection pressure which would ultimately result in a reduction in costs of electric energy, maintenance of injection pumps and equipment, and a longer period between workovers, etc. Although a possible installment of the filter would include its maintenance costs, the savings would be realized through a reduction in all the parameters shown in the sensitivity analysis in the previous chapter.

6.3. The workover of injection wells

The injection wells are equipped with a tubing set on the packer and a long string casing cement. The injection intervals in the oil and gas field A are a combination of ''open hole'' and ''cased and perforated'', while the wells on the field B are ''cased and perforated''. The injection wells workovers regarding the period from 2009 to 2014 were performed four times on field A and two times on field B. According **to Ochi & Hofsaess (2015)**, the wells with cased and perforated injection intervals require a better water quality than those with open hole injection intervals. Furthermore, wells with cased and perforated injection intervals require also a bigger injection pressure than those with open hole injection intervals. As stated in the previous chapter, the increase in the formation water quality and a regular workover can lead to greater injection capacity, a lowered injection pressure, lower electric energy costs, etc. Regular workovers achieve a larger injection capacity, while simultaneously decreasing maintenance costs which significantly influences the rentability of the field regardless of the eventual increase of well maintenance costs.

7. Conclusion

The central injection system is applicable in the analyzed space regarding the oil and gas fields that occupy a minor surface (<12 km^2), large injection rates (>1200 m^3/d) and relatively minor injection intervals depths (<1000 m); while in the other cases a single injection system is used. Regarding the amount of formation water analysed in this paper, the central system is more efficient regarding the oil and gas fields with a greater amount (>1200 m^3/d), while the single water-injection system is more efficient regarding minor amounts (<450 m^3/d). Economically speaking, the central injection system is cheaper than the single one. The unit cost of formation water injection regarding the oil and gas field A (central system) is 5.92 ± 1.60 HRK/m^3, while the oil and gas field B (single system) is 8.68 ± 2.00 HRK/m^3. The sensitivity analysis made has shown that the change in the principal expenses (electric energy, maintenance, etc.) significantly influences the final formation water expenses. It has also shown that the optimization of the injection systems (injection pumps, workovers, formation water quality) using the example of the oil and gas fields A and B can achieve significant financial savings (10-20 % of the injection system's expenses), depending on the capital investments in the system. With the decrease in oil prices on the markets, the operating costs and the rentability of oil and gas fields comes to focus. By optimizing the formation water injection prices, the gains regarding the exploitation fields can be increased, even with lesser prices regarding the production of a 1 m^3 of the equivalent of oil. This means that the field becomes more rentable and its lifespan is directly extended. According to the remaining hydrocarbon reserves mentioned in chapter 3, with the rationalization and optimation of the injection system, larger quantities of oil can economically be gained, which consequently increases the ultimate recovery of mature fields.

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8. References

Arnold, K.E. (1987): Surface Facilities for Waterflooding and Saltwater Disposal. Bradley, H. B. (ed.):Petroleum engineering handbook, Richardson, 34 p.

Bendeković, J., Bendeković, D., Brozović, T., Jančin. T. & Lasić, V. (2007): Priprema i ocjena investicijskih projekata (Preparation and evaluation of investment projects), FOIP 1974. d.o.o., (in Croatian), 442 p.Dunn-Norman, S. & May, E.A. (1997): An Overview of Injection Design, SPE Production Operations Symposium, 1997. March 9-11, Oklahoma City.

Fakhru'l-Razi, A., Alireza, P., Luqman Chuah, A., Dayang Radiah, A.B., Sayed Siavash, M., Zurina Zainal, A. (2009): Review of technologies for oil and gas produced water treatment, Journal of Hazardous Materials 170, 530-551, Elsevier.

Gas Processors Suppliers Association (2004): Engineering data book, GPSA, 822 p.

Igunnu, E.T. & Chen G.Z.(2012): Produced water treatment tecnologies, International Journal od Low-Carbon Technologies, 1-21.Ivšinović, J. & Dekanić, I. (2015): The Basic of Model for Marginal Testing Of Costs for Disposal of Extracted Formation Water, The Mining-Geology-Petroleum Engineering Bulletin, 85-100.

Newman, K., Woolsey, G., McCosh, K., Hand, E & Boodhai, M. (2009): Multistage Centrifugal Pumps for Drilling and Production Waste Injection Operations, SPE Asia Pacific Health Safety, Security, and Environment Conference an Exhibition, 2009. August 4-6, Jakarta.

Ochi, J. & Hofsaess, T. (2015): Role of Well Completion in PWRI design, SPE European Formation Damage Conference and Exhibition, 2015. June 3-5, Budapest.

Palsson, B., Davies, D. R., Todd, A.C. & Somerville, J.M. (2003): Water Injection Optimized with Statistical Methods, SPE Annual Technical Conference and Exhibition, 2003. October 5-8, Denver.

Patton, C.C. (1990): Injection-Water Quality, The Journal of Petroleum Technology, 1238-1240.

Pedenaud, P. (2006): TOTAL Experience To Reduce Discharge of Hydrocarbons Through Produced Water, SPE International Conference of Health Safety, and Environment in Oil and Gas Exploration and Production, 2006. April 2-4, Abu Dhabi.

Sečen, J. (2006): Metode povećanja iscrpka nafte (Methods of enhanced oil recovery), INA, Industrija nafte d.d., (in Croatian), 608 p.

Velić, J., Malvić, T. & Cvetković, M. (2015): Geologija i istraživanje ležišta ugljikovodika (Geology and exploration of hydrocarbons reservoir), University of Zagreb, Faculty of Mining, Geology and Petroleum Engineering, Zagreb, (in Croatian).

Velić, J., Malvić, T., Cvetković, M. & Vrbanac B. (2012): Reservoir geology, hydrocarbon reserves and production in the Croatian part of the Pannonian Basin System, Geologia Croatica 65/1, 91-101.

SAŽETAK

Analiza utisnog sustava vode u pješčenjačka ležišta ugljikovodika, primjer iz zapadnog dijela Savske depresije

Utiskivanje slojne vode sastavni je dio proizvodnoga ciklusa ugljikovodika u sekundarnoj fazi pridobivanja. Utisni sustavi mogu se podijeliti na središnji i pojedinačni. U radu su opisani troškovi utiskivanja slojne vode na primjerima polja A (središnji utisni sustav) i B (pojedinačni utisni sustav) koji se nalaze u zapadnome dijelu Savske depresije. Ležišne su stijene naftno-plinskih polja A i B sitnozrnati do srednjezrnati pijesci i kvarcno-tinjčasti pješčenjaci donjopontske starosti. Srednja poroznost u polju A iznosi 15 – 35 %, a u polju B 10 – 31 %, ovisno o dubini i postotku cementacije. Za obrađena naftno-plinska polja u ovome radu napravljena je usporedba troškova i analiza osjetljivosti utisnoga sustava te moguća optimizacija i racionalizacija troškova utisnih sustava.

Ključne riječi
utisno-vodni sustavi, analiza osjetljivosti, ekonomika utisnih sustava, Savska depresija, pješčenjaci