Available online at http://ijcpe.uobaghdad.edu.iq and www.iasj.net
Iraqi Journal of Chemical and Petroleum Engineering
Vol. 24 No.3 (September 2023) 103 – 111
EISSN: 2618-0707, PISSN: 1997-4884

Effect of Heterogeneity on Recovery Factor for Carbonate Reservoirs. A Case Study for Mishrif Formation in West Qurna Oilfield, Southern Iraq

Ahmed N. Al-Dujaili [a] **, Mehdi Shabani** [a, *]**, and Mohammed S. AL-Jawad** [b]

a Amirkabir University of Technology, Petroleum Engineering Department, Iran
b University of Baghdad, Petroleum Engineering Department, Baghdad, Karrada, Al-Jadriya, Iraq

Abstract

Oil recovery could be impacted by the relation between vertical permeability (K_v) and horizontal permeability (K_h) (K_v/K_h). 4816 plugs that have been getting hold of 18 wells of Mishrif formation in the West Qurna oilfield were used. K_v/K_h data provided some scatter, but the mean is ~1. K_v/K_h =1 was used for the Petrel model before upscaling according to the heterogeneity of each layer. K_v/K_h values for Mishrif Formation in West Qurna Oilfield are 0.8 for relatively homogeneous, 0.4 for heterogeneous rock, and 0.1 for cap rocks (CRII).

Eclipse ^{TM} was used for reservoir simulation. PVT and SCAL data enhanced the simulation process. The results showed that the reduction of K_v/K_h to 0.9 for the mA unit would reduce the recovery factor (RF) by ~0.9% and continuing lowering would reduce RF more, while the same reduction would reduce RF by ~1% in the mB1 unit. The reduction would be 0.8, which increases RF by ~0.5% for the mB2U unit, while there was no effect on RF in the CRII unit whatever the reductions.

Keywords: West Qurna; Mishrif Formation; Heterogeneity; Recovery factor; Carbonate.

Received on 23/11/2022, Received in Revised Form on 09/01/2023, Accepted on 15/01/2023, Published on 30/09/2023

https://doi.org/10.31699/IJCPE.2023.3.10

1- Introduction

Heterogeneity is a substantial characteristic of all carbonate reservoirs around the world. The petrophysical feature of carbonate reservoirs significantly varies both horizontally and perpendicularly. Sidelong changes are ordinarily a result of diverse depositional environments, while vertical-axis heterogeneities are the reason for basin evolution throughout the age of the reservoir [1]. In a straightforward way, heterogeneity attends to divergence in characteristics in a single cluster. The terms variability, contradiction, randomness, complication, divergence, and perversion from criterion could be matched with this sense [2]. In studies of reservoir characteristics, fluid flow, and reserve-related features are interesting factors, so the researchers are focusing on these two parts [3]. All reservoirs concerning changeable are included in this term. Common examples include mineralogy, absolute and relative permeability, pore types, pore volume, pore throat size distribution, grain size, sorting, cementation and dissolution, and the production rate [4, 5].

On one hand, some researchers confirm that the alteration in any attribute of petrophysical properties in a three-dimensional void will cause heterogeneity of the regulation [6, 7], while on another hand, the concept of time has been appended to the term of heterogeneity [8]. Changing a property over time also leads to an increase in heterogeneity; variation in insular item density in the domain was defined as heterogeneity [9].

Permeability (K) is one of the main substantial properties of reservoirs. Manifest research has gathered permeability data linked to sedimentological/stratigraphic patterns with the objective of examining the domination of permeability allocation and their viability to oil and gas reservoirs [10]. By the study of well cores, outcrops can give much preferable ideation and authoritative assessment of the sedimentary structure dominant fluid flow, especially lateral divergences in lithofacies and related properties [11]. In addition, available proof supports the basic supposition that statistical measurements of changeability and spatial relations are preserved in underground reservoirs, although absolute values of k and permeability tendencies may be varied [12,13].

Horizontal permeability (K_h) is parallel to the bedding level and is mostly higher than vertical (K_v). Low vertical permeability leads to a larger pressure decline close to the wellbore and affects the skin factor immediately. (K_v) is substantial in the management and development of any reservoir. The priority includes the best choice of wells, which will be drilled and production flow rate, horizontal well implementations, optimum completion processes, selection of the location of the perforations, and the

---

*Corresponding Author: Name: Mehdi Shabani, Email: mehdi.shabani@aut.ac.ir

design plans of enhanced oil recovery [14]. The term (K_v/K_h) clarifies the disparity in permeability between the vertical and horizontal levels within a formula called anisotropic permeability [15]. This ratio is remarkable in reservoir simulation methods because it is usable in vertical wells and will be more significant in partially penetrated or horizontal wells. Reservoirs that identify as (layered reservoirs) are divided into layers based on the (K_v/K_h) relationships [16].

The retrievable amount of hydrocarbon is initially in place, normally used as a proportion. The recovery factor (RF) is an assignment of the displacement technique. An important objective of enhanced oil recovery is in order to increase the recovery factor [17]. The definitive recovery factor is known as the relation between the definitive recovery and the original oil in place (OOIP) [18]:

$$RF = \frac{N_{Pmax}}{N} \tag{1}$$

N_{Pmax} = definitive recovery. N = Original oil in place.

The recovery factor can be utilized for the entire reservoir or for selected units. The recovery factor is counted for a given point equal to the displacement competence derived by the current oil recovery mechanisms at just this point [19]. Five correlations have been adopted for Mishrif Reservoir in the West Qurna/1 oilfield, which linked Kv with Kh according to the heterogeneity effect. The correlations showed that the permeability is affected by porosity in the upper Mishrif due to the semi homogeneity and the upper part of the lower Mishrif has a higher anisotropy than the other units [20].

The study by (Liu, H., et al., 2018) demonstrated that Mishrif Formation characteristics in the West Qurna oilfield are held by prevailing pore types, which are the decisive sources for reservoir heterogeneity [21]. Recently, results revealed that the Mishrif reservoir units were strongly influenced by sequence stratigraphy, sedimentation, and diagenesis [22].

Many procedures have been adopted in order to quantitatively characterize the reservoir heterogeneity by sharing the results of processing [23]. The Dykstra-Parsons permeability variation is defined by the following expression (Eq. 2 and Fig. 1):

$$V = \frac{K_{50} - K_{84.1}}{K_{50}} \tag{2}$$

Where: K_{50} = permeability at 84.1% (m.D). $K_{84.1}$= the mean permeability at 50% (m.D). V = permeability variation.

A new parameter was developed in order to characterize the reservoir heterogeneity according to Dykstra and Parson's procedure [24]. The variation coefficient of permeability represents the ratio of the standard deviation of permeability to the mean permeability. This coefficient was advanced into two coefficients, the permeability dart coefficient, and the permeability contrast coefficient to identify reservoir heterogeneity [25]. Moreover, many other parameters are also adopted to characterize reservoir heterogeneity, such as (Lorenz and permeability diversity coefficient, entropy weight method, and Thiel index) [26 - 29].

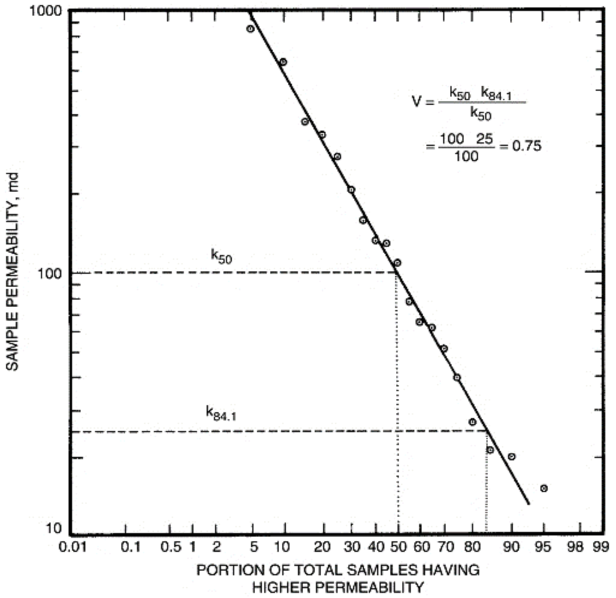


Fig. 1. Dykstra - Parsons Plot of Permeability Variation [23]

1.1. Geological setting

The West Qurna Oilfield is located about 14 km from Qurna city, at the north edge of Basrah Governorate. This oilfield represents the extension of the giant North Rumaila Oilfield in southern Iraq. Tectonically, it is part of a long-pivot anticline that mostly has the direction N–S, but in northern parts, the pivot will change to NW-SE. [30] Fig. 2. The West Qurna Oilfield is about 40 km long and 17 km wide. The field subsists on the external platform of the Arabian Plate in the Mesopotamia tub [31].

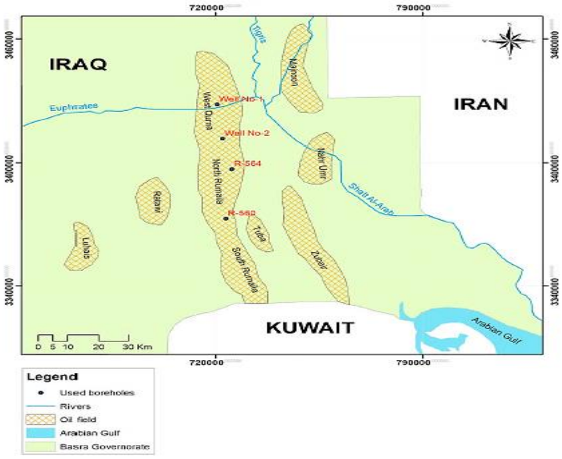


Fig. 2. The Geographical Location of West Qurna Oilfield and Well Locations in this Study [30]

1.2. Reservoir Zonation

Mishrif Formation expounds the Cretaceous era is the fundamental carbonate reservoir in southern Iraqi oil fields, characterized features by of heterogeneity and complication [32, 33].

Six facies represent this Formation (starting from the mid-decline facies to peripheral facies) [34]. Mishrif Formation consists of five units (some researchers considered the Rumaila unit as a part of Mishrif and called it mC). (mA) or upper Mishrif is located between Cap Rock I which represents the top of the Mishrif and Cap Rock II. The features of mA indicate a high-quality homogeneous or semi-homogeneous productive unit.

(mB1 and mB2) which represents the lower part of the Mishrif varies from observed sharp heterogeneity in the mB1 unit to the minimal heterogeneity in the lower part of the mB2 unit Fig. 3 [35].

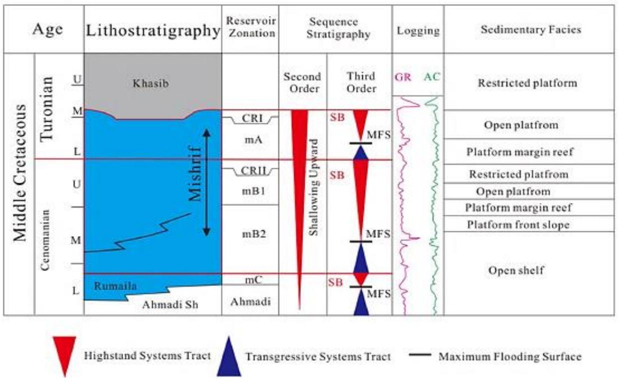


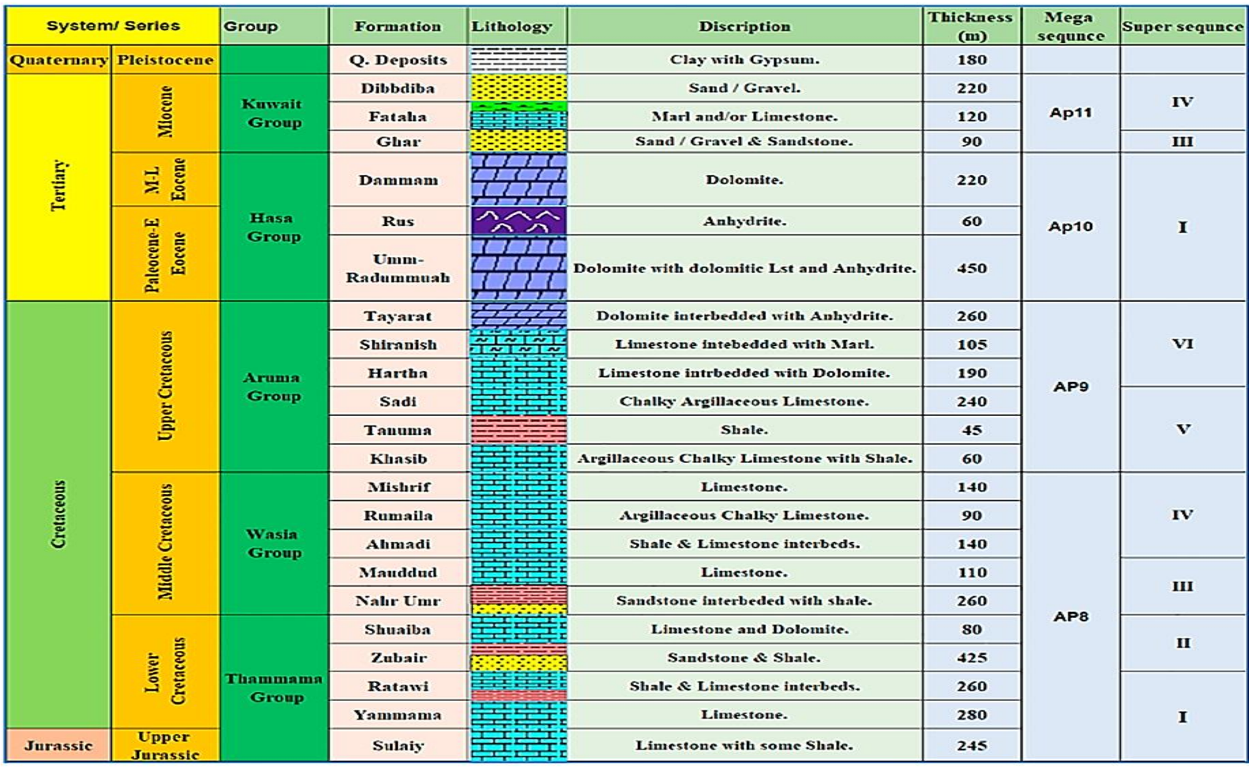
Fig. 3. The Sequence Stratigraphy, Deposit Facies, and Units of Mishrif Formation [20]

Carbonates and shale are the main components of rocks in the Mishrif Formation characterized by vertical phase transmission conditions, but also it holds some additional elements [36]. Mishrif Formation is composed of rudist, algal, foraminifera, bivalves, coral, gastropods, and echinoderms [37].

1.3. Depositional Environments

Mishrif sedimentary environments are distributed to many types as basins, steeps, superficial marine environments, Rudist biostromes, posterior superficial, and lagoons [38, 39]. (mB2) rocks, which in general represent mid-decline facies are characterized overall, as composed of wackestone to packstone rocks. The upper part of mB2, which is located under the (mB1) unit directly, refers to shallow facies, while the rock type for the mB1 layer mainly represents a form of packstone to grainstone with the existence of wackestone, which refers to superficial facies [40].

The mA Unit has a set of rock types consequent to facies ranging by different degrees of superficial facies in the upper formation of the mA unit. The mA unit contains a three-flow unit, while the lower Mishrif has eight flow units [35, 41]. The Mishrif formation is a bit of a second-form regulation trajectory of Arabian massive gradation, which is identified as (AP8) [42, 43]. Albian era to the initial Turonian represents the sequence of the Mishrif Formation, which represents 95 to 89 million years ago, starting from late Cenomanian to early Turonian [44, 45] Fig. 4.



System/ Series		Group	Formation	Lithology	Discription	Thickness (m)	Mega sequnce	Super sequnce
Quaternary	Pleistocene		Q. Deposits		Clay with Gypsum.	180		
Tertiary	Miocene	Kuwait Group	Dibbdiba		Sand / Gravel.	220	Ap11	IV
			Fataha		Marl and/or Limestone.	120		
			Ghar		Sand / Gravel & Sandstone.	90		III
	M-L Eocene	Hasa Group	Dammam		Dolomite.	220	Ap10	I
	Paleocene-E Eocene		Rus		Anhydrite.	60		
			Umm-Radummuah		Dolomite with dolomitic Lst and Anhydrite.	450		
Cretaceous	Upper Cretaceous	Aruma Group	Tayarat		Dolomite interbedded with Anhydrite.	260	AP9	VI
			Shiranish		Limestone intebedded with Marl.	105		
			Hartha		Limestone intrbedded with Dolomite.	190		
			Sadi		Chalky Argillaceous Limestone.	240		V
			Tanuma		Shale.	45		
			Khasib		Argillaceous Chalky Limestone with Shale.	60		
	Middle Cretaceous	Wasia Group	Mishrif		Limestone.	140	AP8	IV
			Rumaila		Argillaceous Chalky Limestone.	90		
			Ahmadi		Shale & Limestone interbeds.	140		
			Mauddud		Limestone.	110		III
			Nahr Umr		Sandstone interbeded with shale.	260		
	Lower Cretaceous	Thammama Group	Shuaiba		Limestone and Dolomite.	80		II
			Zubair		Sandstone & Shale.	425		
			Ratawi		Shale & Limestone interbeds.	260		I
			Yammama		Limestone.	280		
Jurassic	Upper Jurassic		Sulaiy		Limestone with some Shale.	245		

Fig. 4. Stratigraphic Column for Mesopotamia Basin [30]

2- Methodology

2.1. Materials

This study focused on 4816 plugs that have been getting hold of 18 wells of Mishrif formation in the West Qurna oilfield. The numbers of plugs and their source are shown in Table 1.

4-5” in diameter 5-8” in height (for non-WQ1-355 cores) and 1’ in WQ1-355 with the exception of three cores with 4’ height.

Table 1. Numbers and Source of Plugs used in this Study [35]

Mishrif Unit	No. of Plugs	Range of φ (Frac.)	Range of K (mD.)
mA	1024	0.010 - 0.319	0.01 - 1384
CRII	80	0.021 - 0.267	0.001 - 282
mB1	1284	0.010 - 0.352	0.01 - 2214
mB2	1528	0.019 - 0.377	0.01 - 1350

Fig. 5 Shows Significant heterogeneity in CRI, CRII, mB1, and lower mC, some heterogeneity in mA, and relatively homogeneous in mB2U, mB2L, and upper mC.

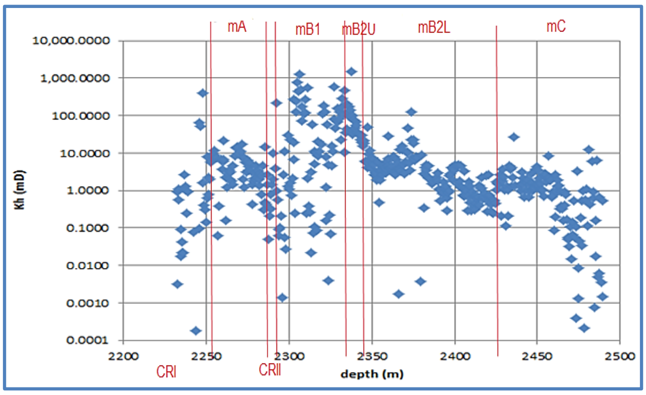


Fig. 5. Distribution of K_h Vs Depth for Units of Mishrif Formation for some Selected Wells

2.2. Methods

2.2.1. Permeability and porosity calculations

4816 plugs have been experimented with from the Mishrif Formation. Permeability and porosity were measured by Routine core analyses (RCA). The average rock density for the cores used in the experiment was 2.691g/cm^3.

Analyses with either the same depth values or similar depth values (within ~0.5 m) were paired. Values with no pair (H but no V or V but no H) were deleted. Plugs from Mishrif Formation (and a few Rumaila Unit -mC) analyses only.

2.2.2. Simulation process with Petrel^{TM} and Eclipse^{TM}

Petrel^{TM} V.2017 and Eclipse^{TM} were utilized for the simulation process. K_v/K_h=1 was used for the Petrel model before upscaling. There are two components of K_v upscaling:

1- From plug level to Petrel layer level.
2- From Petrel level to simulation layer level using flow-based permeability upscaling. Mishrif Petrel layers are 1 meter thick. Mishrif simulation layers are ~2 meters thick in upper reservoirs, but the lower reservoirs mB2L and mC were thicker.
3- The simulation process has been done by Eclipse.

The possible recommendations for the plug to Petrel level are shown in Table 2 and Fig. 6.

Table 2. K_v/K_h Values used in Petrel Simulation

K_v/K_h Value	Unit Homogeneity	Core diameters	Notes
0.8	relatively homogeneous rock	3”- 4” full cores	
0.4	heterogeneous rock	4”-5” full cores	0.4 is slightly less than the mean of 0.5, which included homogeneous rocks in particular, CRII
0.1	cap rocks		

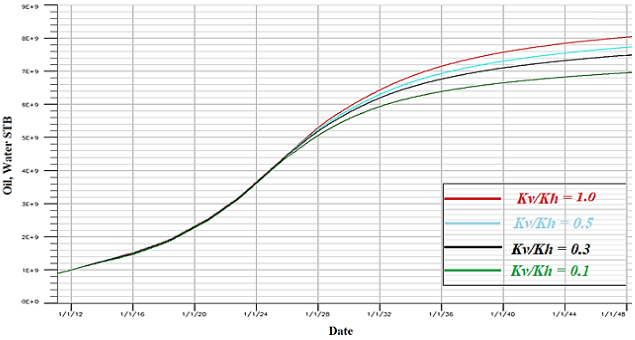


Fig. 6. Basic Simulation Process for All Units

3- Results

The data were from 18 wells for the Mishrif Formation in the West Qurna oilfield and from production data. The results obtained by the simulation process in Petrel software are:

3.1. Effect of K_v/K_h on RF for mA unit

Two values of K_v/K_h were applied for the mA unit in two steps, The first was considered to be homogeneous, which led to K_v/K_h being equal to 0.8, in the second step the value was 0.4. Fig. 7.

From Fig. 7 A, Reducing K_v/K_h from 1.0 to 0.4 for the mA unit would reduce RF by ~2.5% for the next 30 years while lowering it to 0.8 would reduce RF by ~0.9% (Fig. 7 B).

3.2. Effect of K_v/K_h on production for CRII unit

There is no significant effect of K_v/K_h on recovery in this unit when it was reduced to 0.1 and 0.01. Fig. 8. The two curves were fully matched.

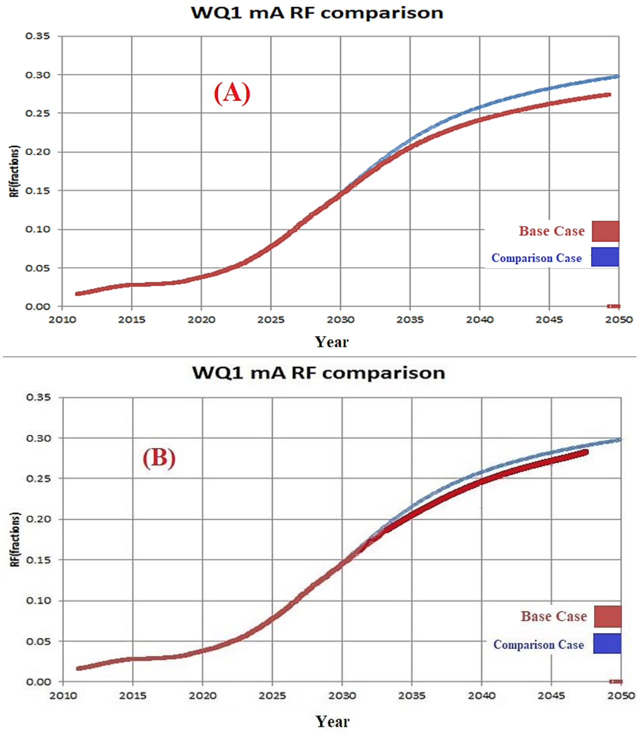


Fig. 7. Effect of K_v/K_h on RF for mA Unit

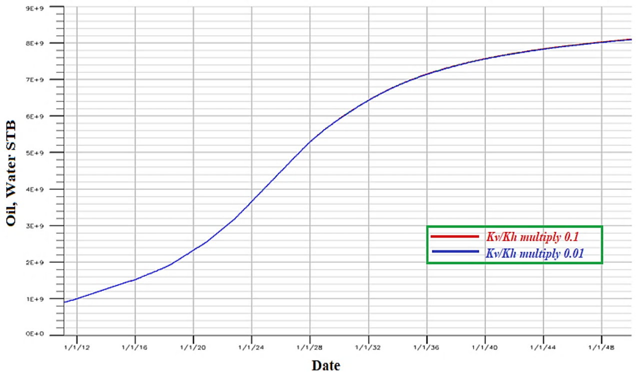


Fig. 8. Effect of K_v/K_h on Recovery for CRII Unit

3.3. Effect of K_v/K_h on RF for mB1 unit

From Fig. 9, Reducing K_v/K_h from 1.0 to 0.4 for the mB1 unit would reduce RF by ~1% for the next 30 years.

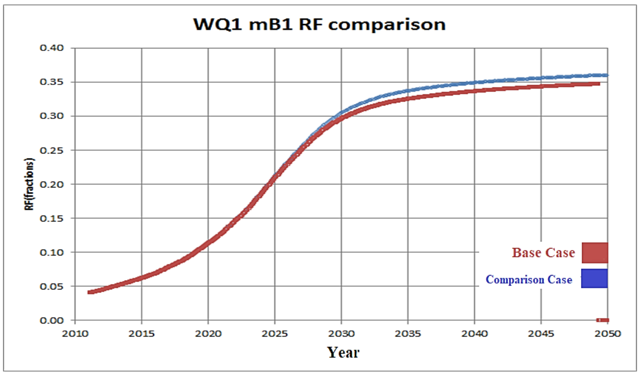


Fig. 9. Effect of K_v/K_h on RF for mB1 Unit

3.4. Effect of K_v/K_h on RF for mB2U unit

From Fig. 10, Reducing K_v/K_h from 1.0 to 0.8 for the Upper mB2 unit would increase RF by ~0.5% for the next 30 years.

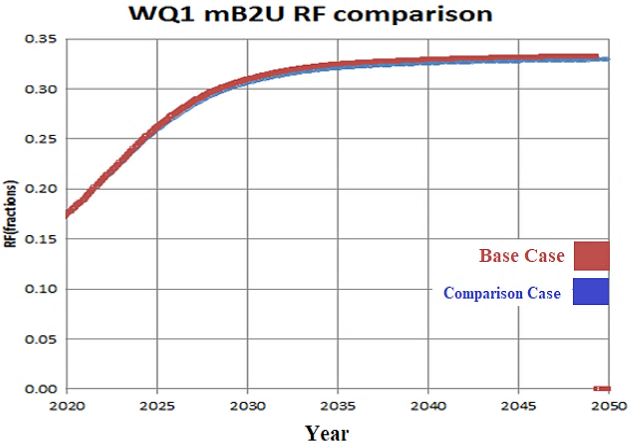


Fig. 10. Effect of K_v/K_h on RF for mB2U Unit

4- Discussion

Full diameter cores K_v/K_h from 4 wells averaged 0.5, less than WQ1-355 core plug K_v/K_h of ~0.8. This is expected from the harmonic averaging of K_v and is consistent with our investigation of stacking multiple core plugs together. Changing only K_v/K_h values for the CRII unit (multiply 0.1 and 0.01) did not impact the recovery factor. That is because the unit is a non-productive unit, it's only Cap rock.

Potentially lower recovery at lower K_v/K_h if multiplying K_v/K_h by a factor in 2011 without a pre-history match. Part of the K_v/K_h impact was reflected during the history matching process where K_v/K_h was modified.

Full core values of K_v/K_h were less than core plug K_v/K_h, especially at high range, due to harmonic averaging of K_v K_v/K_h from that obtained from 4 wells averaged 0.5, which is less than from K_v/K_h of others (~0.8.). This is expected from harmonic averaging of Kv and consistent with our investigation of stacking multiple core plugs together.

The K_v/K_h of 0.63-0.95, an average of ~0.8, was represented in the well WQ1-20 of rather homogeneous rock, not representative of heterogeneous rock like mB1, and cap rocks in other wells. The full core for WQ1-355 belongs to mA unit, which is relatively homogeneous in this well, but heterogeneous in some other wells

The comparison between the effect of K_v/K_h (for heterogeneous and homogenous units) on the recovery factor is shown in Fig. 11.

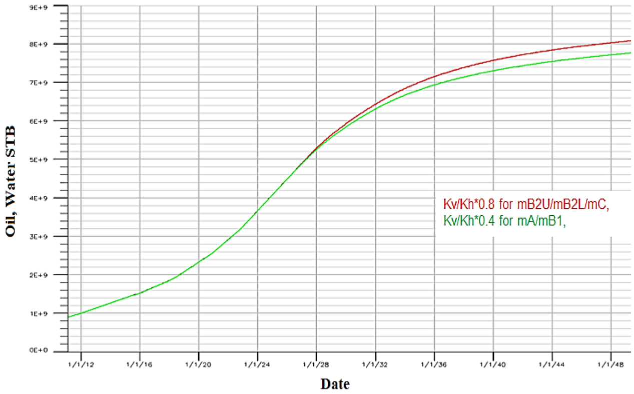


Fig. 11. The Effect of K_v/K_h on Recovery for All Units

5- Conclusions

This study participated in the recognition of the effect of heterogeneity on recovery factor for all units of Mishrif Formation in the West Qurna oilfield using cores and production data as follows:

1- K_v/K_h values for Mishrif Formation in West Qurna Oilfield are 0.8 for relatively homogeneous rock, 0.4 for heterogeneous rock, and 0.1 for cap rocks (CRII).

2- The lithofacies data show that the mA interval is characterized by low porosity with moderate permeability. Cap rocks 2 (CRII) are characterized by low permeability and low porosity rocks (flow barriers, baffles). mB1 interval shows rocks with low porosity and high permeability. Highly porous and permeable rocks (10s to 100s mD) represent the mB2U interval. Microporous rocks in the mB2L interval show high porosity (over 37%) with low permeability (0.1–10's mD).

3- Simulation results showed the potential impact of K_v/K_h on oil recovery and potentially reduced mA and mB1 recovery applications for the other reservoirs.

4- Core plugs tests showed relative homogeneity in mA, and mB2 units and heterogeneity in CRI, CRI, and mB1 units.

5- Reducing K_v/K_h from 1.0 to 0.4 for the mA unit would reduce RF by ~2.5% while lowering it to 0.8 would reduce RF by ~0.9%.

6- Reducing K_v/K_h from 1.0 to 0.4 would reduce RF by ~1% for the mB1 unit while reducing to 0.8 for mB2U would increase RF by ~0.5%.

7- There is no significant effect of K_v/K_h on production in this unit when it is reduced to 0.1 and 0.01.

Nomenclature

AP8	Arabian Plate 8
CRI	Cap Rock 1
CRII	Cap Rock 2
Frac.	Fraction
g/cm3	grams per cubic centimeter
K	Permeability
K_h	horizontal permeability
K_v	vertical permeability
mA	Upper Mishrif
mB1	Lower Mishrif part 1
mB2	Lower Mishrif part 2
mC	Rumaila Unit or sometimes considered as Lower Mishrif part 3
md or mD	milli-Darcy
N	Initial oil in place
N_{Pmax}	definitive recovery
OOIP	Original Oil in Place
RCA	Routine Core Analysis
RF	Recovery Factor
SCAL	Special Core Analysis
WQ1	West Qurna Oilfield 1
~	Approximately
φ	porosity

Acknowledgments

The authors are deeply grateful to Basrah Oil Company (BOC) and all Engineers and Geologists who assisted in the achievement of this study, which was done by the Petroleum Engineering Dept. - Amirkabir University of Technology and the University of Baghdad.

References

[1] Lucia F. Carbonate reservoir characterization: an integrated approach. Springer, Berlin, (2007). p 341. https://doi.org/10.1007/978-3-540-72742-2

[2] Tavakoli, Vahid. *Carbonate Reservoir Heterogeneity: Overcoming the Challenges*. Springer Nature, (2019). https://doi.org/10.1007/978-3-030-34773-4

[3] Li, H., and J. F. Reynolds. "On definition and quantification of heterogeneity." *Oikos*. (1995): 280-284. https://doi.org/10.2307/3545921

[4] Flügel, Erik, and Axel Munnecke. Microfacies of carbonate rocks: analysis, interpretation and application. Vol. 976. Berlin: springer, (2010). https://doi.org/10.1007/978-3-642-03796-2

[5] Lucia, F. Jerry. "Rock-fabric/petrophysical classification of carbonate pore space for reservoir characterization." *AAPG bulletin.* 79.9; (1995) 1275-1300. https://doi.org/10.1306/7834D4A4-1721-11D7-8645000102C1865D

[6] Zhengquan, W., Qingcheng, W., Yandong, Z. *et al.* Quantification of spatial heterogeneity in old growth forests of Korean pine. *Journal of Forestry Research*. 8; **(**1997) 65–73. https://doi.org/10.1007/BF02864969

[7] Dutilleul, Pierre. "Spatial heterogeneity and the design of ecological field experiments." *Ecology*. (1993). 74.6; 1646-1658. https://doi.org/10.2307/1939923

[8] Fitch, Peter JR, et al. "An integrated and quantitative approach to petrophysical heterogeneity." *Marine and Petroleum Geology*. 63; (2015) 82-96. https://doi.org/10.1016/j.marpetgeo.2015.02.014

[9] Frazer, Gordon W., Michael A. Wulder, and K. Olaf Niemann. "Simulation and quantification of the fine-scale spatial pattern and heterogeneity of forest canopy structure: A lacunarity-based method designed for analysis of continuous canopy heights." *Forest ecology and management*. 214.1-3; (2005) 65-90. https://doi.org/10.1016/j.foreco.2005.03.056

[10] Lewis, J.J.M. "Outcrop-Derived Quantitative Models of Permeability Heterogeneity for Genetically Different Sand Bodies." Paper presented at the SPE Annual Technical Conference and Exhibition, Houston, Texas, October (1988). https://doi.org/10.2118/18153-MS

[11] Meyer, Rudi, and Federico F. Krause. "Permeability anisotropy and heterogeneity of a sandstone reservoir analogue: An estuarine to shoreface depositional system in the Virgelle Member, Milk River Formation, Writing-on-Stone Provincial Park, southern Alberta." *Bulletin of Canadian Petroleum Geology*.54.4; (2006) 301-318. https://doi.org/10.2113/gscpgbull.54.4.301

[12] J. D. Doyle, M. L. Sweet; Three-Dimensional Distribution of Lithofacies, Bounding Surfaces, Porosity, and Permeability in a Fluvial Sandstone—Gypsy Sandstone of Northern Oklahoma. *AAPG Bulletin*.79 (1); (1995) 70–95. https://doi.org/10.1306/8D2B14BC-171E-11D7-8645000102C1865D

[13] Goggin, D.J., Chandler, M.A., Kocurek, Gary, and Larry W. Lake. "Permeability Transects of Eolian Sands and Their Use in Generating Random Permeability Fields." *SPE Form Eval*. (1992). 7; 7–16. https://doi.org/10.2118/19586-PA

[14] Zahaf K, Tiab D, "Vertical permeability from in situ horizontal measurements in shaly-sand reservoirs." *J Can Pet Technol*. (2002). https://doi.org/10.2118/02-08-01

[15] Muskat, Morris. "The flow of homogeneous fluids through porous media." *Soil Science*. (1938) 46.2; 169.

[16] Henley, D.H., Owens, W.W., and F.F. Craig. "A Scale-Model Study of Bottom-Water Drives." *J Pet Technol*.13; (1961) 90–98. https://doi.org/10.2118/1539-G-PA

[17] Salih, T. A., Sahi, S. H., & AL-Dujaili, A. N. "Using Different Surfactants to Increase Oil Recovery of Rumaila Field (Experimental Work)". *Iraqi Journal of Chemical and Petroleum Engineering*. (2016). 17(3), 11–31. https://doi.org/10.31699/IJCPE.2016.3.2

[18] Awadeesian, Awadees MR, et al. "A modified water injection technique to improve oil recovery: Mishrif carbonate reservoirs in southern Iraq oil fields, case study." *The Iraqi Geological Journal* (2019): 125-146. https://doi.org/10.46717/igj.52.1.8Ms-2019-06-30

[19] Sahu, Chandan, Rajnish Kumar, and Jitendra S. Sangwai. "Comprehensive review on exploration and drilling techniques for natural gas hydrate reservoirs." *Energy & Fuels*.34.10; (2020) 11813-11839. https://doi.org/10.1021/acs.energyfuels.0c02202

[20] Al-Dujaili A.N., Shabani M. and AL-Jawad M.S. "Identification of the best correlations of permeability anisotropy for Mishrif reservoir in West Qurna/1 oil Field, Southern Iraq. "*Egyptian Journal of Petroleum*.30.3; (2021a) 27-33. https://doi.org/10.1016/j.ejpe.2021.06.001

[21] Liu, H., Tian, Z., Liu, B., Guo, R., Yang, D., Deng, Yu, Y. & Shi, K. "Pore types, origins and control on reservoir heterogeneity of carbonate rocks in Middle Cretaceous Mishrif Formation of the West Qurna oilfield, Iraq." *Journal of Petroleum Science and Engineering*.171; (2018) 1338-1349. https://doi.org/10.1016/j.petrol.2018.08.034

[22] Fang, X., Feng, H., Wang, H. *et al.* "Study on origin, classification, and identification of complex porous carbonate reservoir: a case study of the middle cretaceous Mishrif Formation in W Oil field." *Carbonates Evaporites.* 36; **(**2021) 72 https://doi.org/10.1007/s13146-021-00737-2

[23] Dykstra, H., Parsons, R.L. The Prediction of Oil Recovery by Waterflood, Secondary Recovery of Oil in the United States, second ed. *American Petroleum Institute*. (1950). pp. 160–174.

[24] Moissis, D.E., Wheeler, M.F. Effect of the Structure of the Porous Medium on Unstable Miscible Displacement, Dynamics of Fluids in Hierarchical Porous Media. *Academic Press*. (1990). pp. 243–271.

[25] Song, Q., Sun, Y., Zhou, J. Quantifying the reservoir heterogeneity: a case study of clastic reservoirs, Bohai Bay Basin, China. In: In 2009 SEG Annual Meeting, Society of Exploration Geophysicists. (2009) Houston, Texas. https://doi.org/10.1190/1.3255192

[26] Shao, X. A new characterized parameter for the permeability heterogeneity of the reservoir: calculation method of permeability diversity coefficient and its significance. *Petroleum Geology and Experiment*.32 (4); (2010) 397–399. https://doi.org/10.11781/sysydz201004397

[27] Wang, Z., Zhang, J., Yuan, Y. Application and comparison of Lorenz curve method and traditional method in quantitative representation of reservoir heterogeneity. *Western Resour*.20 (6); (2017) 109–111.

[28] Yang, Z.G., Tang, J., Zhang, Y.P., Zhang, F.B., Li, Z., Wu, X.C., Fan, C.B. Study of quantitative evaluation method for heterogeneity by entropy weight method-case study of Chang 8 reservoir of Xiasiwan in Erdos Basin. *J. Geol*. 36 (4); (2012) 373–378.

[29] Tao, L., Fan, H., Wang, J., Yu, L. A new method named Theil index for quantitative characterization of reservoir heterogeneity. Sino-Global Energy, 24 (2); (2019) 36–39.

[30] Maher J. Ismail, Frank R. Ettensohn, Amna M. Handhal, Alaa Al-Abadi "Facies analysis of the Middle Cretaceous Mishrif Formation in southern Iraq borehole image logs and core thin-sections as a tool." *Marine and Petroleum Geology*. (2021). 133; 105324. https://doi.org/10.1016/j.marpetgeo.2021.105324

[31] Fouad, S.F. "Tectonic and structural evaluation of the Mesopotamia foredeep, Iraq." *Iraqi Bulletin of Geology and Mining*. (2010).

[32] Sadooni, F. N. "The nature and origin of Upper Cretaceous basin-margin rudist buildups of the Mesopotamian Basin, southern Iraq, with consideration of possible hydrocarbon stratigraphic entrapment." *Cretaceous Research*. 26(2); (2005) 213-224. https://doi.org/10.1016/j.cretres.2004.11.016

[33] Aqrawi A, Mahdi T, Sherwani G, Horbury A. "Characterization of the Mid-Cretaceous Mishrif Reservoir of the southern Mesopotamian Basin, Iraq." In: American Association of Petroleum Geologists Conference and Exhibition. (2010). pp 7–10.

[34] Aqrawi A, Thehni G, Sherwani G, Kareem B. "Mid-Cretaceous rudist-bearing carbonates of the Mishrif Formation: an important reservoir sequence in the Mesopotamian Basin, Iraq." *J Pet Geol*. 21; (1998) 57–82. https://doi.org/10.1111/j.1747-5457.1998.tb00646.x

[35] Al-Dujaili, A.N., Shabani, M. and AL-Jawad, M.S. "Characterization of flow units, rock and pore types for Mishrif Reservoir in West Qurna oilfield, Southern Iraq by using lithofacies data." *J Petrol Explor Prod Techno.* 11; (2021b) 4005–4018. https://doi.org/10.1007/s13202-021-01298-9

[36] Al-Mimar, H. S., Awadh, S. M., Al-Yaseri, A. A., and Yaseen, Z. M. "Sedimentary units-layering system and depositional model of the carbonate Mishrif reservoir in Rumaila oilfield, Southern Iraq." *Modeling Earth Systems and Environment*. 4(4); (2018) 1449-1465. https://doi.org/10.1007/s40808-018-0510-5

[37] Al-Ali, A., Stephen, K., and Shams, A. 'Applications of Artificial Neural Network for Seismic Facies Classification: A Case Study from the Mid-Cretaceous Reservoir in Supergiant Oil Field." In SPE Europec. *OnePetro*. (2020) https://doi.org/10.2118/200577-MS

[38] Al-Bahadily, J. K., and Nasser, M. E. "Role of the Cluster Analysis in Logfacies and Depositional Environments Recognition from Well Log Response for Mishrif Formation in Southeast Iraq." *International Journal of Eng. Research and Scienc.* (2017). 3(12).

[39] Ismail M. J. and Al-Najm F. M. "UTILIZING CORE AND NMR DATA TO IDENTIFY ROCK-TYPE AND PORE THROAT RADIUS FOR MISHRIF FORMATION IN WEST QURNA OILFIELD." (2019). https://doi.org/10.46717/igj.52.2.4Ms-2019-12-27

[40] Sharland, P.R., Archer, R., and Casey, D.M. "Arabian Plate Sequence Stratigraphy." Geo Arabia Special Publication, Gulf Petro link. (2001) Bahrain.

[41] Al-Dujaili, A.N., Shabani, M. and AL-Jawad, M.S (2023). Effect of Heterogeneity on Capillary Pressure and Relative Permeability Curves in Carbonate Reservoirs. A Case Study for Mishrif Formation in West Qurna/1 Oilfield, Iraq. *Iraqi Journal of Chemical and Petroleum Engineering*. https://doi.org/10.31699/IJCPE.2023.1.3

[42] Tobia, F.H., Al-Jaleel, H.S. & Ahmed, I.N. "Stable isotope excursions in the Jurassic carbonate System, Imbricated Zone, Northern Iraq." *Arab J Geosci*. 14; (2021) 2262 https://doi.org/10.1007/s12517-021-08651-6

[43] Al-Dujaili, A.N., Shabani, M. and AL-Jawad, M. S. (2023a) lithofacies and electrofacies models for Mishrif Formation in West Qurna Oilfield, Southern Iraq by deterministic and stochastic methods (comparison and analyzing). *Petroleum Science and Technology*. https://doi.org/10.1080/10916466.2023.2168282

[44] Al-Mudhafar, W. J., Al Lawe, E. M., & Noshi, C. I. "Clustering analysis for improved characterization of carbonate reservoirs in a Southern Iraqi Oil Field." In offshore technology conference. *OnePetro.* (2019). https://doi.org/10.4043/29269-MS

[45] Al-Zaidy A. H. and Zainab Amer "Facies Analyses and Diagenetic features development of Albian - Aptian Succession in the Wset Qurna oil field, Southern Iraq, *Iraqi Journal of Science*. 56.4A; (2015) 2887-2901.

تأثير عدم التجانس على معامل الاستخلاص للمكامن الكربونية. دراسة حالة لتكوين مشرف في حقل غرب القرنة النفطي ، جنوب العراق

أحمد نوري الدجيلي [١] ، مهدي شعباني [١، *] ، و محمد صالح الجواد [٢]

١ جامعة أمير كبير التكنولوجية، قسم هندسة النفط، طهران، ايران
٢ جامعة بغداد، كلية الهندسة، قسم هندسة النفط، بغداد، العراق

الخلاصة

يمكن أن يتأثر استخلاص النفط بالعلاقة بين النفاذية الرأسية (Kv) والنفاذية الأفقية (Kh). تم استخدام ٤٨١٦ لبابة صخرية تم الحصول عليها من ١٨ بئرا من تشكيل مشرف في حقل غرب القرنة النفطي. قدمت بيانات Kv / Kh بعض التشتت ، ولكن معدل قيمة النفاذية الرأسية كان مساويا إلى قيمة النفاذية الأفقية تقريبا. تم استخدام Kv / Kh = 1 لنموذج Petrel قبل الترقية وفقًا لعدم تجانس كل طبقة.

قيم Kv / Kh لتكوين مشرف في حقل نفط غرب القرنة هي ٠,٨ للصخور المتجانسة نسبيًا و ٠,٤ للصخور غير المتجانسة و ٠,١ لصخور الغطاء.(CRII)

تم استخدام Eclipse TM لمحاكاة المكامن وعززت بيانات PVT و SCAL عملية المحاكاة. أظهرت النتائج أن خفض نسبة Kv / Kh إلى ٠,٩ لوحدة (mA) من شأنه أن يقلل من معامل الاستخلاص (RF) بنسبة ٠,٩ ٪ تقريبًا وسيؤدي الخفض المستمر في هذه النسبية إلى تقليل هذا المعامل اكثر واكثر ، في حين أن التخفيض سيقلل (RF) بنسبة ١ ٪ تقريبًا في وحدة mB1. بينما عندما يكون التخفيض ٠,٨ ، سيؤدي ذلك إلى زيادة RF بنسبة ٠,٥ ٪ تقريبًا لوحدة mB2U ، بينما لم يكن هناك تأثير على RF في وحدة CRII مهما كانت قيمة التخفيض.

الكلمات الدالة: عدم التجانس، مشرف، غرب القرنة، معامل الاستخلاص، المكامن الكاربونية.