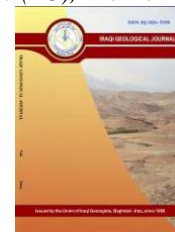




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History Matching of Reservoir Simulation Model: a Case Study from the Mishrif Reservoir, Buzurgan Oilfield, Iraq

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Abstract

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In petroleum reservoir engineering, history matching refers to the calibration process in which a reservoir simulation model is validated through matching simulation outputs with the measurement of observed data. A traditional history matching technique is performed manually by engineering in which the most uncertain observed parameters are changed until a satisfactory match is obtained between the generated model and historical information. This study focuses on step by step and trial and error history matching of the Mishrif reservoir to constrain the appropriate simulated model. Up to 1 January 2021, Buzurgan Oilfield, which has eighty-five producers and sixteen injectors and has been under production for 45 years when it started in 1976. Reservoir exhibits heterogeneity in porosity and permeability throughout the field, therefore it's a big challenge to control all reservoir properties during matching process. The historical matching process includes matching field and wells oil and water production rates, water injection rates, water cut, and reservoir static pressure. Finally, the results show that the good matching between simulated model and observed data; oil and water production rates, water injection rates, water cut, and static reservoir pressure which allow for implementing perfect future production forecasting strategies.

Keywords: History matching; Mishrif Reservoir; Oil production rates; Water injection rate; Reservoir static pressure.

1. Introduction

The method of history matching involves changing the input data (geological description, fluid characteristics, relative permeability, etc.) in a reservoir simulation model so that they match observed data (oil and gas production rates, reservoir static pressures, water cut, and water injection rate). History matching is essentially a testing and validation task based on the idea that if a model can accurately forecast the past under different development types of situations, it would also be beneficial for predicting the future. The only approach technicians ought to minimize the chances (of failing or noticeably poor performance) connected with choices being made against the unavoidable background of data uncertainty is by constructing simulation models and historically matching each one (Gilman and Ozgen, 2013).

The goal of history matching is to create models that can be used to predict reservoir performance within a set of approved tolerances, not merely to match the past. The need to handle reservoir uncertainties as it may affect improvement possible outcomes, the introduction of more affordable and quick computers, and the development of comprehensive geology models have all contributed to a

revitalized intention of trying to effectively automate the history-matching procedure (Gilman and Ozgen, 2013). A trial-and-error process, history matching usually depends on experience and intuition. By engineer to engineer, the process for running a history match may frequently differ (Williams et al., 1998).

The Mishrif Formation in Nassiriyah Oilfield has relatively short-term historical production, where the actual production started in August 2009 with a production rate of 68000 STB/d then the production increased to about 86000 STB/day in 2018. Twenty-five wells were opened to flow. The period of history matching is about ten years. A good matching resulted between the calculated model by the simulator and the observed data of production rates, static pressure and water cut (Huda and Al Jawad, 2020).

The history match starts by confirming that the initial model fluids in situ agree with material-balance and volumetric predictions, as shown in Fig.1a and b. Aquifer size issues, geology description issues (porosity, net pay, and structure), and/or insufficient characterization of fluid variables (compressibility, fluid, and contacts) are all frequently indicated by differences in this region (Williams et al., 1998).

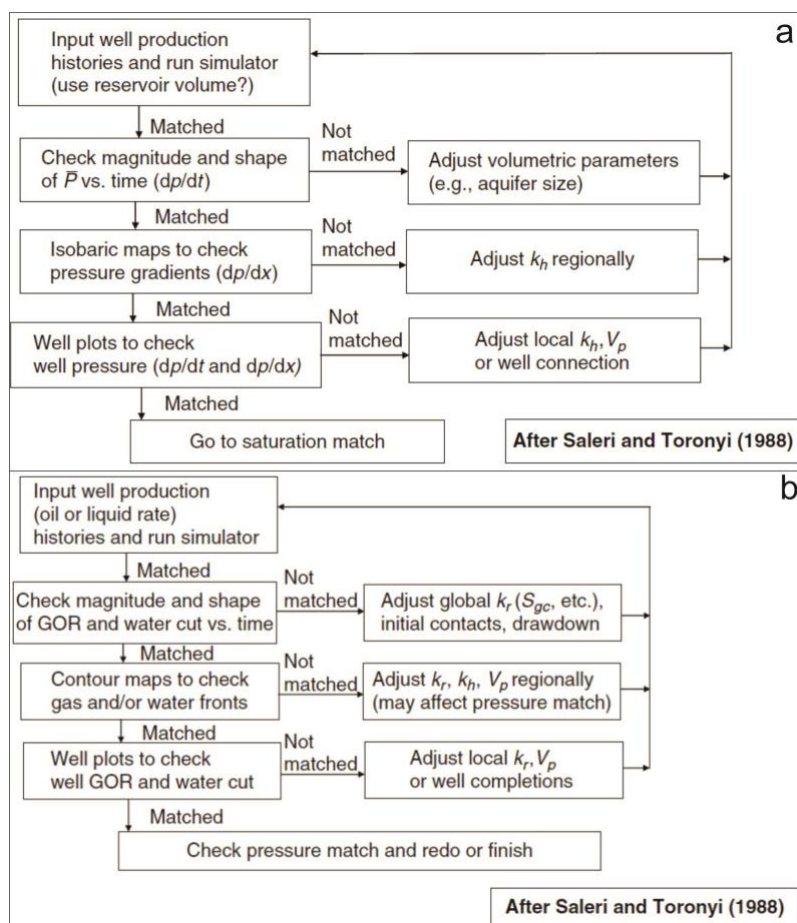


Fig. 1. a. A brief visual representation of the pressure-matching process, b. A brief visual representation of the saturation-matching process (Salari and Toronyi, 1988).

The original reservoir conditions must be accurately represented by the starting model and must match any measurements or quantifications made in the past. Aquifer size, the placement of fluid contacts, or initial water-saturation distributions are a few examples of initialization factors that may need to be changed if attempts to match model performance history are unsuccessful (Salari and Toronyi, 1988).

The process of matching field-wide performance begins with matching pressure by extracting and injecting the proper total reservoir-fluid volumes, then moves on to matching phase rates across the entire field. Without placing too much emphasis on specific well characteristics, these early material-balance stages assist in validating the geology, petrophysical, and geophysical interpretations as a whole (e.g., structure, depositional model, and porosity distributions). When compared to individual well performance, fieldwide variables may frequently be matched considerably more quickly, offering simple quality control checks. There is a very significant likelihood that the starting model is inconsistent if the engineer is unable to match field-wide variables, necessitating a modification of the first interpretations (Gilman and Ozgen, 2013).

The process of historical matching then moves on to matching geographical data, such as pressures. To achieve a regional pressure match, it is frequently required to match the fluid production from certain wells or well groups. The performance of the remaining fluid production can be matched once the pressures are matched. Since the validity of a variable that has already been matched frequently changes when some other variables being confirmed, this is an iterative process that may return to the geomodel. Which variables are least impacted by subsequent model changes are identified by the sequence of variable matching (Williams et al., 1998). The goal of history matching is to identify a numerical reservoir model that can be used to forecast reservoir performance. The numerical model must have its many parameters and attributes adjusted in order to match the reservoir production history using an engineer and model calibration (data inversion) process (Gilman and Ozgen, 2013).

The historical matching is done manually by running the simulation model for the historical period, and then, the results are compared to the known field performance in order to get a good and acceptable match. In general, permeability distribution is most uncertain, hence, it should be selected as the first parameter to adjust. Porosity distribution is usually taken as the second most uncertain parameter if reliable log data are not available. The more commonly used history matching parameters are aquifer size and strength, vertical permeability, the kHh product (permeability thickness) for reservoir and well, the kV/kH ratio, pore volume PV, and relative permeability (Adnan, 2019). History matching is a reverse matter that includes modifying input parameters of the simulation model until the simulation results are fit with the observed data. Selecting a suitable parameterization is valuable to reduce the passed in the reservoir model and get dependable prediction of the oil production through reservoir development plan. The history matching of well static pressure is performed by matching between simulation results of well static pressure and the observed one for more than 40 wells in the Mishrif reservoir (Taher, 2018).

Nevertheless, essential considerations such as initial fluid contact (OWC and GOC) for all units are installed within the initial condition of the Mishrif reservoir, distribution of porosity and permeability, pore-volume-temperature (PVT) Properties of oil and water, curves of relative permeability and saturation, were utilized as input parameters for the initialization of a dynamic model. Finally, well completion was need well locations in grid system, well trajectory, intervals of perforation, as well as, reservoir static pressure, oil, gas, water production rates, and water injection rate. In history strategy, the model first characterizes the oil production rate in producing wells before calculating the gas and water production rates to compare with the data that has been collected. Additionally, the initial reservoir pressure values vary greatly with depth; the lowest value ever recorded is 3760 psia, while the bubble point pressure in the Mishrif reservoir ranges from 2760 to 2760 psia. Mishrif reservoir is therefore initially undersaturated by more than 1000 psia.

2. Materials and Methods

In the present study, the work steps that are required to obtain perfect full-field simulation model are upscaling of fine grid model, representation of the reservoir rock properties, characterization of the

fluid properties and rock-fluid physical data, well modeling, production and water injection schedules, calibration of initialization process, production history validation, and integrated history matching for validating and justifying model input data.

A considerable percentage of the expense of a petroleum reservoir study is generally spent on history matching. Vertical and horizontal permeability, porosity, aquifer characteristics, and relative permeability are the most widely employed historical matching criteria. Oil, gas, and water production rates, well static pressure, bottom hole flowing pressure, average reservoir pressure, gas-oil ratios, water cut, depth of OWC, and breakthrough timings are among the observable performance characteristics to be matched (Carter et al., 1974). The essential characteristics that flow simulation and necessary components well productivity/ injectivity, pressures and saturation of fluid from the vicinity of wells, creating GOR's, WOR's, sweep efficiency, and overall recovery factors are all taken into consideration (Crishlow, 1977). The greatest goal of reservoir simulation research would be to accurately predict well flow rates and/or flowing bottom hole pressures, as well as to calculate pressure and saturation distributions (Peaceman, 1983).

When building a reservoir simulation model is finished, it is particularly important to validate the reservoir simulation model by history matching process. This process is usually achieved by modifying many parameters through reservoir simulator. The results predicted by simulator compare and satisfy with available field observed data (Satter and Thakur, 1996). Reservoir simulation studies are one of the most powerful tools for directing reservoir management choices, and they are used to analyze, anticipate, and match the performance of hydrocarbon reservoirs under various operating situations (Landa and Horne, 1997).

The concept of a successful historical match might differ from one organization to the next, from one engineer to the next within the same company, or from one project to the next by the same engineer. It must be assessed whether the historical match is of sufficient quality to make future predictions. As a result, determining quality is dependent on the study's aims (Fanchi, J.R., 1997). In order to link the well flow rate to the difference between the grid pressure and the wellbore pressure in a simulator, a well model is required. Producer and injector wells are the two types of wells (Computer Modeling Group Ltd., 2005). There can be various solutions that produce adequate fits with the observed reservoir dynamics if done efficiently. In this case, engineering judgment must be used to determine which option is the most logical. Performance prediction studies are carried out for different possible production schemes based on the findings of the history matching. The results of the prediction research will be utilized in an economic feasibility analysis to determine which production plan is the most lucrative.

2.1. History Matching Processes

It begins by running a reservoir simulation model for the historical matching period, then comparing the results to actual data and known field performance to arrive at the best and acceptable match (Tarek and McKinney, 2005).

2.2. Parameters Control Matching

The uncertain parameters that can be used to control the history matching processes are:

- The distributions of k , ϕ , and reservoir rock lithology.
- Reservoir depth and geometry.
- Fluid properties and their distributions.
- primary drive mechanisms.
- Initial conditions and rock compressibility.
- Fluid saturations, reservoir homogeneity, and reservoir continuity.
- Aquifer size and strength.

In fact, only data that are least accurately known in the field or those not measured at reservoir scale should be changed during the history match (Tarek and McKinney, 2005).

2.3. Important Data to Be Matched

The most important items that should be consider as a target for reservoir history matching are (Tarek and McKinney, 2005):

- Oil, water, and gas production rate.
- Bottom-hole static pressure.
- Bottom-hole flowing pressure.
- Injection water rate.
- Production WOR, including water break-through.
- Production GOR, including gas arrival time.
- Wellhead flowing pressure.

Thus, the main items which considered in current work are oil and water production rates, water injection rate and reservoir static pressure.

3. Construction Simulation Model

3.1. Upscaling Geological Model

The Geological models were represented by simple grid model which usually contained thousands of grids. Moreover, in this work, the three-dimensional grid structure of Mishrif formation involves 212 grid cells through the x-axis, 138 grid cells through the y-axis, and 29 sublayers through the vertical direction (z-axis). The total number of grid cells is 848,424. However, due to an excessively high number of grids, many reservoir fluid flow simulators may not operate accurately and effectively. Since there are more than 800,000 cells in the geological model used in this study, it was necessary to start the upscaling operations and the dynamic simulation model right away. The increment for gridding size is established to be 250 m through the x-axis and 250 m along the y-axis, this model can ran through simulations quickly, in about an hour. Typically, the Buzurgan oilfield consists of two domes; south and north dome, as shown in Fig. 2.

3.2. Dynamic Simulation Model

In the current study, the dynamic model is built by "Petrel Re-2017" & "Eclipse-2017: E100" simulators to forecast the flowing of fluid through reservoir and developing of reservoir performance model under managing and enhancement strategies. Thus, a 3D-single porosity black oil reservoir simulation model has been constructed for the Mishrif reservoir in the Buzurgan oilfield.

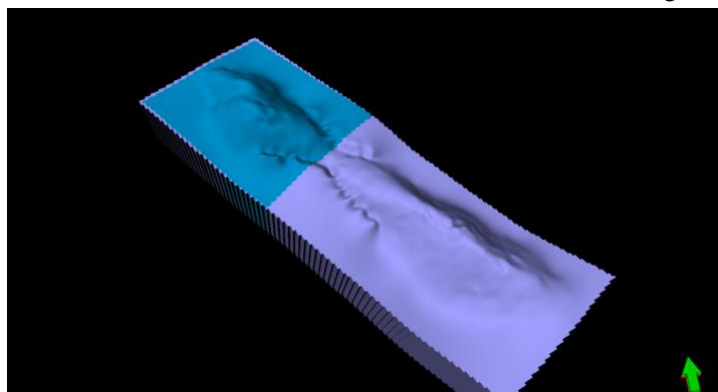


Fig. 2. South and North dome of MB21 unit/Mishrif reservoir/Buzurgan oilfield.

3.3. Reservoir Rock Properties

Typically, after completing the final upscaled porosity, water saturation and N/G distribution for each layer of the simulation model for the Mishrif carbonate reservoir, as well as selecting the 250i*250j grid size for geological model, the reservoir rock properties are allocated and applied for each grid in the reservoir model.

The directional permeability (Kx, Ky and Kz) distribution, which is necessary for generation of dynamic modeling to simulate the flow in the lateral and vertical directions was prepared depending upon available core data of some wells (BU-1, 2, 3, 4, 5, 6, 7, 10, 11, 14, 15, 18) and matching them with log data as well as using the upscaling processes to distribute the directional permeability for each reservoir unit in the dynamic model.

3.4. Reservoir Fluid Properties

The solution gas-oil ratio (Rs), fluid viscosities, and formation volume factors for oil and dissolved gas are the main fluid parameters of the Mishrif reservoir that are often determined as a function of pressure owing to isothermal conditions in the reservoir. As a result, the majority of the features of the oil and gas data came from the examination of differential liberation within PVT reports for 8 fluid samples obtained from 6 wells. These fluid samples really matched three Mishrif formation units (MB21, MC1 and MC2).

The Generation of accurate and final PVT tables are used for simulation processes was be done by PVTP software. Typically, this software works as a fast and accurate thermodynamic fluid evaluation tool that helps production, reservoir, and technologist characterize fluid PVT behaviors and forecast how process parameters will affect the compositions of hydrocarbon molecules (Petroleum Expert IPM, 2015).

Moreover, the work steps show the final PVT tables by using the PVTP software depending upon data getting from (North dome: Bu-1 and Bu-12L; South dome Bu-4, Bu-6, Bu-10 and Bu-16). Table 1 and Fig. 3. show the calculated oil properties for Bu-1 and black oil correlation window respectively.

3.5. Rock – Fluid Properties (Generation of Saturation Function Tables)

In this reservoir simulation model, the properties that depend on the phase saturations, that is the relative permeabilities and capillary pressures are called Rock-Fluid Properties.

In fact, the data of special core analysis which include the relative permeability (Kro and Krw), Capillary pressure (Pc) and Water saturation (Sw) relationships are prepared for two wells (Bu-3 and Bu-4) in order to set represented rock-fluid tables for the whole Mishrif Formation. However, these tables are very important for generating the optimum Dynamic Model.

Table 1. Oil Properties for Bu-1.

pressure(psi)	RS (m3/m3)	Bo	Mo (cp)
6250.1	114.9	1.3641	0.95
2660.0	114.9	1.4083	0.73
2300.0	100.37	1.3667	0.84
2000.1	88.92	1.3355	0.96
1700.0	77.69	1.3057	1.08
1400.0	66.86	1.2764	1.23
1100.0	55.92	1.2471	1.4
800.1	45.08	1.217	1.6
600.1	37.73	1.1956	1.72
400.0	29.73	1.1735	1.98
200.0	19.94	1.1415	2.65
14.2	0	1.0697	2.99

PVTFile1 - Black Oil: Correlation Modifiers

OK Reset Cancel Help

Bubble Point					
	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1:	0.793552	0.830995	0.853224	0.779696	0.810488
Parameter 2:	-932	-676.441	-550.386	-1043.93	-808.763
Std Deviation:	3.86201e-007	6.33157e-007	2.83761e-007	8.66926e-007	

Solution GOR					
	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1:	1.63067	1.34376	1.37896	1.5755	0.430264
Parameter 2:	108.286	124.951	95.9176	108.97	288.562
Std Deviation:	11.6523	5.74088	4.88637	2.84915	

Oil FVF					
	Glaso	Standing	Lasater	Vazquez-Beggs	Petrosky
Parameter 1:	1.03682	0.969837	0.973726	1.31182	4.04591
Parameter 2:	0.0102508	0.048554	0.0435986	-0.342059	-3.75499
Std Deviation:	0.00465836	0.00419549	0.00214905	0.00191549	

Oil Viscosity			
	Beal et al	Beggs et al	Petrosky
Parameter 1:	0.879109	1.44835	0.663984
Parameter 2:	-0.202672	-0.335919	-0.11294
Std Deviation:	0.0268364	0.103694	0.0732917

Fig. 3. Black oil correlation window

4. Simulation Model Processes

4.1. Make Fluid Model

Regarding the PVT analysis, the Oil Black Model is selected to represent the fluid in the Mishrif reservoir. In addition, the heavy oil + gas model is carefully chosen to characterize the initialization phase of the simulation model. Essentially, the reservoir condition that includes maximum, minimum and reference pressure, as well as reference temperature at reservoir datum, be prepared as in Table 2.

Table 2. Reservoir initial condition

No	Reservoir condition	Values
1	Max. Pressure	7000 psi
2	Min. Pressure	2760 psi
3	Reference Pressure	6350 psi
4	Reference Temperature	233.7 F°

Subsequently, the fluid condition for gas, the specific gravity of gas was equal to 0.77 sg air, for oil, the information that was entered is present in Table 3, and for water, the salinity of water was equal to 200000 ppm.

Table 3. Reservoir oil condition

No.	Oil Condition	Information
1	API Gravity	22.5 API
2	Bubble point pressure	2760 psi.
3	Bubble point pressure correlation	Lasater (1958).
4	Solution gas/oil ration correlation	Vasquez and Beggs (1980).
5	Formation volume factor correlation	Vasquez and Beggs (1980).
6	Undersaturated Viscosity	Beal (1946)

In fact, the initial pressure at datum depth and oil water contact depth for productive units of Mishrif Formation are shown in Table 4.

Table 4. Datum and OWC depth for different Mishrif Formation Unit.

No.	Units	OWC Depth North dome	OWC Depth South dome	Datum depth
1	MB21	-3878 m	-3888 m	-3850 m
2	MC1	-3993 m	-3973 m	-3900 m
3	MC2	-4010 m	-4010 m	-3950 m

Thus, Mishrif reservoir has been divided into two regions, reliable with the fluid model, and established the main pressure systems in Mishrif reservoir: the first one represents north dome, and the second one symbolizes south dome, with same value of initial pressure that equal to 6350 psi.

4.2. Make Rock Physics Function

This step was consisted of input the saturation and compaction parameters. For Saturation model, the shaly-sand model has been chosen while the rock compressibility and reference pressure for *north dome* was equal to 5.5×10^{-7} 1/psi and 6350 psi respectively for Compaction model, the shaly-sand model has been chosen also for south dome with rock compressibility and reference pressure for were equal to 4.82×10^{-7} 1/psi and 6350 psi respectively for Compaction model.

4.3. Aquifer Modeling

To apply the aquifer model for the Mishrif reservoir/ Buzurgan oilfield, it needed a unique model to represent the boundary conditions. Therefore, the Fetkovich model is used to simulate the water influx and the flow regime at the boundary of the reservoir. In fact, the aquifer of Mishrif reservoir at Buzurgan oilfield is considered a rather weak-water-drive aquifer. Consequently, the Fetkovich model is, an analytical aquifer which its properties can be adjusted on the way to make a genuine matching across the courses of history matching of Mishrif performance to obtain the optimum dynamic model. Moreover, it is the best option to represent the small-scale and modest aquifer volume.

4.4. Well Modeling

The important issue for achieving the real and best simulated dynamic model is by correct representation of well modeling. It included the location and trajectory of wells as well as the completion parameters such as casings depth, tubing depth, perforation intervals and depth, number of production units, and BHA depth.

In fact, for Buzurgan oilfield, there were more than 106 wells with various well types (vertical, deviated, and horizontal) drilled and completed in the Mishrif reservoir started from period of 1976 to 2021. In addition, considering of the well type, there are 54 vertical wells, one directional well, and 51 horizontal wells drilled through different target units such as (Mb11, Mb21, MC1, and MC2) of the Mishrif Formation/ Buzurgan oilfield. Thus, locations, path, and completion parameters data for every well were inserted into Petrel-2017 software to simulate the wells position, completing, and targeting to build the Mishrif dynamic model.

For optimizing, in the current study, eight wells have been converted from producers to injectors during years 2016 to 2021. Therefore, each well can be utilized for one purpose either producer or injector. Thus, the new wells are Bu-34INJ, Bu-36 INJ, Bu-37 INJ, Bu-38 INJ, Bu-39 INJ, Bu-41 INJ, Bu-42 INJ, and BUCS-48INJ. Fig. 4 shows an example of various drilled well and completion types through the Mishrif reservoir.

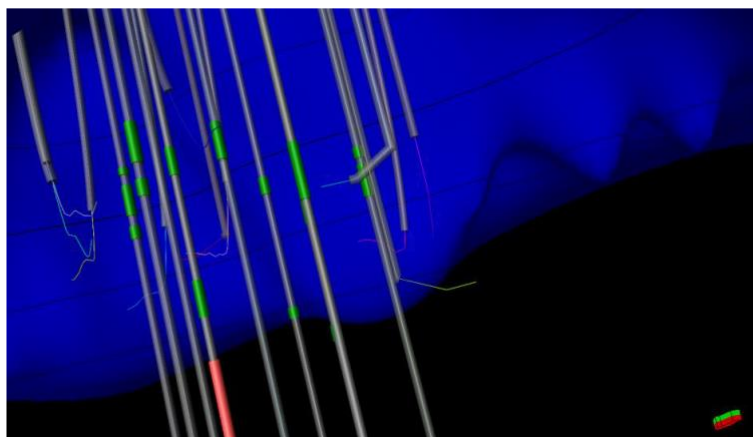


Fig. 4. Vertical, directional and horizontal wells drilled through Mishrif reservoir's units.

4.5. Information of Production and Injection wells

As presented previously, the Buzurgan oilfield has started to be produced in 1976. Thus, the available production and injection data extended from August 1976 until 1/1/2021, therefore, the dynamic simulation model of the Mishrif reservoir is considered a challenge model for long history matching of production and injection rates for approximately 45 years. Moreover, the number of drilled wells is 106 wells, which divided into 3 categories, the first are 85 producer oil wells, the second are 16 injector water wells and the third are 5 dry (abundant) wells. The water injection development strategy has been started in 19/11/2016 over BUCS-48INJ, which was first drilled for oil production purpose, then the number of injection wells gradually increased. However, eight wells were converted from oil producers into water producers.

In addition, at end of December 2020, there were 57 working producers with oil production rate approximately 88 MSTB/D for the whole Mishrif reservoir. As well as these producers have produced water with rate around 18 MSTB/D for whole Mishrif reservoir. However, the injection rate of sixteen injector wells for the full Mishrif reservoir is 120 MSTB/D. So, its an important issue to solve the problem of high water cut percentage that is equal to 17%, as shown in Fig. 5.

Thus, the production rate of oil and water, and water injection rate are presented in Fig.6, while the cumulative production rate of oil and water, and cumulative water injection are shown in Fig.7.

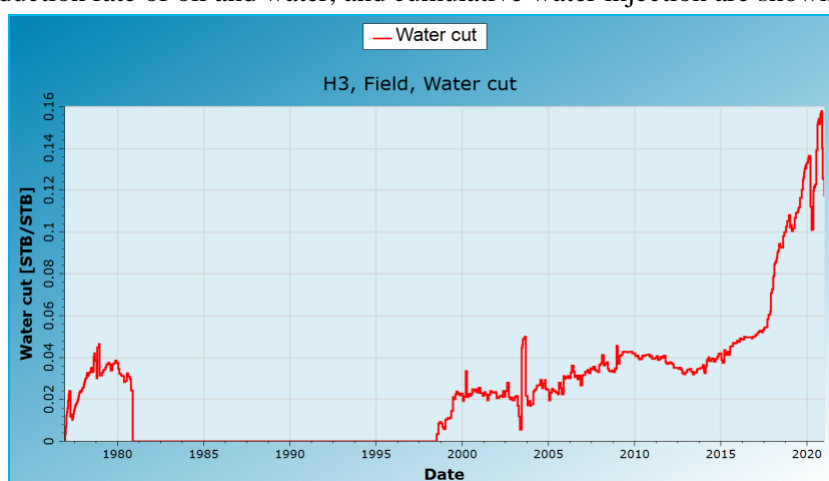


Fig. 5. Water cut production percentage of whole Mishrif Formation.

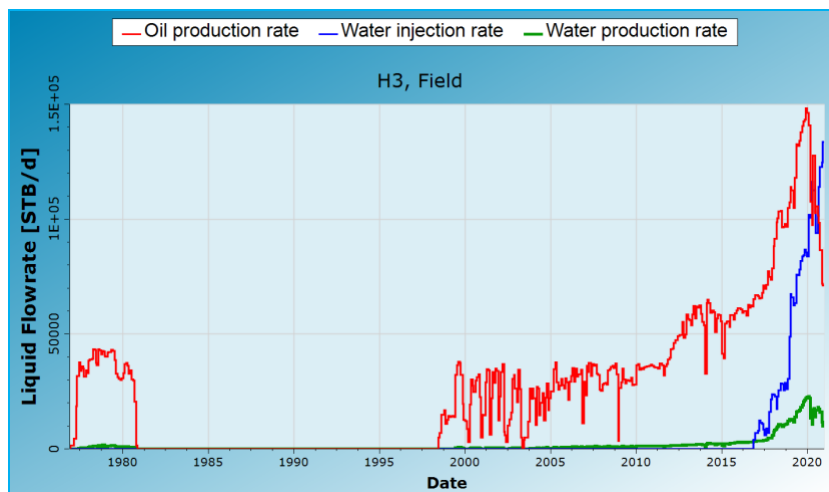


Fig. 6. Production oil, water, and water injection rates for whole Mishrif Formation.

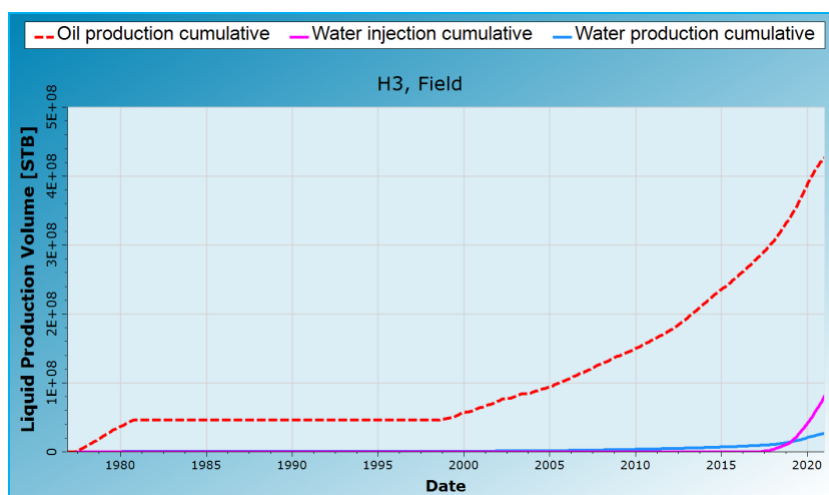


Fig. 7. Cumulative production of oil and water, and cumulative water injection for whole Mishrif Formation

5. Results and Discussion

The objective of history matching implementation is to standardize the dynamic simulation model. Thus, it can be developed to accurately predict the reservoir efficiency in the time ahead depending upon numerous management and improvement strategies (Carter, 1974). In most cases, the value of the history match is clear relative to the quantity and correctness of the accessible data. The procedure of data testing requires an all-encompassing characteristic management level. Essentially, every information case should be evaluated for precision and reliability. However, the cause of faults and their impact should be assessed and examined. Furthermore, information with inaccuracies should simply be emphasized without rejected, or removed (Fanchi, 1997).

Usually, history matching is a main challenge which requires modifying the model constraints such as permeability, formation skin factor, relative permeability of water and oil, capillary pressure and water saturation, and other flow properties till the results of reservoir model simulation are convenient to the observed data, for instance the fluid production flow rate and pressure data.

Furthermore, many times of runs have been accomplished to match the oil production and water injection rates, produced water cut, reservoir average pressure, and the pressure for every individual

well. Before starting history matching, the most effective parameters are specified first, and the uncertainties of matching processes should be resolved. Consequently, the greatest match achieved in the recent simulation is concerned with the next major modifications.

5.1. Oil Production Matching

As mentioned previously, the Buzurgan oilfield has long production period approximately 45 years, so the history matching processes are taken several runs to identical the observed production data. Oil production matching steps are designed depending on adjusting the sensitive properties of the Mishrif reservoir:

- Modifying of Horizontal permeability in the direction of X-coordinate (K_x) and Y-coordinate (K_y) for local reservoir. The modification is included multiplying K_x by 1.8 and K_y by 1.8 also.
- Optimizing the skin factor for many wells of Buzurgan oilfield, thus, permit the oil production rate which was created by simulation model to match the observed data.

Thus, all 93 (85 + 8 wells before converting to injectors) producer wells are getting oil rate production matching with observed data. Moreover, the cumulative oil production volume of observed data is equal to 4.33×10^8 STB which is the same for simulated model. Finally, the matching results of field oil production rate and cumulative are shown in Figs. 8 and 9 of the whole Buzurgan oilfield, as well as Figs. 10 and 11 show oil rate matching for individual wells.

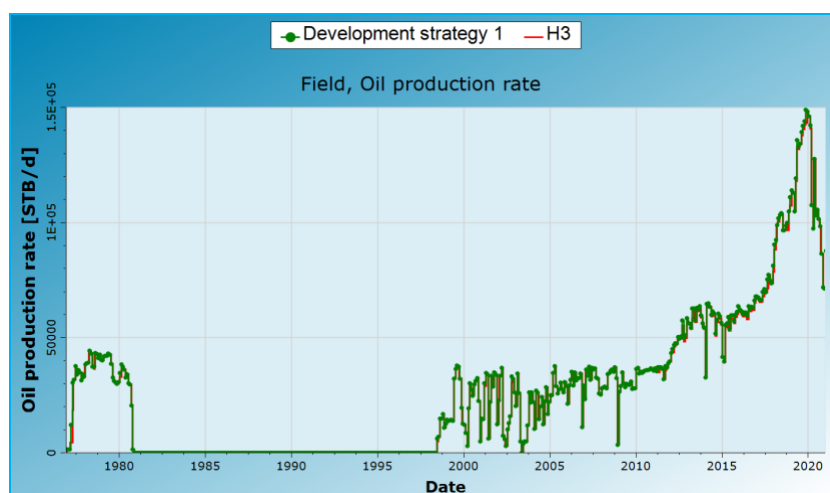


Fig. 8. History matching of oil production rate of whole Buzurgan oilfield.

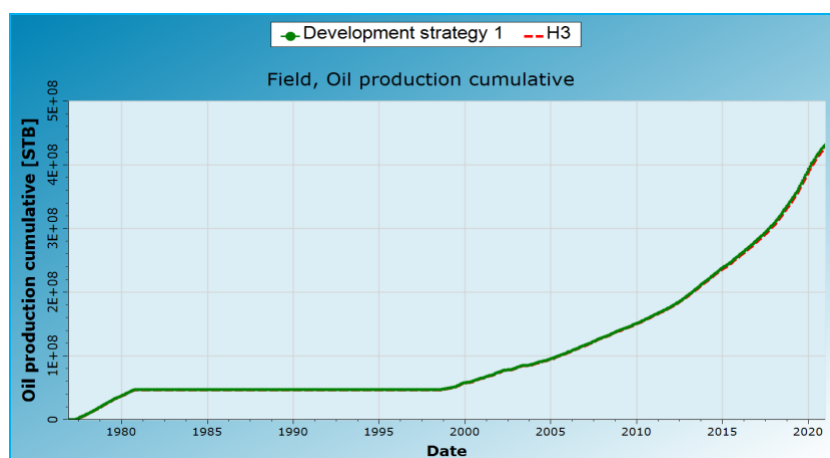


Fig. 9. History matching of cumulative oil production of whole Buzurgan oilfield.

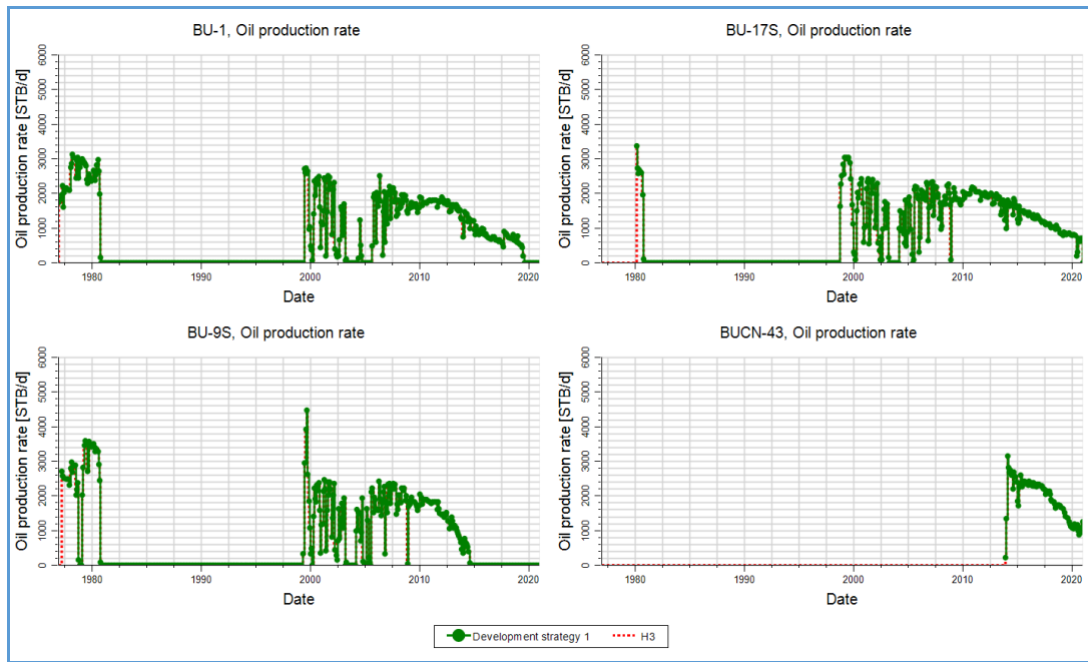


Fig. 10. History matching of oil production rate for selected wells at north dome

5.2. Water Injection Matching

The historical matching period of water injection rate in the Mishrif reservoir is extended to around 4.1 years, which is from 19 November 2016 to 31 December 2020. Essentially, this step was not needing any modification of reservoir characteristic. Thus, all sixteen injector wells have gotten matching between results of simulation model and observed field data for water injection rate at end of history match period. Finally, the water injection rate for different injectors as well as for the whole Buzurgan oilfield results are shown in Figs.12 to 14. Consequently, the cumulative water injection matching progress is done, and it is calculated from the simulation model from 19 Nov. 2016 to 31 Dec. 2020 that equal to 8.3×10^7 STB, as shown in Fig.15.

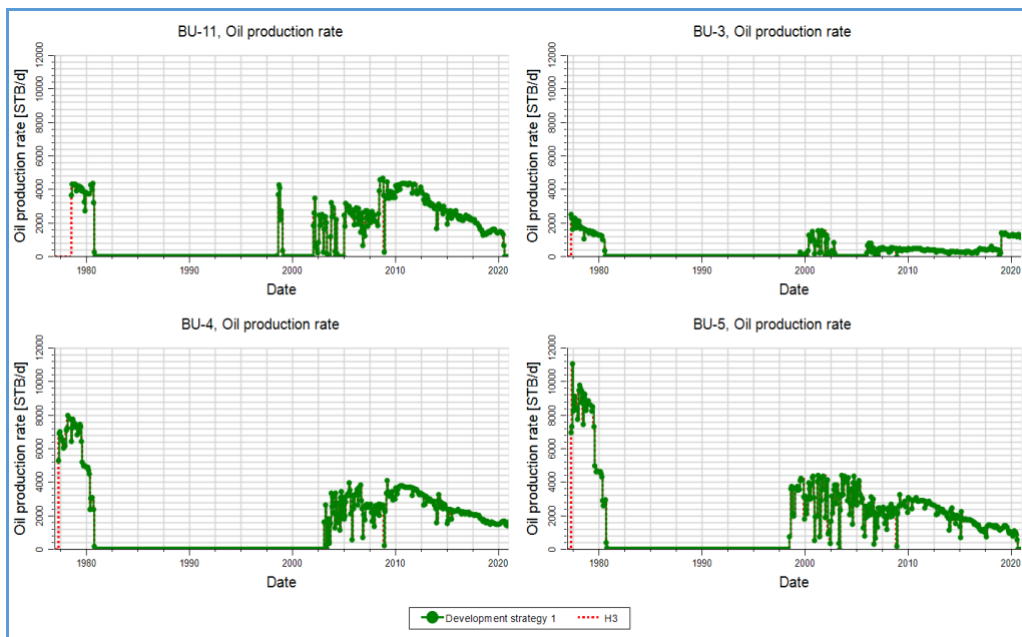


Fig. 11. History matching of oil production rate for selected wells at south dome.

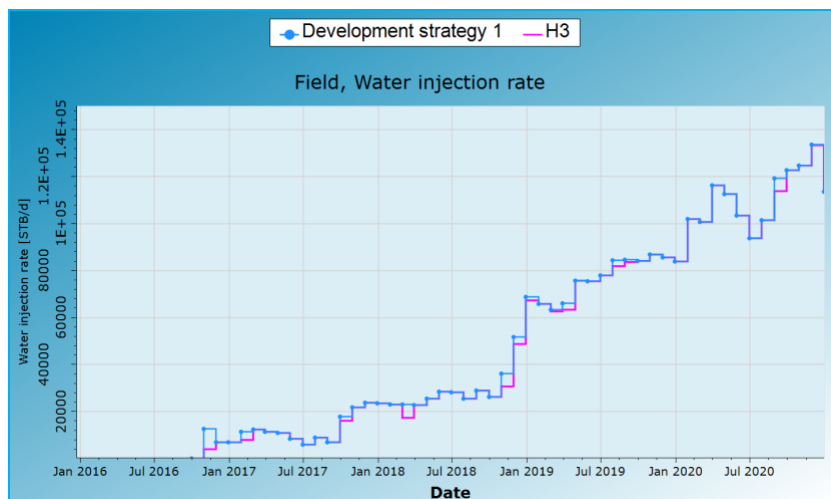


Fig. 12. History matching of field water injection rate

5.3. Water Production Rate History Matching

History matching of water production rate is the foremost step in the history matching progression. However, this matching is normally implemented during simulated and matched oil production, water injection rate and static pressure.

Thus, precise simulation of fluid movements through the reservoir was achieved by applying appropriate matching between the observed water production rate data and simulated model which will lead to more accurate model of forecasted future reservoir performance.

In fact, three periods of water production rate were mentioned in the current study. First, from November 1977 up to October 1980, the maximum reservoir water production rate was about 750 STB/D. Second, from July 1999 up to August 2017, the water production rate increased steadily to maximum production rate is about 2750 STB/D.

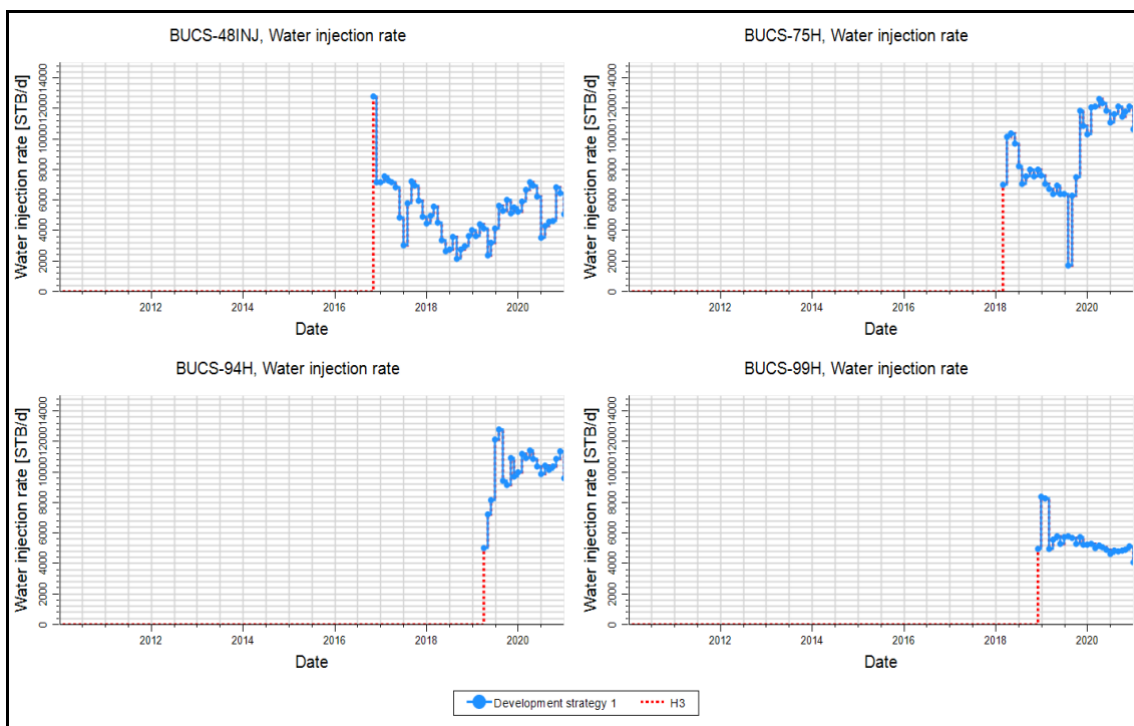


Fig. 13. History matching of water injection rate for selected injectors.

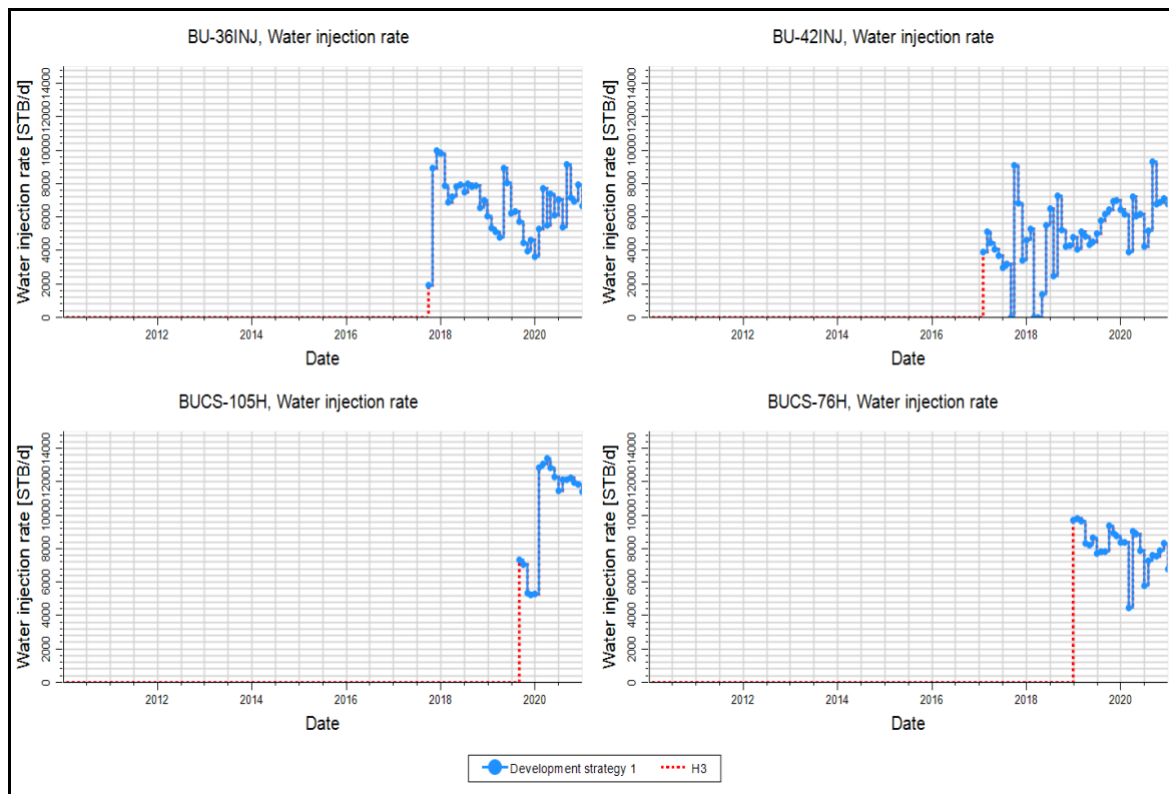


Fig. 14. History matching of water injection rate for selected injectors

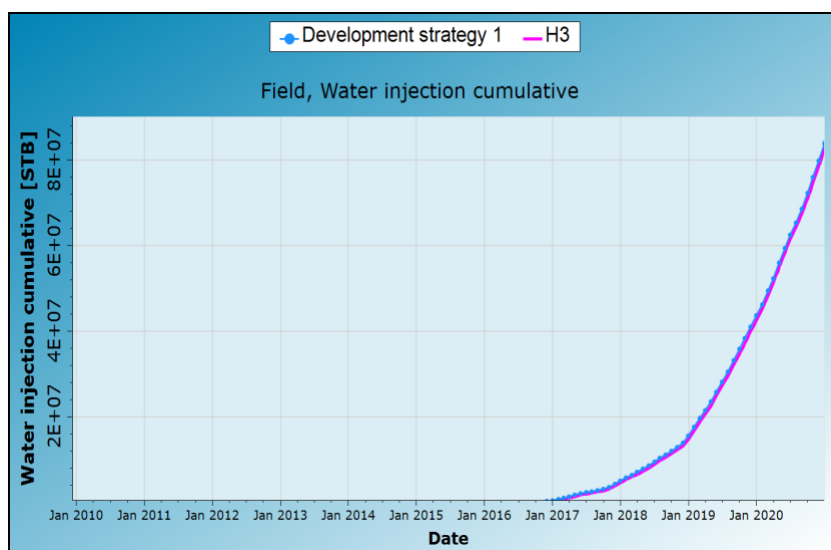


Fig. 15. History matching of cumulative water injection of whole Buzurgan oilfield.

Third, up to December 2020, the water production rate increased dramatically to reach maximum production rate is about 21750 STB/D. So, this massive increase in water production rate was due to started of implementing of water injection plan that started at November 2016. Thus, sixteen injector wells, which include fifteen injectors in south dome and one injector in north dome, were worked to maintain the reservoir pressure as well as lead to increase water production rate and water cut percentage in whole reservoir. Fig.16 shows the history matching results of field water production rate for the whole Mishrif reservoir.

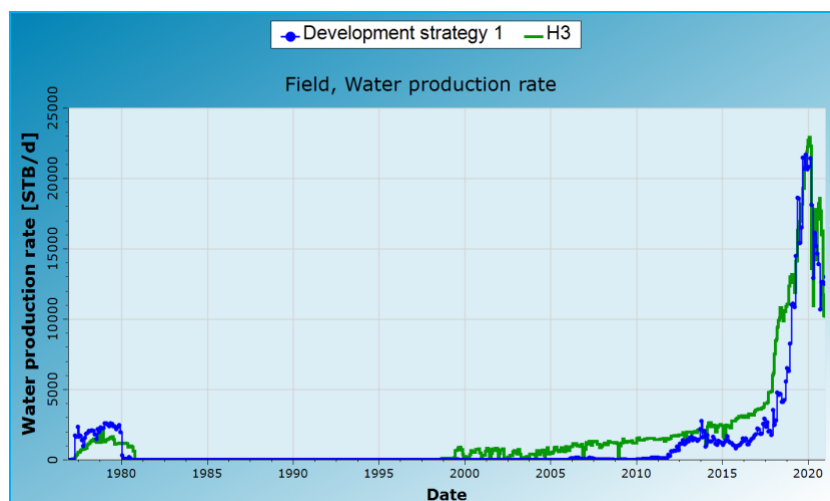


Fig. 16. History matching of water production rate for whole Mishrif reservoir.

From this figure, there are acceptable results and reasonable matching trends have been achieved for the water production rate of the whole Mishrif reservoir. In contrast, there were a number of points with moderately unfortunate matching and nearly divergences between results of simulated model and observed data. For field scale, the unfortunate matching of water production rate was as result of approximately lack of water production rate data in some old wells as well as wells which produce from two units where its data was less reliable.

In addition, Fig.17 presents the matching of water production rate of simulated model with observed data for some selected wells with approximately accepted matching.

However, the detected divergence in some well data and simulated model are possibly a result of many causes; First, the bad quality of cement beneath final perforation intervals which may cause an increase the observed data of water production rate because of cross flowing water behindhand the casing whereas the simulation model presents zero or small value of water production rate. Second, the miss recording the water production rate in some wells was led to increase values of water production rate in simulated model while zero values in observed data.

Third, the observed data were daily recorded while the current model used monthly time step. Fourth, the effect of changing the OWC during 45 years production period had essential impact on simulated model. Last, the controlling parameter in simulated strategy was oil production rate so it was quite hard to fit the observed data with simulated model in some wells. Accordingly, there were some difficulties in obtaining highly accurate matching in the whole reservoir production life.

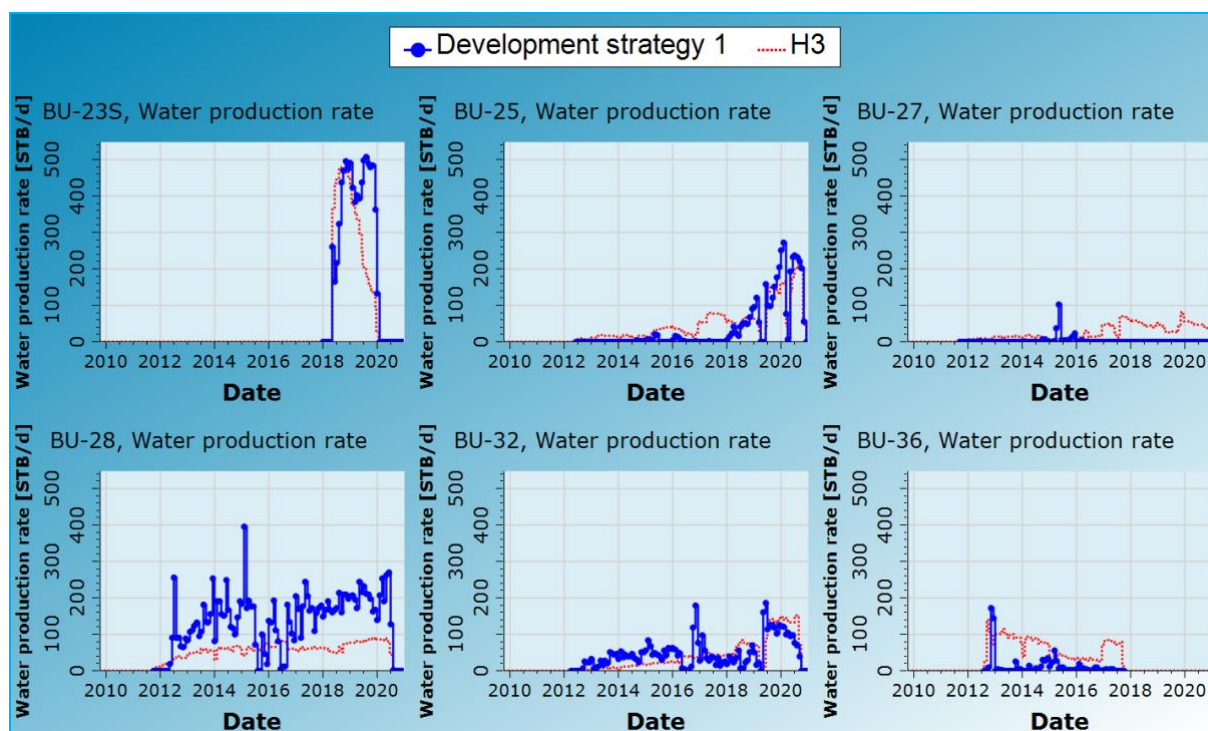


Fig. 17. History matching of water production rate for selected wells at Mishrif reservoir.

5.4. Pressure Matching

In the current study, the pressure matching stage is considered the most complex stage, because of the variation of pressure during the long production time (45 years) for several wells, the production is occurred through four different units (MB11, MB21, MC1, and MC2) and the data of pressure have been recorded from two different domes. Thus, the best match achieved requires the following steps of adjustments for Mishrif reservoir characteristics:

- Controlling the aquifer effects by applying the bottom water drive aquifer and Fetkovich approach.
- Segmentation of the north and south dome into a few secondary smaller regions, this method was assisted to control the permeability for these regions. So, decreasing the horizontal permeability (K_x and K_y) in a certain region with multiplying it by 0.4 to 0.8 as well as increasing the other secondary region with multiplying it by 1.4 to 2.
- Adjusting of vertical permeability (K_z) of Mishrif reservoir for north and south domes, the modification is included multiplying K_z by 1.5 for south dome and 1.8-2.5 for north dome.
- In fact, the static pressure data for 42 (7 wells in north dome and 35 wells in south dome) wells are prepared. However, the pressure matching between the simulated model and observe data was obtained for most of these. Finally, the matching results are be shown in Figs.18 to 20 for individual wells.

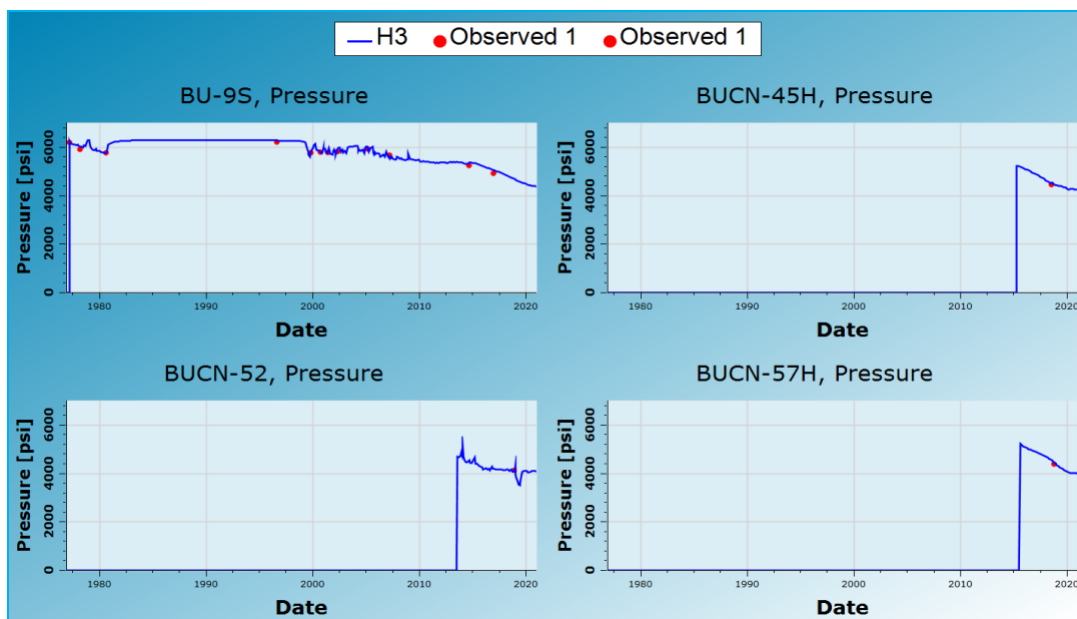


Fig. 18. History matching of static reservoir pressure for selected wells at north dome

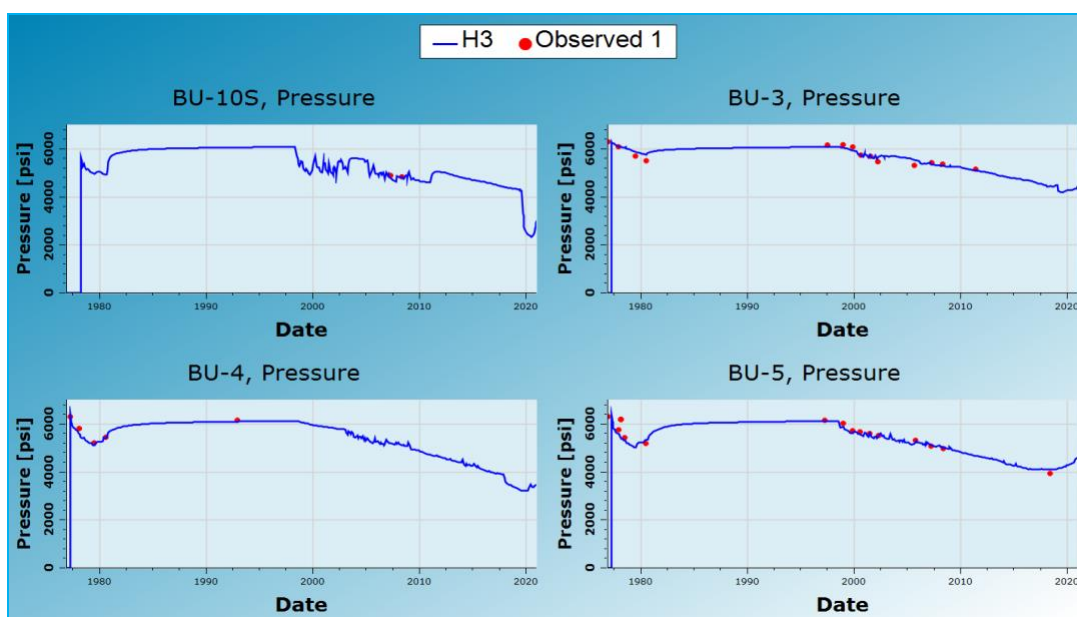


Fig. 19. History matching of static reservoir pressure for selected wells at south dome

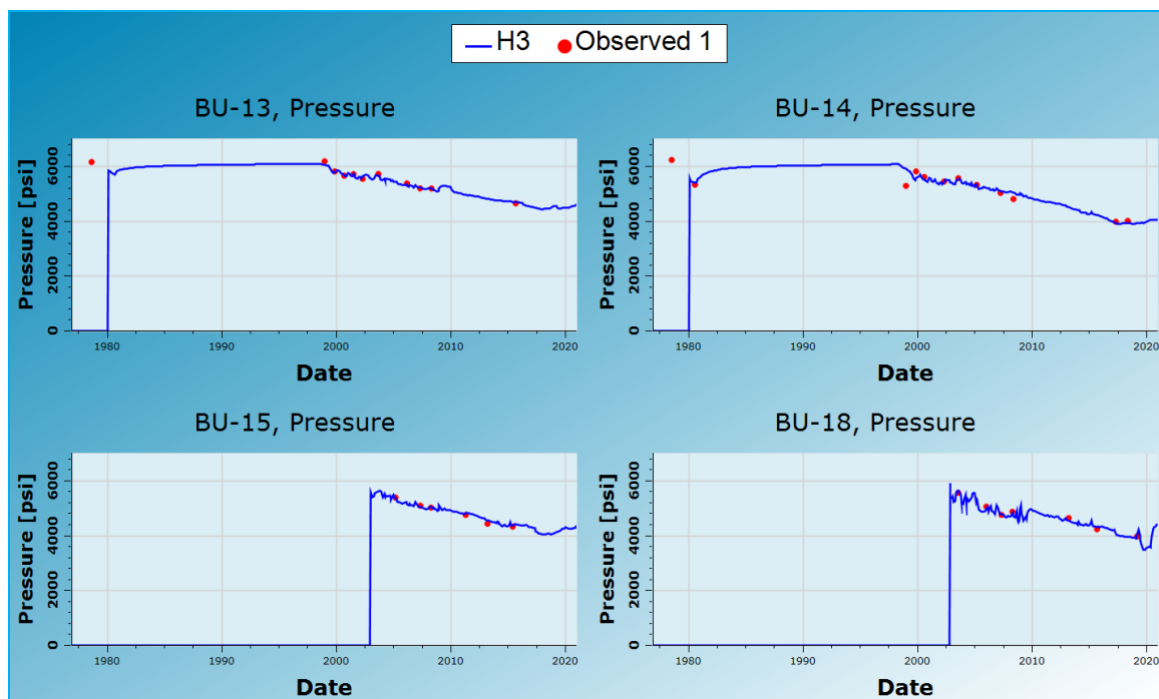


Fig. 20. History matching of static reservoir pressure for selected wells at south dome.

5.5. OIIP by Dynamic Model

The estimated oil initial in place (OIIP) by dynamic model is close to OIIP estimated by geological model with only different increment of 2%. The OIIP in the south dome of the Mishrif Formation is established to be greater than in the north dome due to the fact that the south dome is larger than the north dome in bulk volume and the MB21 unit has strong petrophysical features.

6. Conclusions

A crucial step in validating and calibrating the reservoir characteristics was history matching. More specifically, minimizing the discrepancy between measured and predicted reservoir flow responses validates reservoir modeling. Thus, excellent history matching results are achieved for the Mishrif reservoir/ Buzurgan oilfield depending on calibrating some parameters and performing many tries and errors to obtain best decision making as;

- Static pressure, oil and water production rates, water injection rate and water cut history matching are achieved by adjusting the horizontal permeability for vertical wells and adjusting the vertical permeability for horizontal wells regionally or locally, adjusting the wells skin factor values to optimize the fluid flow across the well, and getting the precise perforation depth. Allow the oil and water production rates, water injection rates and water cut to be perfectly matched with observed data.
- Matching of IOIP of static and dynamic models are achieved by adjusting the curve of relative permeability for oil and water versus water saturation which has great impact on fluid flow through the Mishrif reservoir.
- Adjusting the endpoint values of capillary pressure versus water saturation have great impact of volume of fluid initially in place which without adjusting it, the OIIP was larger than the OIIP from the geological model by ten times.
- Taking appropriate values for water salinity consequently effected water viscosity. Thus, as water viscosity increase the OIIP will increases, so its important parameter during history matching processes. The precise historical matching, is done during maintaining the OIIP at close value to

calculated value in geological model. Depending on a combination of well log data, fluid characteristics the model is established, and information of oil and water production, water injection, and wells static pressure are the main parameters that have to be getting matched while maintain the OIIP unchanged.

- Accurate value of rock compressibility for north and south domes of the Mishrif reservoir as well as appropriate value of directional permeability to supply a perfect reservoir static pressure matching for wells and the whole of Buzurgan field.

Adnan, (2019) expressed that history matching is done manually by running the simulation model for the historical period, and then results are compared to the known field performance in order to get a good and acceptable match. In general, permeability distribution is most uncertain, hence, it should be selected as the first parameter to adjust. Porosity distribution is usually taken as the second most uncertain parameter, if reliable log data are not available. The more commonly used history matching parameters are aquifer size and strength, vertical permeability, the kHh product (permeability thickness) for reservoir and well, the kV/kH ratio, pore volume PV, and relative permeability.

Taher, 2018 presents that history matching is a reverse matter that includes modifying input parameters of the simulation model until the simulation results are fitting with the observed data. Selecting the suitable parameterization is valuable to reduce the passed in the reservoir model and get dependable prediction of the oil production through reservoir development plan. The history matching of well static pressure is performed by matching between simulation results of well static pressure and the observed one for more than 40 wells in the Mishrif reservoir.

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