Application of streamlines for improved waterflood management of iraqi’s reservoir.

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Abstract. In this paper, Using the unique advantages of streamline based (SL) flow simulation, for the first time, we have attempted to simulate waterflood strategies in Buzrgan oil field in southern Iraq and to optimize it. Therefore, in this paper the streamlines are really significant that:

• The numerical calculation of the produced and injection fluid at any given time is possible for each pair of wells.
• Flux pattern maps represent the significant information of the streamlines.
• The runtime in the simulation of the (SL) is much less than finite-difference (FD).

Using this (WAF’s), it is possible to calculate the efficiency of injected wells as the proportion of injected water to the oil delivered at balance wells. With injected efficiencies (IE) known over the field for every injector, water can be reallocated from low-efficiency to high-efficiency wells, in this way computing the assembly for each barrel of water injected, resulting in more sweeping and significant optimization. In addition to this, the IE chart has been given obvious visual of the reservoir management such as (eg, the changes of the wells with low IE to the injection wells.

1. Introduction
In view of the fact that the reservoirs in the middle-east have often come to maturity, or when they are at the stage of reaching their maturity, the use of the secondary recovery operation is suggested/considered. And water flooding is the most common operation for this situation, however due to the limited access to water, it is considered one of the problems of this type of operation.

In this project we have been optimizing the water flooding operation by keeping the water levels constant, in this operation we use the streamline and its unique capabilities to determine the amount of the injected and produced quantities, through the well allocation factors (WAF). The well allocation factors help to calculate the efficiency of the injected wells to improve the productivity of the injection. And the fact that water can be used from the well with low injection efficiency to high efficiency well and, consequently, optimization of the production per injection barrel [2].

2. Streamline simulation
In more than a decade the Streamline based simulation has been transpired as a robust complementary tool to more traditional FD simulation. The streamline simulations statistics can be read in most of the references on the methodology [1, 4, 5, 6, 8, 9, 10, 13, 16, 17]. The information about the streamlines have showed up in the petroleum literature since Muskat’s book [12], the streamlines simulations have taken most of its plan to the streamtube manner of the 1960s and 1970s [14, 15]. One of the strong element of the streamline reproduction is the capability to evaluate and imagine supply stream get from
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At split second, streamlines give a depiction of the manner in which the store is associated and how significantly the liquid is dole out between injector/producer sets. Owing to the fact that streamlines are rely upon a numerical reproduction approach, a streamline model can be changed in accordance with historical data and can be represented nonuniform liquid disseminations and multiphase-stream impacts correspondingly as a FD model can.

The perceiving aspect of a full streamline reenactment as opposed to just following streamlines in a FD test system, is that the general rates and the discrete stage rates between well matches can be determined in light of the fact that a streamline test system takes care of a 1D transport issue in each streamline. what's more, the work to the 1D issue that ushers to the definition IEs either for an injector or an injector/producer pair. This information isn't accessible from the tracing alone.

When the IEs are found, it is feasible to promptly obtain a fieldwide metric of the execution of the waterflood, disregarding of the number of well involved. A metric such as that is indispensable for any successful reservoir management.

3. Reservoir simulation

At first it is essential to require the simulation for the reservoir, to manufacture a sample for the reservoir that consist of both the static and dynamics' properties, and the crucial data that we need to obtain such simulation are:

- Contour Map
- Well top
- Well log
- Some elements of the porosity, permeability and the water saturation.
- A few statistics of geology and petro physics that has been achieved in the reservoir simulation.

![Figure 1: Overview of the designed reservoir's permeability and along with the well's location which is in the southern dome and northern dome of the buzrgan oil field.](image-url)
Table 1: overview of the designed reservoir's permeability and along with the well's location which is in the southern dome and northern dome of the buzrgan oil field.

| Cell number  | 92×34×14 |
|--------------|----------|
| poroducers   | 18       |
| Injectorers  | 3        |
| Rock type    | Shaly sand |

4. History matching
Every simulation that has been carried out require a history matching to assure that the simulations are in line with the actual reservoir, otherwise the simulation will not be acceptable. As luck would have it the data that is required for implementing the history matching is already available and for that reason we can assemble a case study with above 85% of the history matching, which for this research model, this matching is acceptable.

Figure 2: Apparent difference between the field history matching of oil (green line) and water (blue line) production, first illustration after alternation and modification second illustration before the changes, we obtained almost 85% of the history matching.

5. Defined development strategy
After executing the history matching, we could go forth by defining the strategy, we initially designed a production strategy for the following reservoir, we have limited in production data due to the fact of the reservoir’s security problems, and for that reason we have obtained the average rate for all the reservoir observed production data that is available and it is about 500 STB/D for most of the wells, after that we have acquired that the information is safe to the majority of the well’s production rate, so
we used 500 STB/D for every production well. Scheduled time for the injection is when the oil production rate has reached below 600 STB/D and that would be in the near 2047. After this set, we have made an assumption the injection process would be 2700 STB/D for all of injection wells, the injection rate has been deduced from the rule of thumb The injection rate better to be 1.5 times the production rate, which is supposed to be better for waterflooding operation and that is for the following reasons:

- The produced fluid is compressible and the injected fluid is incompressible.
- Waste part of the injection fluids if there are aquifers.
- Leaks portion of the fluid in the adjacent grafts.

We utilize this reservoir to show the fundamental strides of the work process exhibited in this paper.

Note the following points:

- Production toward the finish of 10 years is taken to be the present condition of the field and the minute from which improved injection/production management is to be started.
- The objective is to make the best utilization of as of now (2700 STD/D) and increment oil production by reallocating water among injectors. We expect that there are no limitations in reallocating water in light of surface-facility or well profitability/injectivity issues.
- We contrast our outcomes with a base case thought to be a “do-nothing” scenario and normal waterflooding.

6. Injection efficiency.

The key idea we use all through our optimization approach is that of an injection efficiency, for our optimization approach We used the concept of “Injection Efficiency”, which is defined as follows:

$$I_{eff} = \frac{off - set \ oil \ production \ [STB/day]}{water \ injection \ [STB/day]} \quad \cdots (Eq. \ 1)$$

The accompanying perceptions apply to Eq. 1:

- Being a proportion of rates, Eq. 1 represents to an immediate amount. In any case, the condition likewise can be composed as a proportion of combined volumes, in which case the outcome would be an average efficiency over time.
- It is conceivable to characterize an IE for every active injector in the field. The water-injection rate is known (denominator), while the offset oil production (numerator) must be determined utilizing the data from the WAFs controlled by the streamlines.
- It is additionally conceivable to characterize an injection efficiency ($e_{wp}$) for every producer/injector pair as we have utilized it (injection efficiency) for the improvement activity which is a noteworthy case in this project. For this situation, both water injection (denominator) and offset oil production (numerator) are processed from the WAFs.
- Although in this paper we center only around water injection and oil production, the meaning of an IE can be stretched out to any sort of injected and produced volumes.

7. Toward improved injection management.

Expanding the oil recuperation for each unit volume of water injected is the purpose of every effective waterflood management scheme, subject to production/injection requirements given by surface facilities, (for example, all out accessible water or most extreme injection/production rates) and local pressure maintenance. In spite of the fact that there are numerous ways to deal with dealing with a waterflood, we recognize two principle choices:

- Maintain an oil-production focus by diminishing injected volumes (water) as much as possible.
1. Increase the production of oil as much as possible due to better utilization of available volumes of injection (water).

Both of these purposes can be obtained with the aid of IEs and the workflow presented in this paper. Next, the methodology is applied to a real reservoir with 21 wells, although production rates have been altered for purposes of demonstration and confidentiality. Using the accessible water to increment oil production as contrast to a base case is the strategy that will be used in this case.

![Figure 3: Streamlines after the 5 years of production and for every pair of the production/injection well.](image)

### 7.1 IE of a well pair

The IE of a well pair ($e_{wp}$) is calculated in much the same way as the IE of an injector, except that now it is also necessary to extract the injected-water rate related with each heap of streamlines. These information (WAF) are again promptly accessible as a feature of the streamline computations. The subsequent information to compute $e_{wp}$ values are appeared Table 2. The data related with the streamlines appeared in Fig.3.

### Table 2: (WAF) data used to calculate the Injection Efficiency ($e_{wp}$) for each production/injection pairs.

| Well name | BU-2   | BU8    | BU-21  |
|-----------|--------|--------|--------|
| Water in  | 306.97 | 569.62 | 417.71 |
| Oil out   | 171.09 | 294.39 | 190.11 |
| $e_{wp}$  | 0.557351 | 0.516818 | 0.455124 |

### 7.2 Calculate injection efficiencies at the running time.

The initial phase in the work process is to decide the IEs for every injected well, the average IE of the field is determined utilizing the total of the oil produced partitioned by the water injected. For this situation, the average field efficiency is 0.509%. Note that the average field efficiency is the one number that can generally be determined from the deliberate creation information and does not require a recreation display. A vital part of ascertaining IEs is the means by which to represent injection water lost to the aquifer or, then again, oil produced in light of help from the aquifer. Water lost to the aquifer (i.e., an aquifer that goes about as a sink and that both injection water and dislodged oil may spill out...
to) is incorporated into the IE estimation. Hence, a well that is losing water to the aquifer will see a lower IE than it may somehow or another accomplish if the water were bringing about counterbalanced oil production. Alternately, oil produced in light of a supporting aquifer is excluded in the productivity computations. This is on the grounds that there is no injection over the aquifer, and, in this way, it ought not be incorporated into a metric that is utilized to infer target rates.

7.3 Reallocation of injected water.
Similarly, as the IEs are determined for every injection well, \( e_{wp} \) is additionally determined for each well pair. It is the \( e_{wp} \) values that are utilized in the work process to compute new purpose rates as an example, and the \( e_{wp} \) values for all associations in the model are found in Table 2 these estimations are registered naturally by parsing a WAF file made by the streamline simulator. Once \( e_{wp} \) is known for every injector/producer association, the focal thought is to reallocate water from wasteful to proficient well associations. How is this done? Consider the injection rate related with every injector/producer pair. The thought is to multiply the old injection rate by a factor \( 1+w \), where \( w \) is an element of the \( e_{wp} \) of that association. In other words, we are looking for

\[
q_{i}^{new} = (1 + w) \times q_{i}^{old} \quad \text{(Eq. 2)}
\]

Where \( i \) alludes to the \( i \)th injector/producer pair. In this work, we utilize the average field efficiency as the reference point to choose if the weight \( w \) ought to be bigger or littler than zero. For instance, on the grounds that the average field efficiency is 50.9%, we would need the weight to be bigger than zero for the association of BU-2 since that \( e_{wp} \) is 55.73% (see Table 2), while we need the weight to be littler than zero for the association of BU-21 since that \( e_{wp} \) is just 45.51%. Notice that the decision of utilizing the average field efficiency as a kind of perspective point is subjective. An elective methodology could be to just position all estimations of \( e_{wp} \) and allot loads in that way. In this work, we picked the main methodology and utilized Eq. A-1 in the Appendix to ascertain the loads as a component of average field efficiency, \( e_{wp} \), two key components become an integral factor here:

1. The meaning of an "average" efficiency, with the related principle that estimations of \( e_{wp} \) with an efficiency higher than the average efficiency should discover a rate increment, while estimations of \( e_{wp} \) with a lower efficiency than the average efficiency should discover a rate decline.
2. The immensity of the capacity used to relate \( e_{wp} \) with a weight. This function is completely arbitrary.

Table 3: Statistics of the unconstrained & constrained for the old and current injection rates.

| well name | \( e_{wp} \) | Wi | \( q_{i}^{old} \) | \( (1+w) \times q_{i}^{old} \) |
|-----------|-------------|----|-----------------|---------------------|
|           | STB/D       | STB/D | Unconstrained, | new constrained,    |
| BU-2      | 55.73%      | 0.3 | 900             | 1170                | 1167.435         |
| BU-8      | 51.68%      | 0.00659 | 900             | 905.93              | 903.9463         |
| BU-21     | 45.51%      | -0.3 | 900             | 630                 | 628.6188         |
|           |             |      | 2700            | 2705.932            | 2700             |

\(~w_{max}=0.3; e_{min}=0.4551; e_{max}=0.5573; w_{min}=-0.3;~\)
7.4 New Injection-Rate Targets. 
Utilizing the estimations of $\varepsilon_{wp}$ in Table 2. The figuring in Table 3 are accomplished for every injector in the field, bringing about refreshed target rates for each rate in the sixth section for Table 3. This is only a post-handling step once the WAF information have been created by a streamline test system (3DSL 2006). There is no system in the computation displayed so far to guarantee that the new injection rate targets mean the measure of accessible water. In this precedent, we are keen on regarding an all-out injection imperative of 2700 STB/D. To do this, we essentially rescale the unconstrained target rates by a worldwide proportion given by

$$r = \frac{\text{field target water} - \text{injection rate}}{\sum q_i^\text{new} | \text{unconstrained}} \quad \ldots \quad (Eq. 3)$$

The new target rates for every injector (unconstrained and obliged) are appeared in the fifth section in Table 3.

7.5 Determining the time intervals for the reinjection
We have done the optimization operation once and we used the time data in 1/1/2053 for the optimization as the (WAF) data base.

Note: As a reminder redoing the operation in the time intervals for multiple times will grant us better results, we need to be extra careful that every time there is a change in the average field efficiency, we need to calculate it separately.

8. Conclusions
1. The waterflooding for the useable actual reservoir are capable for operation, it shows an increase 429,000 STB of oil production over a period of 10 years is given in Fig. 5.
2. IEs on a well-pair premise enable a heuristic yet ground-breaking way to deal with improve reservoir management of (water) floods, by moving injected volumes from wasteful to effective injector/proucer sets, it is conceivable to expand oil production around 46243 STB without expanding volumes of injection as given in Fig.4.
3. This is a new exploratory approach, and to achieve accurate results, there must be an integration between the simulated and the actual reservoir.

Figure 4: charts for the 3 different case study in production rates, red is for simple production, blue is for the waterflooding operation, and green is for the optimized waterflooding operation.
Figure 5: Chart for three case of the cumulative oil, green for the simple production, black for the waterflooding, and blue for the optimization waterflooding.

Appendix

\[ e_i > \bar{e}: w_i = \min \left[ w_{\text{max}}; w_{\text{max}} \left( \frac{e_i - \bar{e}}{e_{\text{max}} - \bar{e}} \right)^a \right] \]

…Eq. A-1

\[ e_i < \bar{e}: w_i = \max \left[ w_{\text{min}}; w_{\text{min}} \left( \frac{\bar{e} - e_i}{\bar{e} - e_{\text{min}}} \right)^a \right] \]

Where:
- \( e_i \) Injection efficiency for well i
- \( \bar{e} \) Average field injection efficiency
- \( w_i \) Average field injection efficiency
- \( w_{\text{max}} \) Maximum weight at \( e_{\text{max}} \)
- \( w_{\text{min}} \) Minimum weight at \( e_{\text{min}} \)
- \( e_{\text{max}} \) Upper injection efficiency limit
- \( e_{\text{min}} \) Lower injection efficiency limit
- \( a \) Exponent

References

[1] 3DSL v2.30 User Manual 2006 Streamsim Technologies Inc San Francisco
[2] Marco R Thiele and Rod P Batycky 2006 Using Streamline-Derived Injection Efficiencies for Improved Waterflood Management April SPE-84080-PA
[3] Batycky R P, Blunt M J and Thiele M R 1997 A 3D Field-Scale Streamline-Based Reservoir Simulator SPERE 12 4 246–254 SPE-36726-PA
[4] Batycky R P, Thiele M R, Baker R O and Chugh S H 2005 Revisiting Reservoir Flood Surveillance Methods Using Streamlines Paper SPE 95402 presented at the SPE Annual Technical Conference and Exhibition Dallas 9–12 October
[5] Bratvedt F, Gimse T and Tegnander C 1996 Streamline computations for porous media flow including gravity Transport in Porous Media 25 1 63–78
[6] Baker R O, Kuppe F, Chugh S, Bora R, Stojanovic S and Batycky R 2002 Full-Field Modeling Using Streamline-Based Simulation: Four Case Studies SPERE5 2 126–134 SPE-77172-PA
[7] Thiele M R 2003 Streamline Simulation. Keynote address at the 7th Intl Forum on Reservoir Simulation Baden-Baden Germany 23–27 June
[8] Thiele M R, Batycky R P and Blunt M J 1997 A Streamline-Based 3D Field-Scale Compositional Reservoir Simulator Paper SPE 38889 San Antonio Texas 5–8 October
[9] Thiele M R, Batycky R P and Kent L T 2002 Miscible WAG Simulations Using Streamlines. Paper presented at the 8th European Conference on the Mathematics of Oil Recovery (ECMOR) Freiberg Germany 3–6 September

[10] Thiele M R, Batycky R P, Blunt M J and Orr FM Jr 1996 Simulating Flow in Heterogeneous Systems Using Streamtubes and Streamlines *SPERE* 11 15–12 SPE-27834 PA

[11] Wang P, Litvak M and Aziz K 2002 *Optimization of Production Operations in Petroleum Fields* *Paper SPE* 77658 presented at the SPE Annual Technical Conference and Exhibition San Antonio Texas 29 September–2 October

[12] Muskat M 1937 *The Flow of Homogeneous Fluids Through Porous Media* (McGraw-Hill Book Co. Inc. New York City) p 770

[13] Samier P, Quettier L and Thiele M 2002 Applications of Streamline Simulations to Reservoir Studies *SPERE* E 4 324–332 SPE-78883-PA

[14] Higgins R V and Leighton A J 1962 A Computer Method to Calculate Two-Phase Flow in Any Irregularly Bounded Porous Medium *JPT* 14 6 679–683 SPE-243-PA

[15] LeBlanc J L and Caudle B H 1971 A Streamline Model for Secondary Recovery *SPEJ* 11 3 7–12 SPE-2865-PA

[16] Flanders WA and Bates GR 1987 Optimizing Reservoir Surveillance by Using Streamlines and the Microcomputer *Paper SPE* 16482 presented at the SPE Petroleum Industry Application of Microcomputers Lake Conroe Texas, 23–26 June

[17] Grīnestaff G H 1999 Waterflood Pattern Allocations: Quantifying the Injector to Producer Relationship With Streamline Simulation *Paper SPE* 54616 presented at the SPE Western Regional Meeting Anchorage 26–28 May