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Flood front estimation with streamline modelling: A case study of a mature field in western offshore, India

Abstract

Waterflooding is a tried and true technique for secondary oil recovery and is recognized in the petroleum industry since early 1900's. Waterflood surveillance is integral in assessing reservoir performance and determining suitable measures that will improve ultimate oil recovery. There are varied approaches for monitoring a waterflood and flood front estimation with streamline modelling is an effective tool for perceiving the injected water movement.

This paper illustrates a field example of estimation of flood front movement in a mature, multi-layered field in western offshore of India using a streamline modelling technique developed by Marathe et. al., 1995, 1998 for irregularly shaped reservoir with arbitrary arrangement of production and injection wells. In this case, streamlines were generated for a single layer of the multi-layered reservoir.

Based on the model output infill drilling was optimized by identifying fresh areas, which were not flooded by injected water, which added economic advantage to management's decision.

This case study suggests that this technique can be applied to any oil field under a waterflood and is of great value to mature waterfloods. This innovative method is a faster method of surveillance and supplements reservoir simulation results. This method is instrumental in taking quick and economically advantageous decisions.

Introduction

Streamlines offer a pictorial representation of the instantaneous flow field showing how reservoir properties dictate the flow path of injected water or aquifer which is not easily determined by other simulation techniques. The most attractive features of streamlines is their visualisation power which is the key in understanding fluid front locations in various times. Apart from the visualization appeal, streamlines also determine effectiveness of an injector to its nearby producers thereby opening up opportunities for designing pattern injection and solving water breakthrough problems.

Oil and gas industry has utilized streamlines for determining optimum injection pattern. Higgins and Leighton first introduced the steamtube model in 1962. They were later generated for irregular well positions bur the streamlines were fixed in space. These applications were used to evaluate areal sweep efficiency of pattern injection. However it was applicable only for simple, small, homogeneous and relatively flat reservoirs.

There are various classical water flood surveillance techniques used for monitoring like Hall plot, cumulative oil v/s water oil ratio plot, Chan's plot etc. However, estimation of flood front with simple streamline modelling using tank models (liquid withdrawal creates a void and water injection fills it) is a simple method to understand the injected water movement.

In this case study, injected water movement was modelled with in-house developed streamline modelling technique. The history match had good accuracy and based on the results, un-swept areas were identified for infill drilling. One well was drilled post modelling and actual performance of the well matched the simulated results.

Singular Value Decomposition Technique

This is a technique of linear algebra to determine the streamline distribution for unit mobility ratio displacement which was developed by Marathe.et.al. in 1995. The SVD technique was devised to model boundaries of different shapes, no flow boundaries, constant pressure boundaries, or mixed boundary conditions. The following assumptions was made to describe the potential distribution in the reservoir is as follows:

- The reservoir is plane and the fluid flow is two dimensional
- Flow is steady and local velocity is related to local pressure gradient by Darcy's law.
- Reservoir is considered to be horizontal and there is no distinction between pressure and potential and are used synonymously
- The reservoir is considered to be isotropic
- The wells in the reservoir is taken as line sources (injectors) and sinks (producers)

The methodology of obtaining streamline distribution (Marathe et al. 1995, 1998) is out of the scope of this paper and will not be discussed here. The same methodology is used to for this case study.

Case Study

This mature field is a prolific multi-layered reservoir in western offshore. This field was discovered in 1977 and was put on production in 1984. The field produced primarily on depletion drive for 6 years and was put on water flood from 1990. In this reservoir, basement is overlain by basal clastic (Panna) which is further overlain by limestone above which lies another limestone layer separated by a thin shale. Panna in this field is characterized by two distinct sand deposition underneath the limestone.

Streamlines in this particular case has been generated for Panna layer in the crestal part of the field. An area of 59.98 sq. km was considered for the tank model. Production data for 22 wells was considered in this area including 4 injectors. The average pay thickness of this layer varies between 8-12 m, effective porosity is around 20% and permeability is about 50md. Viscosity of oil is 0.30 cp, oil formation volume factor is 1.39 and oil saturation is 50-60%. Performance history of this block, cumulative oil production and injection bubble maps are shown in Figure 1, 2 and 3 respectively.

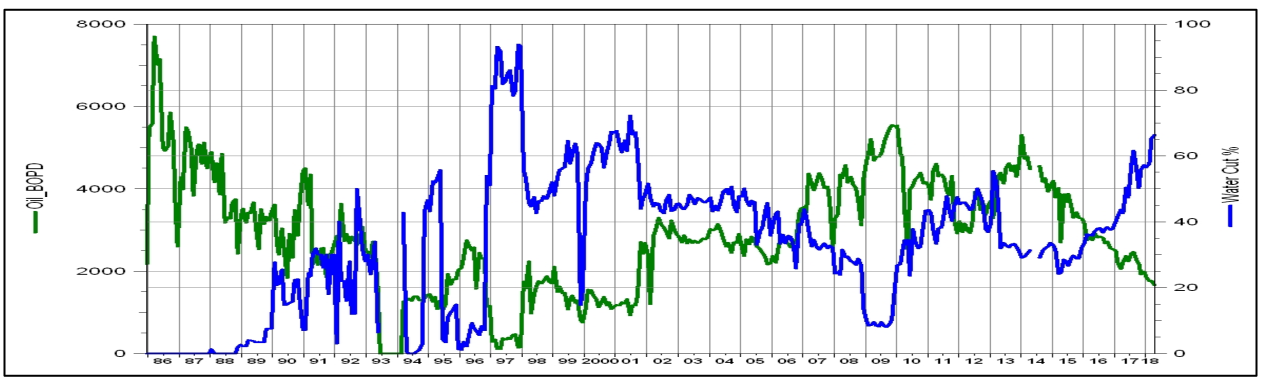

Fig 1: Production Performance of case study area

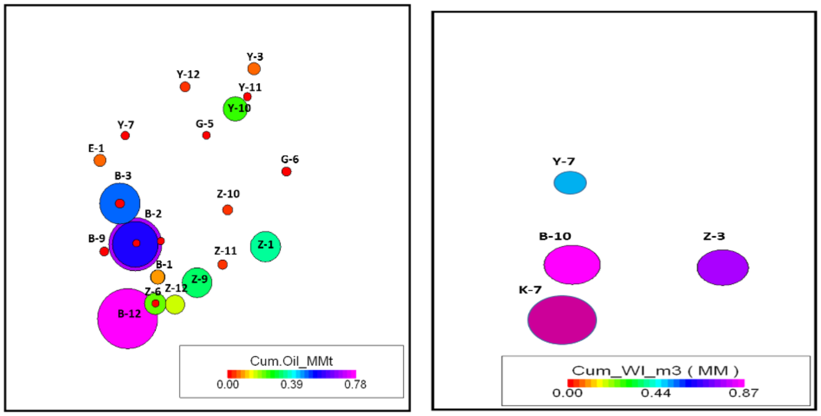

Fig 2 & 3: Bubble map of cumulative oil production and cumulative water injection of case study area

Basic data required as input for the model:

- Boundary coordinates
- Well coordinates
- Liquid production / Injection data of each well
- Area, effective thickness, porosity, oil saturation, residual oil saturation & oil formation volume factor
- Cumulative liquid production
- Cumulative oil production

Step 1: For streamline modelling, the case study area is approximated by a rectangular boundary. The boundaries are considered as no-flow boundaries as there is no aquifer support. Streamline distribution is computed by locating image wells around the boundaries. Boundary coordinates along with well coordinates are generated for input data.

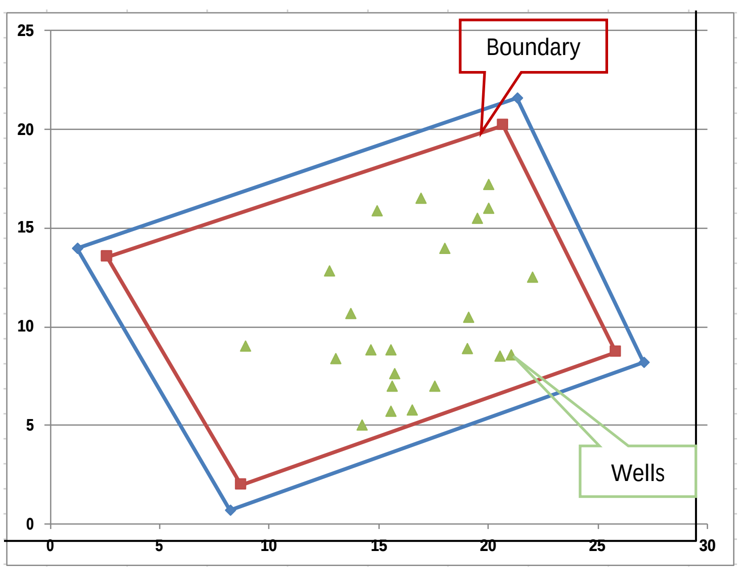

Fig 4: Case study area for tank model

Step 2: Well-wise production and injection data is arranged in tabular form

WELL	X	Y	CUM OIL	CUM WATER	CUM WINJ	DAYS
B-1	15.6	7	39284	23273	0	108
B-2	14.6	8.8	413444	1596793	0	1543
B-3	13.7	10.7	188616	292475	0	1379
B-9	13	8.4	815	38415	0	44
B-12	14.2	5	2360147	1322011	0	3058
E-1	12.7	12.8	366021	386280	0	1944
G-5	18	14	29562	122163	0	1167
G-6	22	12.5	242162	6301	0	646
S-1	8.9	9	52464	135411	0	500
Y-10	19.5	15.5	256481	49719	0	1286
Y-11	20	16	53134	260793	0	1231
Y-12	16.9	16.5	94002	73916	0	1382
Z-1	20.5	8.4	2384009	38084	0	2938
Z-10	19.1	10.5	292702	49002	0	1398
Z-11	19.1	7.5	216889	112368	0	1343
Z-6	15.5	5.7	1265702	1301794	0	2322
Z-9	17.5	7	2385553	97398	0	3002
Z-12	16.5	5.8	1241175	166046	0	1456
Z-3	19	8.9	0	0	3009366	1230
K-7	15.7	7.6	0	0	5428481	708
B-10	15.5	8.8	0	0	4899834	1695
Y-7	14.9	15.9	0	0	2349030	3184

Table 1: Well-wise production and injection data of study area

Step 3: Streamline simulation run was done using in-house model based on the principle of SVD technique (Marathe et al. 1995, 1998). Modelling details is beyond the scope of this paper.

Step 4: Estimated flood front movement was obtained at different time steps, starting from initial till the present time shown in figure 5 and 6 respectively. In this method of modelling the pressure-solution is simply a superposition of line sources. With time it is observed that the movement of the flood front is towards the sink areas. Flooded area is denoted by region void of streamlines.

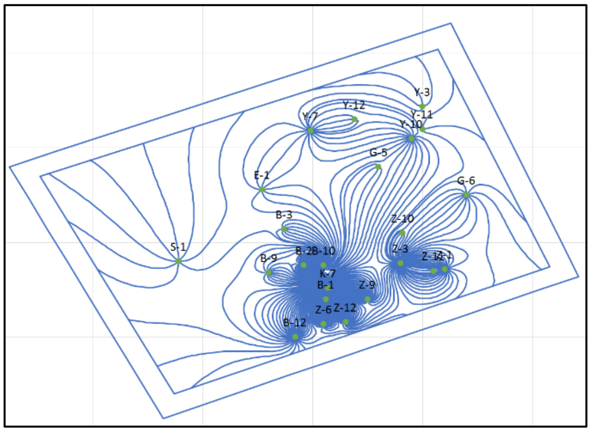

Fig 5: Estimated flood front movement in 1985 (Initial)

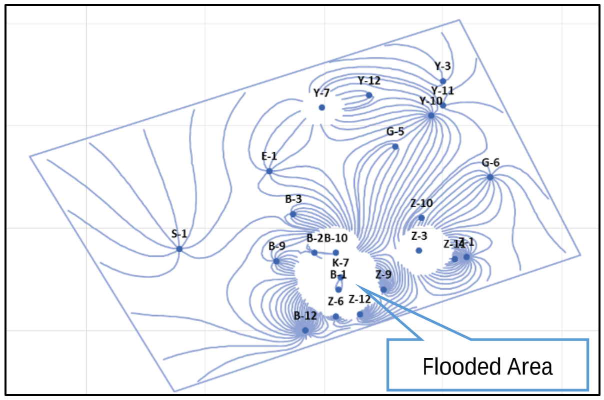

Fig 6: Estimated flood front movement in 2017 (Present)

Comparison with Actual Performance and Application of Output

Post streamline modelling, the result is validated with actual performance of the field. A comparison of streamline pattern with flood front and actual water cut in the study area shows remarkable similarity.

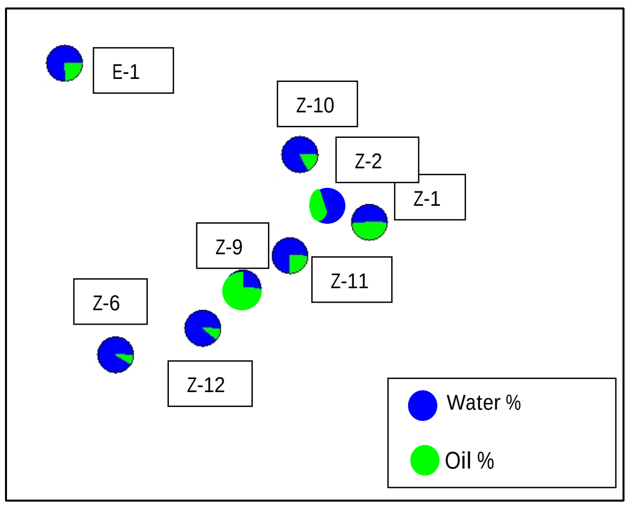

Fig 7: Actual water cut of wells in 2017 (Present)

Performance of well Z-9 (actual water cut 33 %) and Z-6 (actual water cut > 90%) shown in Figure. 7 was compared with their position on the flooded area. As observed in Figure. 6, Z-9 falls in sparsely flooded area whereas Z-6 is located in completely flooded area.

The model was used for fine tuning the proposed location Z-2 based on the streamline distribution showing flooded areas. Originally proposed location of Z-2, was lying in completely flooded area and was shifted to partially flooded zone. The well is currently flowing with 60% water cut.

Conclusion

These streamline based models are useful to understand the reservoir performance in macro level. The output of these models may not represent all the reservoir phenomenon exactly but are effective in capturing the input output relationship. This makes it a valuable decision making tool.

In this case study for the multilayered reservoir, this technique is used for a layer with relatively less thickness than the others. Also this layer does not have a full scale dynamic simulation model. The output of this streamline model served as a quick look tool for reservoir surveillance by identifying flooded areas.

However when used for a thicker layer of the same reservoir, this model did not produce similar result thus making thickness of layer a major constraint.

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