Demystifying the challenges in reservoir simulation of oil reservoir with associated condensate rich gas cap: a case study from Cauvery basin

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Abstract

Understanding the dynamics of fluid movement and developing appropriate fluid model is a prerequisite for developing oil rim reservoirs with associated condensate rich gas cap. This study involves history matching process for two blocks of SD-20 pay in X field of Cauvery Basin. In this area, SD-20 pay is divided into three hydro-dynamically different blocks. Among them, two blocks are high permeability oil reservoir with condensate rich gas cap with aquifer support. The major challenges in this pay are Gas & Water Coning and identification of future prospective areas. All these challenges make history match of high productivity wells a real challenge. In this case, applying black oil fluid model for simulation work by using volume modifier is a make-shift approach which does not accurately represent the process of condensate production from gas cap area with decrease in pressure. The main objective of this work was to develop a suitable workflow for history match considering condensate as an important element and demarcate future prospective areas. The condensate volume introduced herein using modified black oil model, which considers existence of liquid component in both liquid and gas phases under reservoir conditions, was applied for reservoir simulation.

The novelty of this work lies in the incorporation of condensate in the gas cap as an important component of simulation process thereby leading to condensate reserve accretion. The study also identified a number of drilling infill locations for future field development.

Introduction

X field is one of the earliest discoveries in Cauvery Basin and it was put on production from March 1990. The pay sands of this field have been distributed at the stratigraphic level of Nannilam Formation, Andimadam Formation and Kamalapuram Formation. Nannilam sands of Campanian age are the main reservoirs in this field. As on 1.4.2021, total 23 wells have been drilled in this field among which seventeen wells are exploratory and six wells are development. SD-20, the main pay of X field operates under gas cap gas and water drive. As on 1.4.2023, SD-20 is considered as single sand body. However, detail reservoir characterization work and geocellular modelling done at GEOPIC indicate that SD-20 is mainly divided into three sand bodies viz. SD-9, SD-2 and SD-3 from south to north. These three bodies are separated from each other and they can be distinguished from each other based on pressure analysis, performance and fluid contacts. The following section discusses the reservoir compartmentalization of SD-20 in detail.

Reservoir Compartmentalization

Reservoir compartmentalization of SD-20 pay in X field was studied analyzing datum (- 2096 m MSL) converted pressure data of all the wells.

The pressure decline with time has been plotted for all the wells and enumerated in Fig 1. The pressure analysis of SD-20 indicate that the whole area of SD-20 is divided into three different hydrodynamic regimes. From North to south, first hydrodynamic regime includes wells E, F and G. Second hydrodynamic regime includes wells A, B, C and D and third hydrodynamic regime includes wells H, I and J. Performance plot of these regimes are given in Fig 2 to Fig 4 which also indicates three separate fluid regimes.

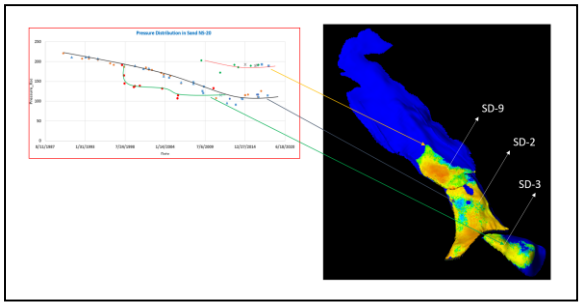


Figure 1: Pressure Regime in SD-20

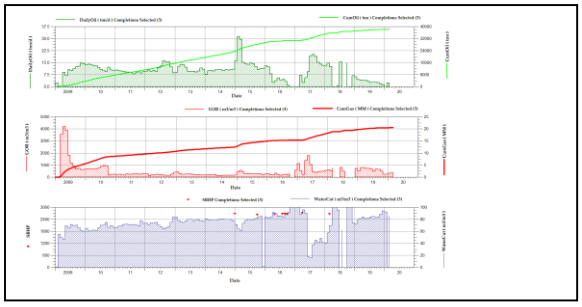


Figure 2: Performance of Block SD-9, Wells: E, F and G

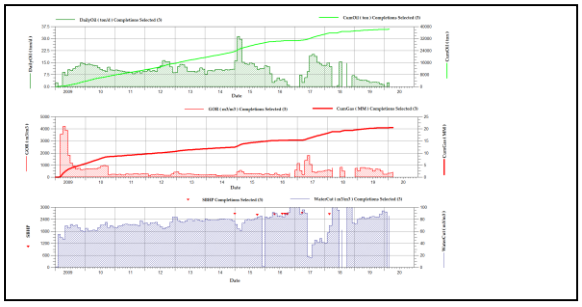


Figure 3: Performance of Block SD-2, Wells: A, B, C and D

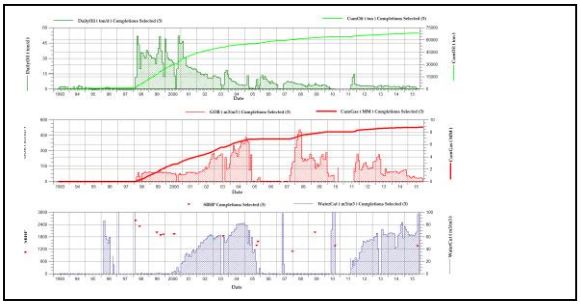


Figure 4: Performance of Block SD-3, Wells: H , I and J

In addition to conventional well performance analysis, excessive water and gas production analysis based on diagnostic plots was carried out and same is depicted below.

Water Control Diagnostic Plot Method

SD-20 pay is an oil rim reservoir wedged between a gas cap above and underlying aquifer. Excessive water and gas production are a typical character of this field. To understand the reason behind this production, Chan method (Chan K.S, 1955) was applied. Chan's plotting the water oil ratio (WOR)/ gas oil ratio (GOR) vs. time on a log-log plot that shows various trends for different mechanisms. Chan's seminal work also shows that the time derivatives of WOR and GOR were found to be capable of differentiating between conning, channelling and near wellbore breakthrough at the well level (Fig. 5). Diagnostic plot of well E as shown in Fig. 6 indicate that a water conning response was observed at around 150 to 2000 days as evident in the WOR derivative plot which shows a negative slope at this time period. Water conning was also observed in well H and multilayer channelling was observed in well B. On the other hand, GOR & GOR derivative vs. Time plot for wells A, B and D indicate gas conning with stable displacement of oil by gas cap drive. Not only has the pressure history that divides the area into three different hydrodynamic sectors, different fluid contacts and well performances also

indicated similar things. Finally, these three sand bodies were named as SD-9, SD-2 and SD-3.

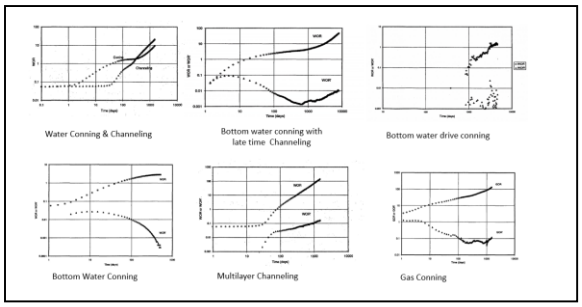


Figure 5: Water Control Diagnostic Plot (Chan 1995)

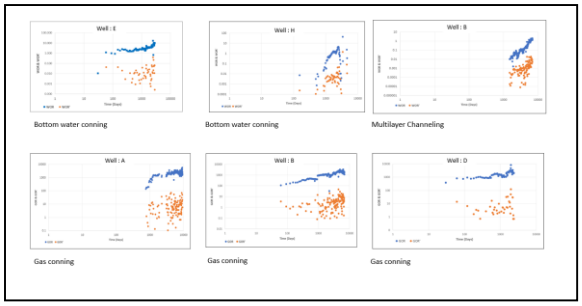


Figure 6: Chan Plot for Well: E, H, B, A and D

Model Building and History Matching

Geocellular model made in PETREL was the basic input for simulation study which was simulated using 3-phase black oil simulator ECLIPSE-100.

In X field, there was no Core data available to generate porosity-permeability transformation for SD-20 pay. The permeability was modelled based on Timur equation (Timur A 1968). The generalized Corey type relative permeability curves have been used in the study. The PVT parameters were generated using standard PVT correlation in Petrel RE. The performance analysis of SD-20 pay in X field indicates that most of the blocks are producing under gas cap and aquifer support. For history matching purpose, Fetkovich analytical aquifer model was used to provide water support in all the blocks.

Modified Black Oil Model

In X Field, gas conning phenomenon was evident in good producing wells viz. Well A, B etc. In SD-2, also significant recovery has been observed which is not explainable by the conventional black oil model. In addition to that good amount of condensate production also observed in Well C and D from gas cap area. To tackle this multiple challenges in history match work, modified black oil model was introduced for history match of SD-2 and SD-9 pays. The Modified Black oil (MBO) simulation approach was first introduced by Spivak and Dixon (1973). The main difference between the conventional black oil simulation and the MBO simulation lies in the treatment of the liquid in the gas phase. The MBO approach assumes that stock tank liquid component can exists in both liquid and gas phases under reservoir conditions. It also assumes that the liquid content of the gas phase can be defined as a sole function of pressure called vaporized oil-gas ratio, Rv. A brief discussion of MBO concept can be found in Rahamanian M. 2015 and same is given in Fig.7. In absence of PVT data, performance of Well B and D was considered for generation of Rv (Vaporized Oil Ratio) vs. Pressure table. The fine-tuned data used for history match work is shown in Fig. 8

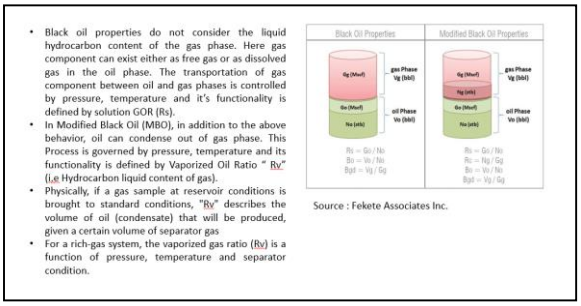
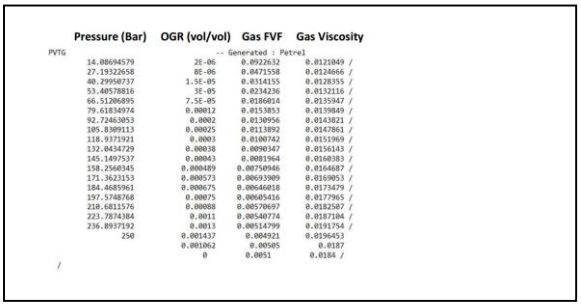


Figure 7: Black Oil vs. Modified Black Oil Properties



	Pressure (Bar)	OGR (vol/vol)	Gas FVF	Gas Viscosity
PVTG		-- Generated : Petrel		
	14.08694579	2E-06	0.0922632	0.0121049 /
	27.19322658	8E-06	0.0471558	0.0124666 /
	40.29950737	1.5E-05	0.0314155	0.0128355 /
	53.40578816	3E-05	0.0234236	0.0132116 /
	66.51206895	7.5E-05	0.0186014	0.0135947 /
	79.61834974	0.00012	0.0153853	0.0139849 /
	92.72463053	0.0002	0.0130956	0.0143821 /
	105.8309113	0.00025	0.0113892	0.0147861 /
	118.9371921	0.0003	0.0100742	0.0151969 /
	132.0434729	0.00038	0.0090347	0.0156143 /
	145.1497537	0.00043	0.0081964	0.0160383 /
	158.2560345	0.000489	0.00750946	0.0164687 /
	171.3623153	0.000573	0.00693909	0.0169053 /
	184.4685961	0.000675	0.00646018	0.0173479 /
	197.5748768	0.00075	0.00605416	0.0177965 /
	210.6811576	0.00088	0.00570697	0.0182507 /
	223.7874384	0.0011	0.00540774	0.0187104 /
	236.8937192	0.0013	0.00514799	0.0191754 /
	250	0.001437	0.004921	0.0196453
		0.001062	0.00505	0.0187
		0	0.0051	0.0184 /
/				

Figure 8: Modified Black Oil Properties

History Matching

The manual history matching technique was applied for simulation of SD-20 pay in Nannilam field. The well wise monthly allocated oil, water and gas production data up to 1.5.2020 were used as input for history matching in 7 wells. For history match, the model was on oil control mode. For wells produced from gas cap area, gas control mode was also applied. Reservoir pressure, GOR and water cut data have been considered as the main history matching parameters. The block wise history match detail is as follows.

Block of SD-2

The pressure measurements made in the Block of SD-2 over its production life indicate that the block pressure has dropped about 102 Ksc over 30 years for an oil production. Modified black oil model along with Fetkovich analytical aquifer model was applied for history match of this block. The history match plot for this block as shown in Fig. 9 indicate good match in Pressure, WC and GOR.

Well A is the first well which was put on production in March 1990. History match plot of this well as shown in Fig. 10 indicates good match of WC and pressure between observed and simulated data. Though GOR match was moderate, model was able to capture the phenomenon of gas conning (Fig. 11 and 12). During initial testing, producing GOR from this well was on higher side (493 to 559 v/v). The simulated GOR as shown in Fig. 11 also gave a GOR of similar range during first two years. During history match, significant amount of gas produced through this well along with vaporized oil.

In well B, overall match of Pressure, GOR and WC was satisfactory (Fig. 13). In addition to that, gas conning phenomenon as represented by classical Chan plot (Fig. 11) was also evident in simulated model (Fig.14). During history match, significant amount of gas produced through this well along with vaporized oil.

Historically, Well D was completed in the gas cap area and produced oil with API of 45^0. For history match of this well, gas mode run was applied. History match plot of this well as shown in Fig. 15 indicate that overall match of oil rate, pressure and WC was satisfactory.

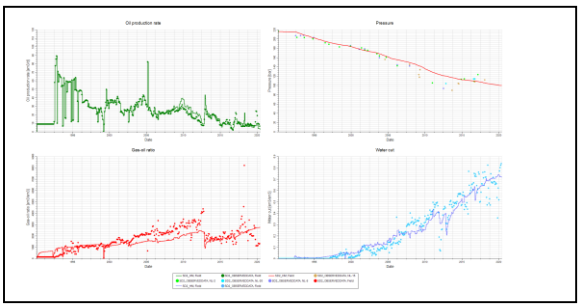


Figure 9: Match of historical vs. simulated data in SD-2

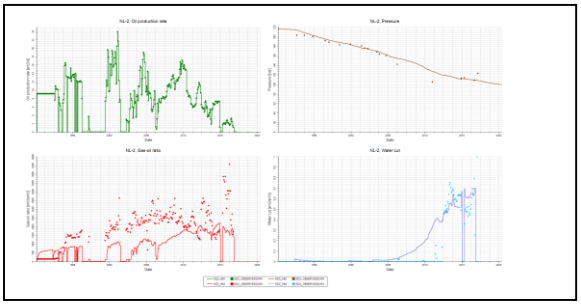


Figure 10: Match of historical vs. simulated data in well A

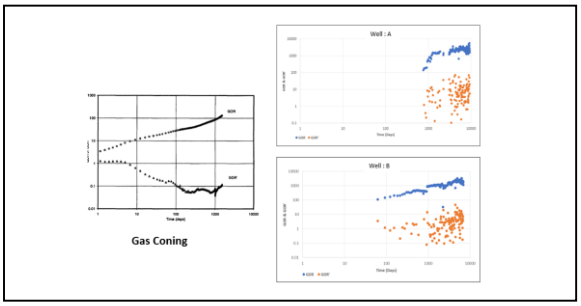


Figure 11: Diagnostic Plots- Coning (Chan 1995)

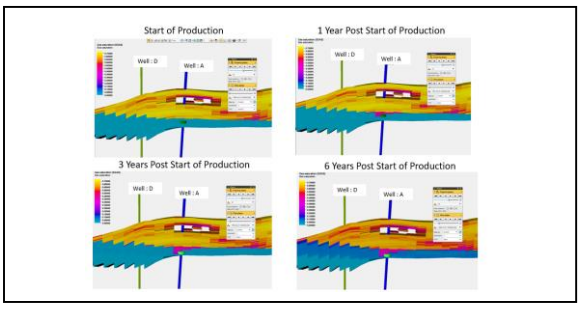


Figure 12: Gas Coning observed in Well A

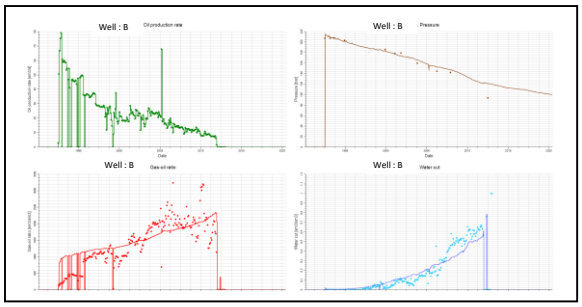


Figure 13: Match of historical vs. simulated data in well B

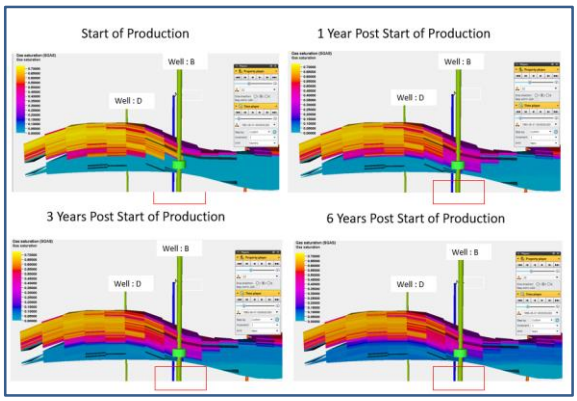


Figure 14: Gas Coning observed in Well B

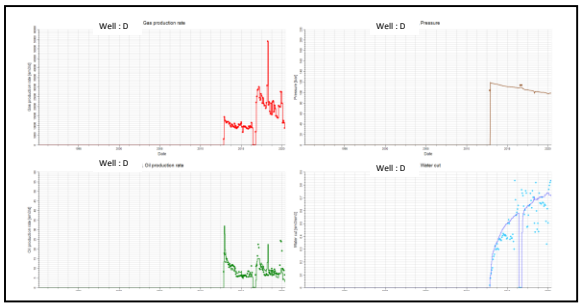


Figure 15: Match of historical vs. simulated data in well D

Block of SD-9

The oil production in this block has been started in Jan 2009 through well E. As on 1.4.2020, three wells viz. E, F and G have produced oil from this block. The pressure measurements made in the block over its production life indicate that the block pressure has dropped about 14 Ksc only over 9 years. The history match plot for this block as shown in Fig. 16 indicate a reasonably good history match in terms of pressure and water cut. However GOR match was moderate.

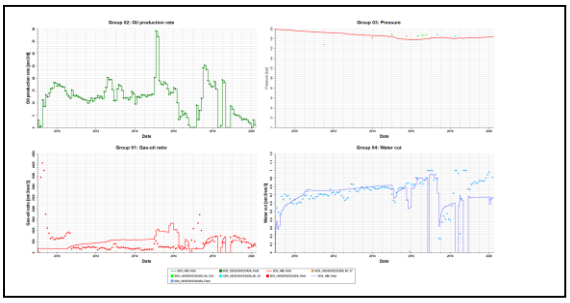


Figure 16: Match of historical vs. simulated data in SD-9

Identification of Prospective Area

After achieving satisfactory history match, simulation opportunity index is calculated on history matched model to identify infill locations. SOI (Simulation opportunity index) maps created (Ghazali M. et al. 2011) were used to identify prospective area for development (Fig. 17)

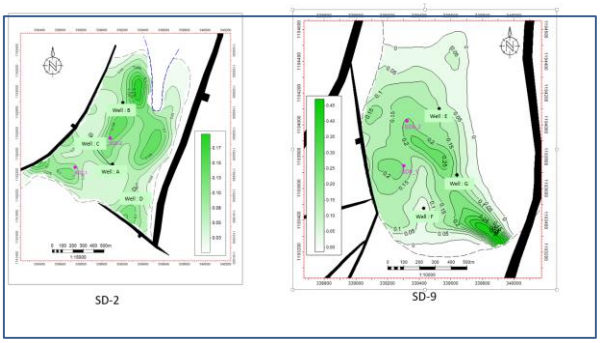


Figure 17: Post History Match Simulation Opportunity Index

Observations & Recommendations:

The main focus of this work was to develop a dynamic simulation model for gas cap gas condensate rich SD-20 pay of X field applying modified black oil model and find out un-drained area for future development. Based on the results, following observations and recommendations were made.

- SD-20 pay in Nannilam field is a multi-layered, compartmentalized reservoir with many challenges. In this area, SD-20 is mainly divided into three separate pools viz. SD-2, SD-3 and SD-9 with different fluid distribution and hydrodynamic condition.

- In SD-2, gas conning effect is evident in well A and B from very beginning as reflected in production testing and same phenomenon is observed during dynamic modelling.

- SD-2 and SD-9 are saturated gas cap reservoir with limited pressure support. The history match of SD-2 and SD-9 was a challenge due to severe gas conning phenomenon and production of condensate from gas cap area. To tackle that problem, modified black oil model was also applied for history match work with satisfactory result.

- In SD-2, at the end of history match, total oil recovered is 9% of model volume and total vaporized oil recovered is 41% of model volume. After history match, two development leads have been identified.

- In SD-9, at the end of history match, total oil recovered is 10% of model oil volume and total vaporized oil recovered is 17% of model volume. After history match, two development leads have been identified.

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The views expressed in this paper are solely of the authors and do not necessarily reflect the view of ONGC.

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