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Effects of Water-Cut and Gas-Oil-Ratio on Oil and Gas Recovery Factors Optimization

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Abstract

Eclipse simulated results for the base case and injection cases for WAG, surfactant and SWAG were tested using statistical analysis to identify which of these; WCT or GOR has better significant effects in the optimization of oil recovery factor or gas recovery factor in concurrent development of oil rim reservoir. Linear regression models were developed, and variance analyses with the former were used to test for the effects of WCT and GOR on oil and gas recovery factors in concurrent development. The linear regression model under the test for the GOR effect gave the coefficient value of -0.1280 for R_{fgas} and -0.4443 for R_{foil}. The variance analysis result gave P-value for GOR to be 0.0315, which is less than the level of significance. Hence, because the coefficient of R_{fgas} is more than R_{foil} in the regression model, and the GOR P-value is less than the level of significance, GOR has a more significant effect in the optimization of gas recovery during concurrent development of oil and gas in oil rim reservoir. Similarly, the linear regression model under test for the WCT effect gave the coefficient value of 0.18553 for R_{foil} and 0.02828 for R_{fgas}. The variance analysis result gave P-value for WCT to be 0.0474. Because the P-value is less than the level of significance and the coefficient value of R_{foil} is more than R_{fgas}, hence WCT has a more significant effect than GOR in the optimization of oil recovery factor in concurrent development of oil and gas.

Keywords: *Water cut; GOR; Concurrent development; Gas recovery factor; Oil recovery factor.*

1. Introduction

Oil rim reservoir with a large gas cap can be developed concurrently under the conventional development (traditional natural pressure depletion development) option or by injection option [1-6]. In recent times, there is a rapid shift in research toward concurrent development of oil and gas in order to meet up with the world's energy demand due to rapid population growth and to boost the existing reserves because the discovery of new fields is rare. Concurrent development under traditional natural pressure depletion causes two major technical challenges; high gas-oil ratio (GOR) and early water cut (WCT) thus, reducing the oil and gas recovery factors of the reservoir [7].

Large gas cap offers the technical challenge of high GOR, which causes oil shrinkage. This oil shrinkage eventually leads to a low oil recovery factor [8]. Similarly, early water cut is a problem that is common with the oil rim reservoir [7,9-11]. Early water cut causes technical challenges of reservoir pressure decline [12]. These technical challenges are responsible for the low ultimate recovery of oil from the thin oil column with a large gas cap in the natural depletion development option. However, the injection development option in concurrent development delays water cut and reduces the value of GOR and consequently gives the optimization effect on the gas and oil recovery factors [7]. The question is which of the recovery factors (R_{fgas} or R_{foil}) does change in GOR or WCT will have a significant optimization effect under concurrent development of oil and gas? Hence, this present research work is aimed at using statistical tools to study the effects of controlling the WCT and GOR by injection during concurrent development of oil and gas on recoveries factors of oil and gas and to identify which of the two if controlled will enhance optimization of oil recovery factor or gas recovery factor.

2. Materials and methods

Eclipse 100 was used to simulate concurrent development of oil and gas in an oil rim reservoir using data from the "Y" field in the Niger Delta Basin as a case study. Four different cases of development were modeled; base case (under natural pressure depletion or without injection), water-alternating-gas (WAG) injection, surfactant-water-alternating-gas (SWAG) injection, and surfactant injection. Injection well position for each of the injection case was at Gas-Oil-Contact (GOC) and Oil-Water-Contact (OWC). The oil recovery factor, gas recovery factor, water cut, and GOR, at each case, were noted. Statistical analyses were carried out on the result of the GOR and water cut, which are the response variables in order to delineate the enhancement effect of each of these parameters on oil and gas recovery factors, which are the explanatory variables. Multiple regression analysis was used to develop a linear regression model base on equations (1) and (2) using R-software and analysis of variance (ANOVA) was done using statistical R-software.

$$lm(formula\ =\ wct \sim Rfoil\ +\ Rfgas) \quad (1)$$

$$lm(formula\ =\ GOR \sim Rfoil\ +\ Rfgas \quad (2)$$

where: lm = linear model; GOR = gas oil ratio; WCT = water cut; R_{fgas} = gas recovery factor; R_{foil} = oil recovery factor.

From the linear regression model, the response variable (WCT) on the explanatory variables (R_{foil} and R_{fgas}) is as given in the regression equation below:

$$wct =\ 2.31731 + 0.18553Rfoil\ +\ 0.02838Rfgas \quad (3)$$

From the linear regression model, the response variable (GOR) on the explanatory variables (R_{foil} and R_{fgas}) is as given in the regression equation below:

$$GOR =\ 8.1817 - 0.4443\mathrm{R}_{\mathrm{f}_{\mathrm{oil}}}\ - 0.1280Rfgas \quad (4)$$

3. Result and discussion

The simulated result from the "Y" field in the Niger Delta Basin when the reservoir in the field was developed concurrently for gas and oil without injection (Base case), the cumulative oil produced was 2.57 MMSTB, and that of gas was 15 BSCF (Table 1).

Table 1. Simulated Eclipse Result using field data from the "Y" field in the Niger Delta Basin, Nigeria

Dev. Cases	Base case	WAG G/W injection @GOC	Surfactant inject. @ OWC	WAG inject. @ OWC	Surfactant @ inject. GOC	SWAG @ OWC	SWAG @ GOC
Cum oil (MMSTB)	2.57	2.73	3.05	2.87	2.89	3.35	3.21
Cum Gas (BSCF)	15	15.94	15.11	14.63	16.02	14.74	16.05
WCT (%)	0.61	0.55	0.26	0.46	0.25	0.26	0.31
R_{foil} (%)	5.8	6.16	6.89	6.48	6.53	7.7	7.25
R_{fgas} (%)	23.69	25.18	23.87	23.11	25.31	23.92	25.36
Oil percentage increase	-	6.21	18.8	11.7	12.45	32.75	25
Gas percentage increase	-	6.29	0.75	-2.47	6.8	0.97	7.05
GOR (MSCF/STB)	1.75	3.05	1.65	3.21	1.69	1.64	1.67

However, when surfactant, WAG, and SWAG were injected at OWC and GOC, there were increased in both oil and gas recovery factors except for when WAG was injected at OWC, there was decreased in gas recovery factor by 2.47% (Table 1). The Water cut (WCT) and GOR under base case development were 0.61% and 1.75 MSCF/STB, respectively, as shown in Table 1. However, under the three injection cases (WAG, Surfactant, and SWAG injections) at injection positions of OWC and GOC, there were significant changes in the WCT and GOR values different from the values obtained under base case concurrent development. These changes observed in the WCT and GOR during concurrent development under injection cases showed synonymous effects on the oil and gas recovery factors under injection development.

3.1. Effect of WCT on recovery factors optimization in concurrent development

From the regression model in Equation (3) generated from the data obtained from the simulated field data by Eclipse 100 in the field "Y", Niger Delta Basin using R-statistical software, the coefficient value of the of oil recovery factor (R_{foil}) is 0.18553. The coefficient value of the oil recovery factor is higher than the coefficient value of the gas recovery factor (R_{fgas}), which is 0.02828 (Fig. 1).

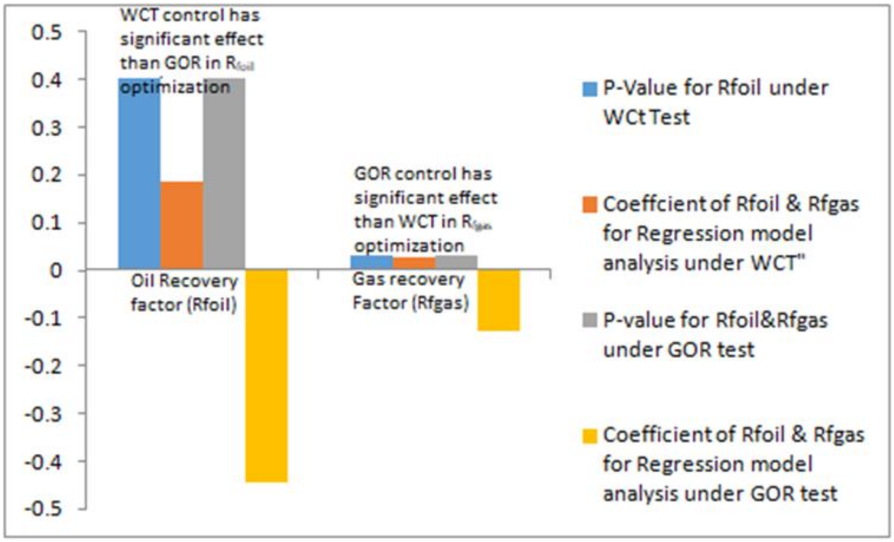

Figure 1. The plot of coefficient of R_{foil} & R_{fgas} for regression model and P-values under WCT and GOR test for the significant effect

The higher value in the coefficient of oil recovery factor than gas recovery factor is an indication that WCT, which is a response variable, has a more significant effect on optimizing oil recovery factor than gas recovery factor in concurrent development of thin oil rim reservoir.

Table 2. ANOVA table for WCT response to oil and gas recovery factors in "Y" field Niger Delta Basin, Nigeria

Response: WCT	D_f	Sum sq.	Mean sq.	F value	P-Value
R_{foil}	1	0.089696	0.089696	7.9977	0.04744 *
R_{fgas}	1	0.004014	0.004014	0.3579	0.58189
Residuals	4	0.044861	0.011215		

Similarly, from the ANOVA analysis (Table 2), WCT is more significant in the recovery of oil than gas in concurrent development of oil rim reservoir because the P-value (0.04744) is less than the level of significant ($\alpha = 0.05$). Therefore, WCT has a more significant effect in optimizing the recovery factor of oil than the recovery factor of gas (Fig. 1) in concurrent development of oil and gas in an oil rim reservoir. However, a particular type of injection fluid injected also gave additional effect recovery optimization apart from the effect of GOR and WCT control, as shown in Figure 1. The type of injection fluid that was injected and the position of injection well have a significant effect on the changes that occurred on the WCT and GOR (Fig. 2). In all the fluid injection types, there was synonymous increased in the oil recovery factor as the water cut decreased below the base case water cut (Fig. 2)

3.2. Effect of GOR on recovery factors optimization in concurrent development

The coefficient value of R_{fgas} in the regression model generated as Equation (4) from the data obtained from simulated field data by Eclipse 100 simulator in field "Y", Niger Delta Basin using R-statistical software is -0.1280. This coefficient value of R_{fgas} is higher than that of R_{foil}, which is -0.4443 (Fig. 1). This result shows that GOR, which is the response variable, has a more significant effect in the optimization of gas recovery factor (R_{fgas}) than the oil recovery factor (R_{foil}) (Fig. 1) in concurrent development of oil and gas in thin oil rim reservoir. This implies that a change in GOR will have more effect on the quantity of gas that will be recovered than oil from a reservoir that is developed concurrently. The ANOVA analysis (Table 3) of the response variable and the explanatory variables tallies with the result of the regression model. The result of ANOVA analysis shows that GOR is more significant in the recovery of gas because the P-value (0.0315) is less than the level of significance ($\alpha = 0.05$). Therefore, we conclude that GOR has a more significant effect in the optimization of gas recovery factor than that of the oil recovery factor. In all the fluid injection types, there was synonymously increased in the gas recovery factor as the GOR decreased below the base case except for the WAG injection case at OWC and GOC, where the GOR increased to 3.21MSCF/STB and 3.05MSCF/STB respectively. There was decreased and increased in gas recovery factor respectively at OWC and GOC (Fig. 2)

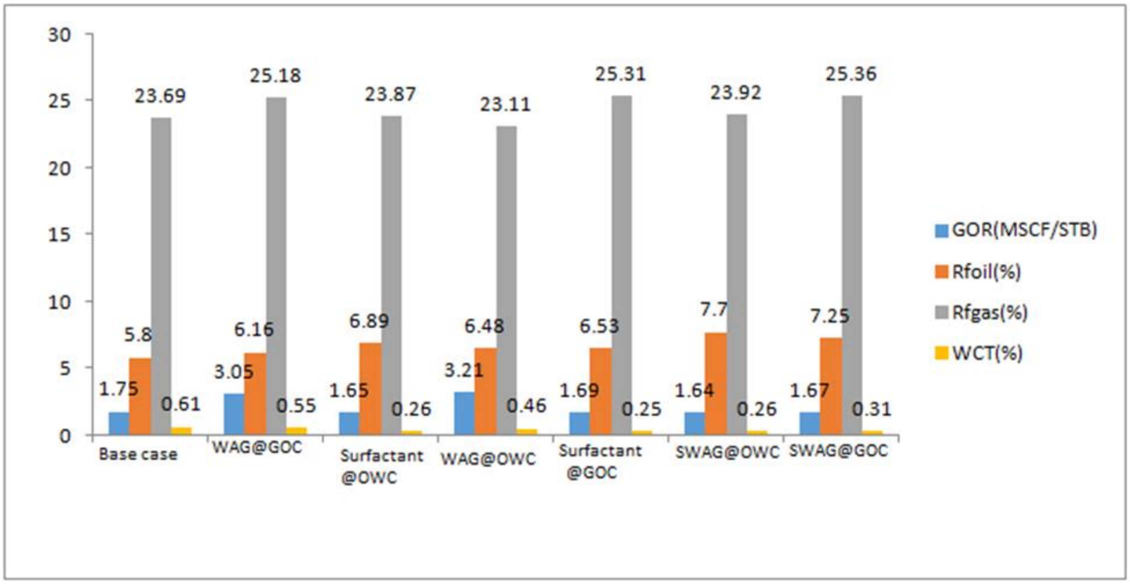

Figure 2. Multiple bar chart showing WCT, GOR, R_{foil}, and R_{fgas} for different development cases

Table 3. ANOVA table for GOR response to oil and gas recovery factors in "Y" field Niger Delta Basin

Response: WCT	D_f	Sum sq.	Mean sq.	F value	P-Value
R_{foil}	1	0.53016	0.53016	0.8792	0.40158
R_{fgas}	1	0.08168	0.08168	0.1354	0.0315*
Residuals	4	2.41214	0.60303		

4. Conclusion

A study on the effects of water cut and gas-oil ratio on oil and gas recovery factors optimization in concurrent development of oil and gas has been done using statistical analysis of Eclipse simulated result of the "Y" field in the Niger Delta Basin. The study showed that control of early water cut by injection during concurrent development of oil and gas in a thin oil rim reservoir had enhanced effect than GOR in the optimization of oil recovery factor. However, WCT does not have a significant effect in the optimization of gas recovery factor rather; control of GOR by injection during concurrent development of oil in a thin oil rim reservoir has a significant effect on gas recovery factor optimization. Aside from these controls of WCT and GOR, the kind of fluid injected and position of injection have combined effect with GOR and WCT control on the recovery factor optimization.

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