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Ongoing Relative Performance Evaluation for a CO_2 EOR Asset in a Worldwide Peer Group

C F Zhao[1,4,5], X S Li[1], G H Wang[2] and L Li[3]

1.EOR Research Institute, China University of Petroleum – Beijing, China
2.CNPC Middle East Company, Beijing, China
3.Oil and Gas Development Management Center, Sinopec Shengli Oilfield Company,Dongying, Shandong,China
4.Corresponding author: zhaochuanfeng@cup.edu.cn

Abstract. Operators of a CO_2 EOR asset need to know the relative performance level of their asset against its peers. The ongoing relative performance evaluation method is appropriate for this purpose. We first choose 52 CO_2 assets around the world as the peer group, and then define the four ranking levels in terms of CO_2consumption ratio. Only the final values of CO_2consumption ratio for the group are obtained, and therefore cannot be used for an ongoing evaluation during a CO_2 EOR asset's life circle. Consequently, numerical reservoir simulation is employed to quantify the process values corresponding to the four ranking levels. Type curve plots are generated on the basis of the process values and utilized for the ongoing relative performance evaluation of a CO_2 EOR asset in China.

1. Introduction

CO_2, known as the greenhouse gas if directly emitted to the air, can be injected into an oil reservoir for the purpose of enhanced oil recovery (hereafter abbreviated as EOR). Operators of a CO_2 EOR asset need to make decisions, such as expanding or reducing or even suspending their investment, according to their knowledge about the development process of their CO_2 EOR asset and its relative performance level against its peer assets. A method, called ongoing relative performance evaluation, stands out for this purpose. A large number of examples using this method have been found in fields of human resources, but none in oil industry. In this paper we present its major steps involved in the assessment of a CO_2 EOR asset in China.

2. Steps of ongoing relative performance in a peer group

A CO_2 EOR asset in China is producing crude oil during its life cycle. The aim is to conduct an ongoing relative performance evaluation for it in a worldwide peer group.Suppose there are N CO_2 EOR assets in a peer group not including the target asset. The life cycle of the *i*th asset is T_i, and the evaluation index of the *i*th asset is $X_t^{(i)}$, where $0<t\leqslant T_i$, $1\leqslant i\leqslant N$.

2.1. Choosing a peer group

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CO_2 EOR is a promising oil recovery technique, but lower oil prices and insufficient CO_2 sources put limitations to its application. Only 52peer assets have been found in publically published articles, most in USA and China. Maybe there are other peer assets not publically reported. Unfortunately we have no way to gather their information.Therefore, the capacity of the peer group is *N*, that is 52.

2.2. Choosingan evaluation index

Although many indices are available for a CO_2 EOR asset, most are inappropriate for evaluation purpose for they are strongly related with the oil reserves and CO_2 injection volumes. It is unfair to assess an asset with small reserves and injection volumes against another with larger ones. However, CO_2consumption ratio is an exceptional index. With unit oft/t, this index isdefined as the mass of injected CO_2 needed toobtainan oil incremental of 1.0t.A lower value of this index indicates higher utilization efficiency of CO_2. Its ability to eliminate the differences in reserves and injection volumes between assets makes it appropriate for a relative performance evaluation.

The values of CO_2consumption ratio for the peer group distribute within the range of 0.18~7.69, with the arithmetic average of 2.8 and the median of 2.6 (figure 1)[1~12].

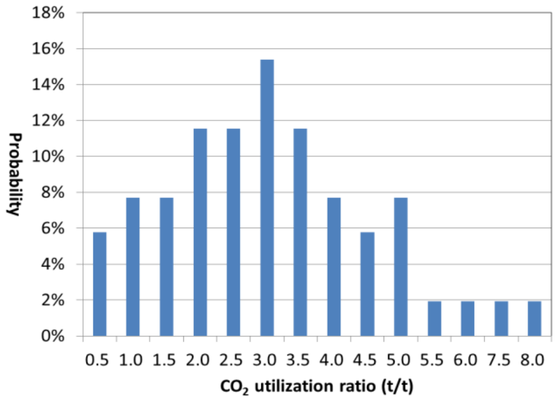

Figure 1. Probability distribution of CO_2consumption ratio in the peer group.

2.3. Defining ranking levels

According to the general classification method in Probability Theory and Mathematical Statistics, a cumulative probability distribution curve can be divided into four ranges, that is, [0.00%, 17.37%), [17.37%, 50.00%), [50.00%, 82.63%), [82.63%, 100.00%], respectively representing A, B, C and D levels (figure 2). The three boundary values, $V^{(1)}$, $V^{(2)}$ and $V^{(3)}$, are successively 1.2t/t, 2.6t/t and 4.2t/t. The lower the consumption ratio of an asset is, the higher its relative remark and its ranking level.

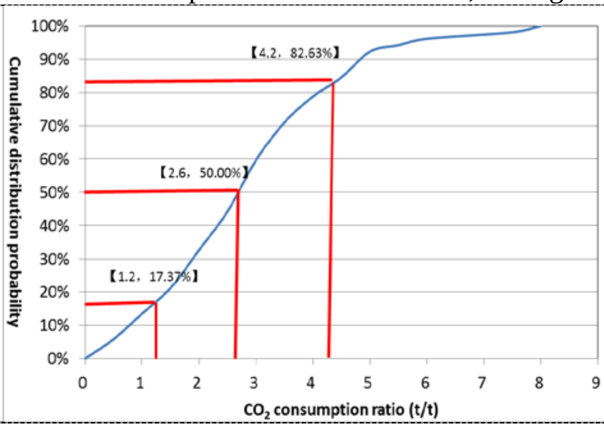

Figure 2. The cumulative probability distribution curve of CO2 consumption ratio in the peer group.

2.4. Type curve plots for ongoing relative performance evaluation

Suppose the sequence number of the target asset is 0. Now it is expected that we can conduct the ongoing relative performance evaluation for the target asset by comparing $X_t^{(0)}$ against the aggregate $\{X_t^{(1)}, X_t^{(2)}, \ldots, X_t^{(N)}\}$. However, a problem arises from the fact that all the values of CO_2 consumption ratio are final values at the end of the life cycles of these peers, that is, $X_{Ti}^{(i)}$ (i=1, 2, …, *N*). These values are justified to be used for a post relative performance evaluation rather than an ongoing evaluation.

Though the process values during life cycle are unavailable, we have luckily obtained the three boundary values, $V^{(1)}$, $V^{(2)}$ and $V^{(3)}$. Numerical reservoir simulation can be used to synthesize process values corresponding to the three boundary values. Then the ongoing evaluation is feasible.

2.4.1. Numerical reservoir simulation

Numerical reservoir models are built to represent the potential ranges of reservoir and fluid properties of the target asset. The number of simulation scenarios should be large enough to ensure that almost allits possible geological realizationscan be covered. Finally three simulation scenarios reveal themselves from the scenario pool respectively corresponding to the three boundary values.As a result, we now have three process boundary value series, $V_t^{(1)}$, $V_t^{(2)}$ and $V_t^{(3)}$ ($0<t\leqslant T_0$). $V_{T0}^{(1)}=V^{(1)}$, $V_{T0}^{(2)}=V^{(2)}$,$V_{T0}^{(3)}=V^{(3)}$. In fact, process boundary value series of three more indices, such as recovery percentage during CO_2 EOR life cycle, EOR incremental during CO_2 EOR life cycle over waterflooding and oil displacement efficiency during CO_2 EOR life cycle, can be gained from the simulation results including $R_t^{(1)}$, $R_t^{(2)}$, $R_t^{(3)}$, $I_t^{(1)}$, $I_t^{(2)}$, $I_t^{(3)}$, $D_t^{(1)}$, $D_t^{(2)}$, $D_t^{(3)}$. These indices can be employed for ongoing relative evaluation of economic benefit, technical effect and effective EOR mechanism.

2.4.2. Type curve plot for ongoing relative evaluation of economic benefit

With recovery percentage during CO_2 EOR life cycle as the horizontal ordinate and CO_2 consumption ratio as the vertical ordinate, we can obtain the type curve plot for relative evaluation of economic benefit (figure 3).

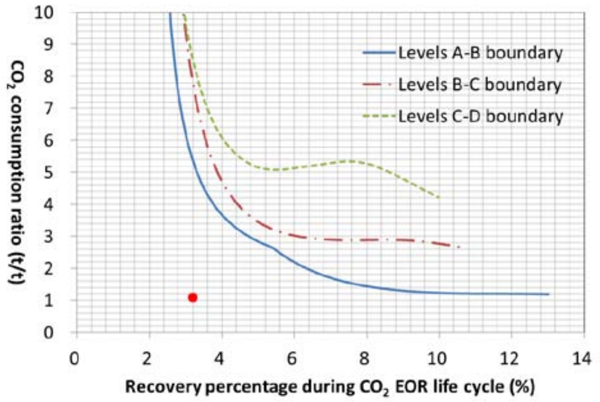

Figure 3. Type curve plot for ongoing relative evaluation of economic benefit.

2.4.3. Type curve plot for ongoing relative evaluation of technical effect

With recovery percentage during CO_2 EOR life cycle as the horizontal ordinate and EOR incremental during CO_2 EOR life cycleover water flooding as the vertical ordinate, we can obtain the type curve plot for relative evaluation of technical effect (figure 4).

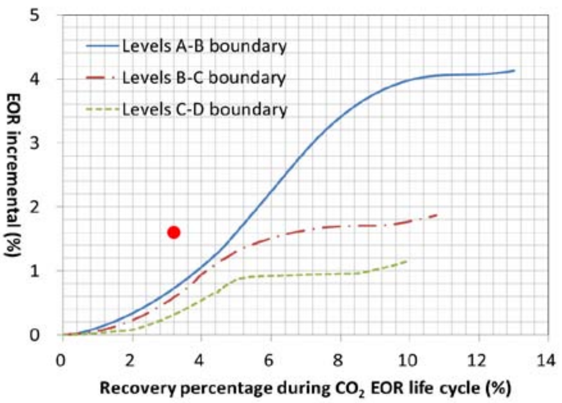

Figure 4. Type curve plot for ongoing relative evaluation of technical effect.

2.4.4. Type curve plot for ongoing relative evaluation ofeffective EOR mechanism

The primary EOR mechanism of a CO_2EOR asset lies in improving the oil displacement efficiency rather than the sweep efficiency. With recovery percentage during CO_2 EOR life cycle as the horizontal ordinate and oil displacement efficiency during CO_2 EOR life cycle as the vertical ordinate, we can obtain the type curve plot for relative evaluation of effective EOR mechanism (figure 5).

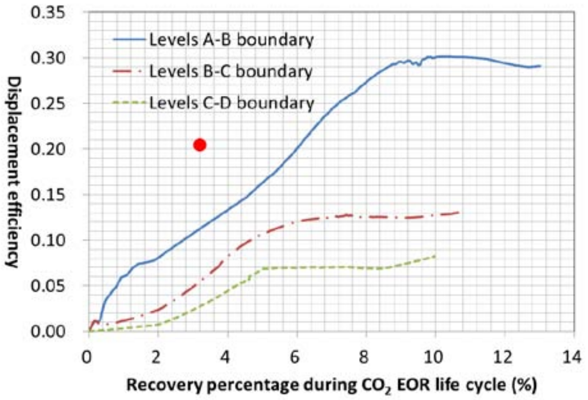

Figure 5. Type curve plot for ongoing relative evaluation of effective EOR mechanism.

3. Field case

Up to December, 2016, the recovery percentage of the original oil reserves in the target oilfield was 9.6%. The recovery percentage during CO_2 EOR life cycle was 3.2%, and the EOR incremental was 1.6%. The oil displacement efficiency was calculated as 0.202 with the methods in references 13~16. The gas consumption ratio was 1.1t/t.

In figure 3, a point is pictured on the type curve plot for ongoing relative evaluation of economic benefit. In figure 4, a point is pictured on the type curve plot for ongoing relative evaluation of technical effect. And in figure 5, a point is pictured on the type curve plot for ongoing relative evaluation of technical effect. It can be seen that this point lies at the region corresponding to the ranking level of A, indicating that the target asset was ranked top 17.37% in the peer group.

4. Conclusions

The ongoing relative performance evaluation method can be used to assess one CO_2 EOR asset against its peers. This method involvessteps including choosing a peer group and an evaluation index, defining ranking levels, and conducting evaluation.

With the help of numerical reservoir simulation, three type curve plots are established for ongoing relative performance evaluation of economic benefit, technical effect and effective EOR mechanism. The ongoing relative performance evaluationindicates that the target CO_2 EOR assetis ranked as Level A in terms of economic benefit, technical effect and effective EOR mechanism, and top 17.37% in the worldwide peer group.

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