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挥发性油藏CO_2驱动态混相特征

王 锐[1],吕成远[1],伦增珉[1],王进安[2],赵淑霞[1],王 欣[1],许 寻[2]
(1.中国石化石油勘探开发研究院,北京 100083;2.中国石化中原油田分公司 勘探开发研究院,河南 濮阳 457000)

摘要:挥发性油藏地层能量充足,原始地层压力高,常规水驱开发难以实施。CO_2驱以其良好的驱油特性在该类油藏中得到了应用,但由于挥发性原油气油比高,溶解气中甲烷含量高,导致CO_2驱混相压力高,使得其驱油效果受到一定的影响。通过室内实验和数值模拟,研究挥发性油藏注CO_2过程中的动态混相特征,并剖析衰竭开发转CO_2驱界限。结果表明:挥发性油藏存在着适度衰竭转CO_2驱"脱气降混"机理,即随着地层压力的降低,原油中甲烷成分部分脱出,有助于CO_2驱最小混相压力的降低。另外,其脱气降混程度与其原油类型和溶解气油比有关,原油越接近于凝析油,气油比越高,混相压力降低程度越大;反之,原油越接近于黑油,气油比越低,混相压力降低程度越小。结合动态混相机理,提出了挥发性油藏衰竭开发转CO_2驱界限,即气油比越高,其转驱界限越低,脱气后CO_2混相驱补充地层能量幅度越小;反之,转驱界限越高,补充地层能量幅度越大。

关键词:挥发性油藏;CO_2驱;脱气降混;转驱界限;混相压力
中图分类号:TE357.45 **文献标识码**:A

Dynamic miscibility characteristics of CO_2 flooding in volatile oil reservoirs

WANG Rui[1], LÜ Chengyuan[1], LUN Zengmin[1], WANG Jin'an[2], ZHAO Shuxia[1], WANG Xin[1], XU Xun[2]
(1.*Petroleum Exploration & Production Research Institute*, *SINOPEC*, *Beijing City*, 100083, *China*; 2.*Exploration & Production Research Institute*, *Zhongyuan Branch Company*, *SINOPEC*, *Puyang City*, *Henan Province*, 457000, *China*)

Abstract: It is difficult to carry out water flooding in volatile oil reservoirs due to the sufficient formation energy and the high initial pressure. CO_2 flooding has been implemented in this type of reservoir for its excellent oil displacement characteristics. However, the higher dissolved gas oil ratio and the higher methane content contribute to a higher minimum miscible pressure (MMP) of CO_2 flooding, which decreases the displacement performance. Dynamic miscibility characteristics and the injection timing of CO_2 injection for volatile oil reservoirs are studied through laboratory experiment and numerical simulation. The results show that the characteristics of releasing methane and decreasing CO_2 MMP is evident in the CO_2 flooding after a depletion production of volatile oil reservoirs. That is to say, methane partially releases from the crude oil as the formation pressure decreases, which is favorable to the decreasing of CO_2 MMP. The extent of decreasing CO_2 MMP is closely related to the crude oil type and initial dissolved gas-oil ratio. When the crude oil is closer to the condensate oil, a higher dissolved gas-oil ratio results in a lager decreasing degree of MMP. On the contrary, when the crude oil is closer to black oil, a lower dissolved gas-oil ratio results in a smaller degreasing degree of MMP. The CO_2 injection timing after the depletion of volatile oil reservoirs is proposed according to the dynamic miscibility mechanism. It is found that as the dissolved gas-oil ratio increases, the injection timing and the formation energy supplement decrease. Otherwise, the injection timing and the formation energy supplement increase.

Key words: volatile oil reservoirs; CO_2 flooding; releasing methane and decreasing CO_2 MMP; injection timing; miscibility pressure

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作者简介:王锐(1981—),男,湖北潜江人,高级工程师,博士,从事提高采收率技术研究。E-mail:wangrui2009.syky@sinopec.com。
基金项目:国家重点研发项目"致密油藏CO_2驱多相多组分流动机理及CCUS集成优化分析"(2016YFB0600805-1),国家自然科学基金青年基金项目"富CO_2流体作用下储层和盖层溶蚀及充填作用机理——以黄桥富CO_2油气藏为例"(41602160)。

挥发性油藏是指地层温度低于临界温度,靠近临界点的油藏,其烃类流体性质接近临界状态,中间烃(C_2—C_6)含量高,组分和热力学参数介于黑油和凝析气之间,原油性质与常规黑油存在较大差异。挥发性油藏埋藏深,地层压力高,气油比较高,原油收缩率大,这些性质决定了挥发性油藏的开发与常规黑油油藏的开发有很大的区别[1-4]。挥发性油藏在衰竭开发过程中,原油急剧收缩脱气,地层能量迅速消耗,并且气液组成不断发生变化,低于饱和压力开采时,油气体积比急剧上升,原油体积迅速收缩,导致衰竭开发采收率低。因此,该类油藏必须保持压力开采,即压力必须保持在饱和压力以上[5-6]。除此之外,一般挥发性油藏采取注水和注气能取得较好的开发效果。对于埋藏深、渗透率低的挥发性油藏,注水压力高,水驱难以实施,注气成为该类油藏提高采收率的主要手段[7-8]。常用的注气介质主要包括烃类气体、N_2和CO_2等。相比于烃类气体和N_2来说,CO_2在原油中的溶解能力更强,泡点压力上升更慢,降黏和膨胀能力更强,因此具有更好的注入性和驱油效果[9-12]。然而,挥发性油藏CO_2注入能力差,混相驱压力高,难以实施混相驱。笔者以目标区挥发性油藏为研究对象,通过室内实验和数值模拟研究其注CO_2过程中的动态混相特征,并剖析衰竭开发转CO_2驱界限。

1 原油物性分析

对目标区挥发性原油样品进行高温高压物性测试分析,结果表明,目标区挥发性油藏埋深大于3 300 m,地层压力大于38 MPa,油藏温度大于120 ℃,溶解气油比大于130 m³/m³(表1)。通过三元组分相图(图1)分析可知,区块A为典型的高挥发性油藏,区块B和C为弱挥发性油藏。

表1 目标区挥发性油藏基础参数

Table1 Basic parameters of volatile oil reservoirs in target area

区块	埋深(m)	地层压力(MPa)	油藏温度(℃)	溶解气油比(m³/m³)	渗透率(mD)
A	4 128.5~4 174.0	75.7	148	413.28	11.20
B	3 999.6~4 176.5	70.1	153	153.00	3.20
C	3 343.9~3 372.8	38.8	122	132.10	2.25

2 CO_2驱动态混相压力研究

2.1 高挥发性油藏最小混相压力测试

原油组分分析　选取区块A的原油样品进行不同衰竭阶段的脱出气及剩余油全烃组分分析,结果(图2,图3)表明,随着衰竭压力水平的降低,脱出气中CH_4含量逐步降低,中间烃(C_2—C_5)含量缓慢升

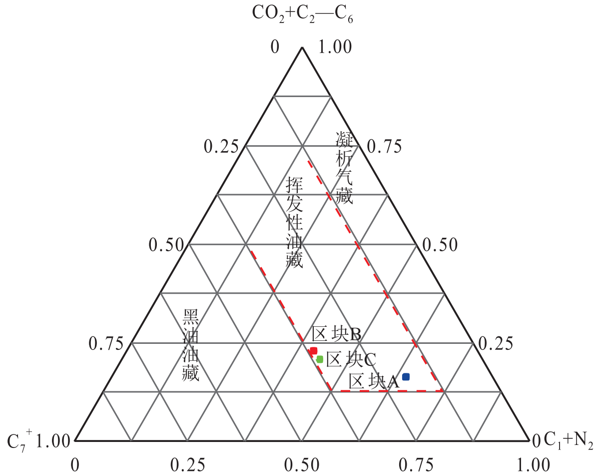

图1 挥发性油藏类型分析

Fig.1 Analysis of volatile oil reservoir types

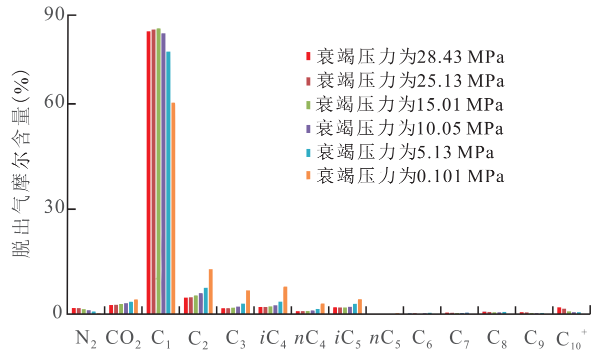

图2 区块A不同衰竭阶段脱出气组分变化

Fig.2 Variation of released gas components at different depletion stages for Block A

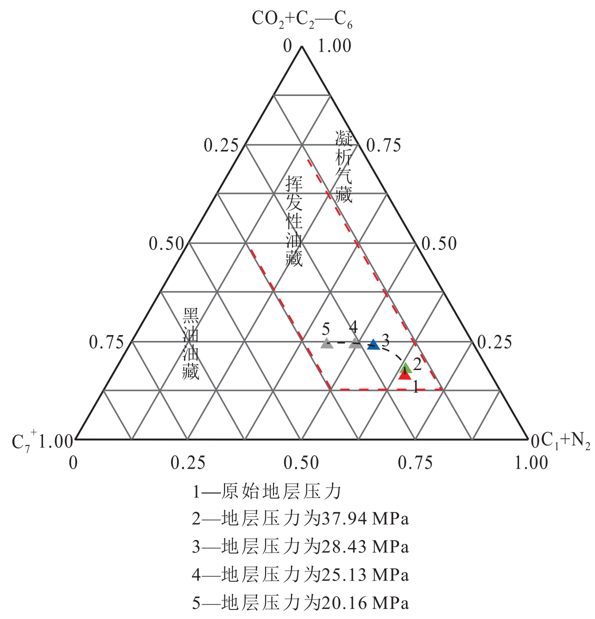

图3 区块A不同衰竭阶段剩余油全烃组分变化路径

Fig.3 Residual oil components change path at different depletion stages for Block A

高。不同衰竭阶段剩余油中CH_4+N_2含量逐步降低，中间烃(C_2—C_5)含量缓慢升高，原油组分从典型挥发性原油逐步向弱挥发性原油和黑油过渡区转变。

剩余油CO_2驱最小混相压力测试　利用不同衰竭阶段剩余油开展CO_2驱长细管最小混相压力(MMP)测试。结果(图4)表明，随着衰竭压力的降低，MMP逐步降低，衰竭压力降低至5.13 MPa时，MMP从38.03 MPa降低至12.57 MPa，表明挥发性油藏衰竭过程会导致CO_2驱混相压力的降低。其主要原因是衰竭过程使得溶解气中CH_4含量显著降低，中间烃相对含量上升，从而使得该类油藏具有适度衰竭“脱气降混”特征。

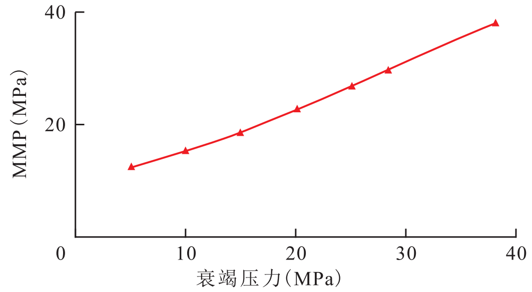

图4　不同衰竭阶段剩余油CO_2驱最小混相压力降低幅度测试

Fig.4　CO_2 MMP decreasing degree test for the residual oil at different depletion stages

2.2　弱挥发性油藏最小混相压力预测数值模拟计算

为了进一步明确挥发性油藏CO_2驱“脱气降混”特征，选取另外2种弱挥发性油藏原油样品进行衰竭过程中最小混相压力数值模拟计算研究。首先用PVTsim软件进行2种原始原油流体相态、注气膨胀实验、最小混相压力实验拟合；然后，利用相态软件进行不同衰竭压力下剩余油的最小混相压力数值模拟计算。结果(图5)表明，不同挥发性油藏衰竭后CO_2驱最小混相压力均表现出降低的趋势。

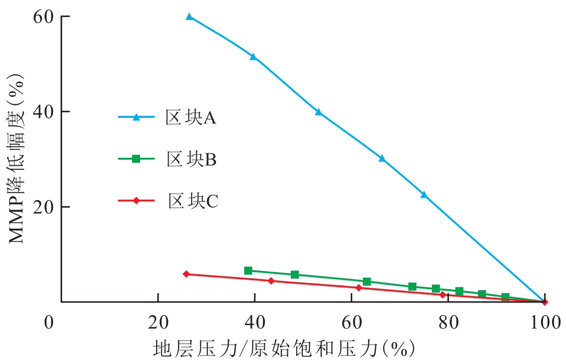

图5　不同挥发性油藏CO_2驱“脱气降混”特征比较

Fig.5　Comparison of characteristics of releasing methane and decreasing CO_2 MMP for different volatile oil reservoirs

其中，溶解气油比较大的油样，CO_2驱“脱气降混”程度较大，反之则越小。显然，挥发性油藏中溶解气CH_4含量对CO_2驱混相压力影响较大，通过适度的压力衰竭后，脱出部分CH_4后再注入CO_2，可以有效降低CO_2混相压力。

3　衰竭开发转CO_2驱界限

挥发性油藏衰竭开发转CO_2驱具有“脱气降混”特征，为了明确“脱气降混”特征对衰竭开发转CO_2驱界限的影响规律，对3个区块挥发性油藏衰竭开发转CO_2驱界限进行分析。利用地层压力/原始泡点压力表示衰竭压力水平；当地层压力低于MMP时，CO_2驱混相驱无法实现，其对应的界限即为衰竭开发转CO_2驱界限。结果(图6—图8)表明，区块A衰竭开发转CO_2驱压力水平界限为100.2%，区块B为126.1%，区块C为127.8%。即原油溶解气油比越高的油藏，其衰竭开发转CO_2驱的压力水平界限越低，反之则越高。当衰竭压力水平在该界限以下时，要实施CO_2混相驱则需要提前补充地层能量。另外，随着压力衰竭至原油泡点压力以下后，其CO_2驱最小混相压力有降低的趋势，原始溶解气油比越高，其“脱气降混”的程度越大，后续需要注CO_2补充

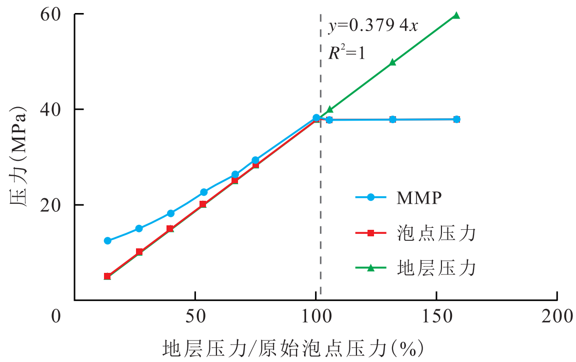

图6　区块A衰竭开发转CO_2驱界限

Fig.6　CO_2 injection timing after depletion for Block A

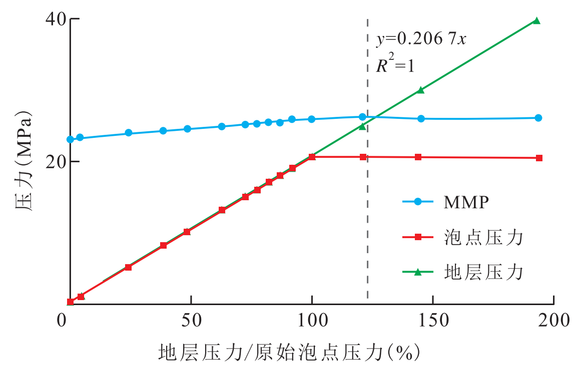

图7　区块B衰竭开发转CO_2驱界限

Fig.7　CO_2 injection timing after depletion for Block B

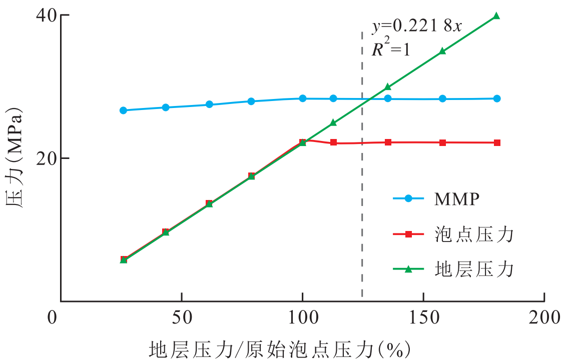

图8 区块C衰竭开发转CO_2驱界限

Fig.8 CO_2 injection timing after depletion for Block C

地层能量的幅度就越小,反之则越高。

4 结论

挥发性油藏衰竭开发转CO_2驱存在"脱气降混"特征,即随着地层压力的降低,原油中CH_4组分部分脱出,有助于CO_2驱最小混相压力的降低,其"脱气降混"程度随着溶解气油比的升高而增加。提出了挥发性油藏衰竭开发转CO_2驱界限,即原油溶解气油比越高,其衰竭开发转CO_2驱界限越低,脱气后CO_2混相驱补充地层能量幅度越小;反之,转驱界限越高,补充地层能量幅度越大。

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