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BZ19-6 低渗透储层反凝析污染及解除方法实验研究

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摘要: BZ19-6 凝析气田储量大、地露压差小、储层高温高压且低孔低渗, 生产作业过程中极易产生反凝析污染。评价反凝析污染程度, 采用合适的污染解除措施, 对改善 BZ19-6 凝析气田反凝析污染具有重要意义。利用复配凝析气开展长岩心衰竭实验, 模拟反凝析油污染, 测试不同衰竭压力点对应的气相渗透率并评价反凝析污染程度; 同时开展了注活性剂 (TC281)、注甲醇、注甲醇+活性剂 3 组解除反凝析污染实验, 及注甲醇+活性剂 1 组解除反凝析+水锁综合液相污染实验。实验结果表明: 注活性剂 (TC281)、注甲醇、注甲醇+活性剂 3 种方案对解除反凝析污染均有一定效果, 注甲醇+活性剂 1 组解除反凝析污染效果最好, 渗透率恢复率达 84%; 注甲醇解除反凝析污染渗透率恢复率为 81%; 注活性剂 1 组解除反凝析渗透率恢复率为 54%; 注甲醇+活性剂 1 组解除反凝析+水锁综合液相污染, 渗透率恢复率达到 80%。实验为 BZ19-6 凝析气田解除反凝析污染提供了方案指导。

关键词: 低渗透; 凝析气藏; 反凝析污染; 解除污染; 渗透率恢复率

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Retrograde condensation pollution and removal method of BZ19-6 low permeability reservoir

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Abstract: The BZ19-6 condensate gas field, characterized by large reserves, small surface pressure differential, high temperature and pressure reservoir conditions, and low porosity and permeability, is highly susceptible to retrograde condensation contamination during production operations. Evaluating the degree of retrograde condensation contamination and adopting appropriate contamination remediation measures are crucial for improving the situation in the BZ19-6 condensate gas field. The long core failure experiment was carried out using the mixed condensate gas to simulate the reverse condensate pollution, test the gas permeability corresponding to different exhaustion pressure points and evaluate the degree of reverse condensate pollution. Additionally, experiments on remediation of retrograde condensation contamination were carried out using three different approaches: injection of surfactant (TC281), injection of methanol, and injection of a combination of methanol and surfactant. Furthermore, an experiment was conducted using a combination of methanol and surfactant to address both retrograde condensation and water blockage, a comprehensive liquid phase contamination. The experimental results indicate that all three schemes of injecting active agent (TC281), injecting methanol and injecting methanol + active agent have certain effects on removing retrograde condensation pollution. The group of injecting methanol + active agent 1 has the best effect on removing retrograde

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condensation and removing retrograde condensation pollution, and the permeability recovery rate is 84%. The permeability recovery rate of methanol injection to remove retrograde condensation pollution is 81%. The recovery rate of retrograde condensate permeability in the surfactant injection group 1 was 54%. The injection of methanol + active agent 1 relieved the comprehensive liquid phase pollution of reverse condensation + water lock, and the permeability recovery rate reached 80%. These experiments provide guidance for remediation strategies to address retrograde condensation contamination in the BZ19-6 condensate gas field.

Keywords: low permeability; condensate gas reservoir; retrograde condensate damage; remove damage; permeability recovering rate

在凝析气藏的开发过程中,当地层压力低于露点压力时,凝析气体系统中的重质组分会以凝析油的形式析出^[1-3]。随着压降逐渐向地层远处扩展,从井底到气藏外边界可能出现3个渗流区域^[4-5](图1),析出的凝析油不仅会占据孔隙空间,使得气相流动通道减小,而且还会增加气相在渗流过程中需要克服的附加阻力,使得气相渗透率降低。同时在气井的生产作业过程中,井底积液反向渗吸会导致反凝析+水锁的综合液相污染,使得渗流阻力增大,从而导致气井减产甚至停产^[6-9]。低孔低渗凝析气藏一旦发生反凝析伤害,会使得储层气相渗透率降低,影响气井产能,严重可致气藏废弃^[10-13]。BZ19-6凝析气藏储层温度高达179℃,压力达49.40 MPa,凝析油含量高达743 g/m³,储层岩性主要为二长片麻岩,属于特低孔、特低渗储层,在生产及作业过程中极易产生反凝析及水锁污染。目前国内外凝析气相关反凝析伤害室内实验研究温度最高不超过140℃,超高温高压凝析气藏反凝析伤害特征及解除方法室内实验研究较少,亟需开展此类凝析气藏污染评价及解除污染的方法研究。解除凝析气藏储层污染常用的方法有

循环注气、压裂、注表面活性剂和注甲醇等^[14-18]。循环注气包括注干气、注富气、注贫气、注CO₂和注N₂等,但是工艺需要注气井、增加管线和加压设备,投入高、见效慢。压裂工艺复杂、投入高、周期长。甲醇属于易挥发的极性物质,能同时溶解于水和凝析油,可以起到消除反凝析液堵和水锁的作用,注入表面活性剂能有效降低液相界面张力,使表面呈活化状态,有利于解除反凝析污染,通过注入溶剂使地层凝析油反蒸发是解除反凝析污染的重要措施^[19-23]。因此,开展了高温高压长岩心衰竭实验,注活性剂(TC281酰胺基双子表面活性剂)、注甲醇、注甲醇+活性剂解除反凝析污染实验,以及注“甲醇+活性剂”解堵体系,解除反凝析+水锁综合液相污染实验,旨在为该气藏污染解除提供技术支撑。

1 气藏概况

1.1 地质概况

BZ19-6气田位于BZ凹陷西南部,构造上为BZ西南洼、BZ主洼、BZ南洼和黄河口凹陷环绕的近南北向构造脊,整体表现为被3条走滑断层及其派生断层复杂化的具有背斜特征的断块气藏,气藏埋深3 870~5 470 m。储层主力层系太古界潜山,岩性主要为二长片麻岩、斜长片麻岩,潜山孔隙度为2%~4.46%,平均孔隙度为3.35%,渗透率为(0.001~4)×10⁻³ μm²,平均渗透率为0.42×10⁻³ μm²,属于特低孔、特低渗储层;地层温度梯度3.6℃/hm,压力系数为1.139,属正常压力和温度系统,地面气甲烷含量75%~78%,中高含CO₂(约10%),微含H₂S(9.2~36.6 mg/m³)。岩心和镜下观察表明(图2),BZ19-6气田储层岩石结构较致密,原生孔隙不发育,储集空间类型以微裂缝为主,为裂缝型储层。

1.2 流体概况

BZ19-6-A1H井目的层储层温度为179℃,地层

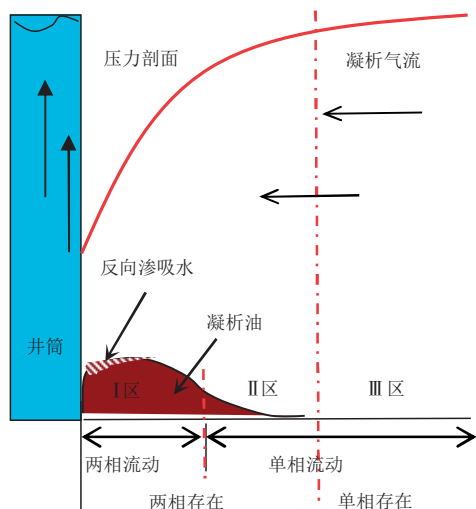


图1 井底周围渗流特征

Fig. 1 Seepage characteristics around the bottom hole

压力为49.40 MPa,该井地层流体属于高含甲烷、中高含中间烃和重质烃的凝析气体系。其组成为: C_1+N_2 摩尔分数为68.22%, CO_2 和 C_2-C_{10} 摩尔分数为28.47%, C_{11+} 摩尔分数为3.31%。图3为井流物P-T相图,在地层温度(179 °C)条件下,气藏流体露点压力为40.99 MPa,地露压差为8.41 MPa。目前地层条件下储层中不存在凝析油。

定容衰竭过程中,最大反凝析液量达16.1%,最大反凝析压力为14 MPa(图4),当压力低于露点压力后反凝析液量迅速增加,该气藏在衰竭式开采过程中反凝析严重。

2 反凝析污染评价实验

2.1 样品准备

根据国家标准《油气藏流体物性分析方法:GB/T 26981—2020》及流体PVT(压力-体积-温度)相态资料,利用现场取得的凝析油和天然气样品按露点压力和气油比资料复配凝析气,检测复配凝析气样品组分与井流体组分,确保复配凝析气样品合格。长岩心总长30.39 cm,平均渗透率为 $0.24 \times 10^{-3} \mu m^2$,其基本物性参数见表1。

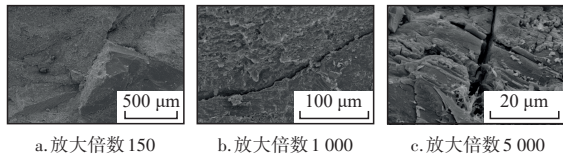


图2 太古界岩样电镜扫描

Fig. 2 Electron microscope scanning of Archean samples

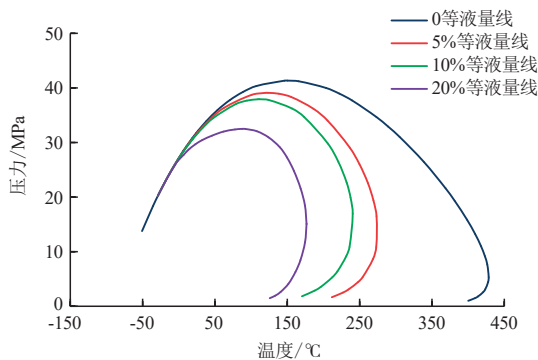


图3 BZ19-6-A1H井流物P-T相图

Fig. 3 P-T phase diagram of flow in well BZ19-6-A1H

2.2 实验条件

复配凝析气的气油比为 $1\ 138\ m^3/m^3$,地层温度为179 °C,地层压力为49.40 MPa,露点压力为40.99 MPa,最大反凝析压力为14 MPa。衰竭同时降低围压,保持围压高于岩心内压5 MPa的压差,中间测试压力为45、41、37、33、29、25、21、17、13、9、5 MPa。

2.3 实验步骤

1) 将岩心抽真空,充分饱和地层水,然后用离心泵离心,除去短岩心中可动水,建立束缚水饱和度后对岩心测试核磁 T_2 谱,将短岩心按调和平均方式排列组装好长岩心。在实验温度下用干气建立长岩心系统压力。

2) 用配好的凝析气驱替干气,确保凝析气在通过长岩心时无反凝析发生。待出口气体与配制凝析气的组成、气油比参数基本一致时即可,测试此时长岩心渗透率,记为未发生反凝析污染时的渗透率 K_0 。

3) 控制长岩心压力从高于露点压力缓慢下降,同时控制凝析气容器压力同步降低,当岩心压力降至每个衰竭压力点时,用凝析气容器上部对应压力的平衡凝析气驱替测量此时长岩心的气相有效渗透率,记为 K_i 。

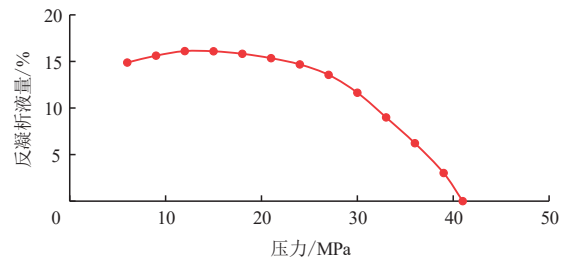


图4 反凝析液量与压力关系曲线

Fig. 4 Relation curve of reverse condensate volume and pressure

表1 岩心物性参数

Table 1 Core physical property parameters

取心编号	长岩心编号	孔隙度/%	渗透率/ $10^{-3} \mu m^2$	长度/cm	直径/cm
2-003A	5	5.44	0.15	5.02	2.52
2-004A	3	4.11	0.07	5.09	2.53
2-005A	4	5.89	0.09	5.03	2.53
2-006A	6	7.51	0.14	5.18	2.53
2-008A	1	7.25	0.64	5.05	2.53
2-009A	2	7.49	0.34	5.02	2.52

4) 实验结束后将发生反凝析污染的岩心取出进行核磁 T_2 谱测试。处理实验数据,计算各级衰竭压力点下长岩心的渗透率,评价污染程度。

污染程度评价计算方法为:

$$I_s = \frac{K_0 - K_i}{K_0} \times 100\% \quad (1)$$

式中: I_s 为岩心渗透率污染程度; K_0 为岩心束缚水饱和度渗透率,单位 $10^{-3} \mu\text{m}^2$; K_i 为岩心衰竭至不同压力点污染后渗透率,单位 $10^{-3} \mu\text{m}^2$ 。

3 解除污染实验

在最大反凝析压力下设计并开展注活性剂(TC281)、注甲醇、注“甲醇+活性剂”3组解除反凝析污染实验及注甲醇+活性剂体系解除综合液相污染实验。实施解除措施后测试气相渗透率,评价污染解除效果。

3.1 解除反凝析污染实验步骤

1) 用干气建立长岩心压力至地层压力后,用配好的凝析气驱替干气,待出口端气体与配制凝析气的组成、气油比参数基本一致时即可,测试此时长岩心渗透率,记为未发生反凝析污染时的渗透率 K_0 。

2) 将岩心系统压力衰竭至 14 MPa,压力稳定后用凝析气容器上部对应压力的平衡凝析气测试此时的渗透率,记为反凝析伤害时的渗透率 K_1 。

3) 岩心出口端反向注入 0.1 PV 污染解除试剂,措施实施后用凝析气容器上部对应压力的平衡凝析气驱替测试渗透率记为 K_2 。

解除反凝析污染渗透率恢复率计算方法为:

$$D_s = \frac{K_2}{K_0} \times 100\% \quad (2)$$

式中: D_s 为岩心渗透率恢复率; K_2 为岩心解除反凝析污染后渗透率,单位 $10^{-3} \mu\text{m}^2$ 。

3.2 解除综合液相污染实验步骤

1) 用干气建立长岩心压力至地层压力后,用配好的凝析气驱替干气,待出口端气体与配制凝析气的组成、气油比参数基本一致时即可,测试此时长岩心渗透率,记为未发生反凝析污染时的渗透率 K_0 。

2) 将岩心系统压力衰竭至 14 MPa,压力稳定后用凝析气容器上部对应压力的平衡凝析气测试此时

的渗透率,记为反凝析伤害时的渗透率 K_1 。

3) 岩心出口端反向注入 0.1 PV 地层水,措施实施后用凝析气容器上部对应压力的平衡凝析气驱替测试反凝析+水锁污染后的渗透率记为 K_2 。

4) 岩心出口端反向注入 0.05 PV 甲醇+0.05 PV 活性剂,措施实施后用凝析气容器上部对应压力的平衡凝析气测试解除反凝析+水锁污染后的渗透率记为 K_3 。

解除综合液相污染后渗透率恢复率计算方法为:

$$D_s = \frac{K_3}{K_0} \times 100\% \quad (3)$$

式中: D_s 为岩心渗透率恢复率; K_3 为岩心解除“反凝析+水锁”污染后渗透率,单位 $10^{-3} \mu\text{m}^2$; K_0 为岩心束缚水饱和度渗透率,单位 $10^{-3} \mu\text{m}^2$ 。

4 实验结果及分析

4.1 反凝析污染评价

通过对气相有效渗透率与衰竭压力关系及污染程度与衰竭压力关系的分析,如图 5、图 6 可知,当衰竭压力大于露点压力(40.99 MPa)时,储层内流动的流体只有气相,气相有效渗透率为 $1.78 \times 10^{-5} \mu\text{m}^2$,当

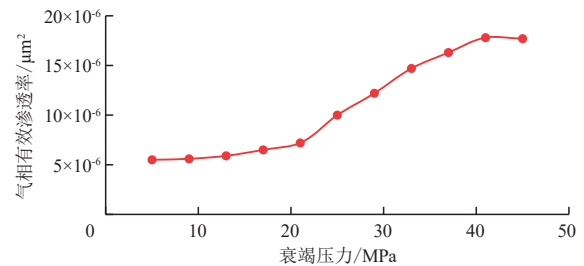


图 5 气相有效渗透率与衰竭压力关系

Fig. 5 Relationship between effective permeability of gas phase and exhaustion pressure

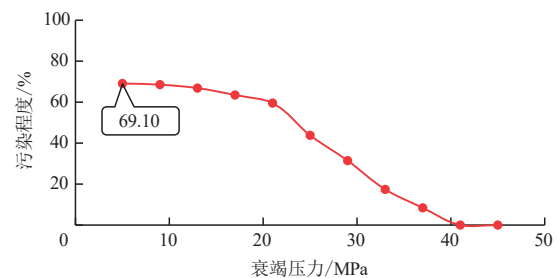


图 6 渗透率污染程度与衰竭压力关系

Fig. 6 Relationship between permeability pollution degree and exhaustion pressure

在低于但接近露点压力时,由于反凝析液量相对较少,凝析油达到最小流动饱和度之前不流动,随着压力继续降低,岩心中反凝析液增多,储层含油饱和度增大,气体的流动通道越来越小,流动阻力越来越大,气相有效渗透率出现急速下降,污染程度明显增大。当压力衰竭至20 MPa左右时,气相有效渗透率下降速度变缓,此时凝析油析出量趋于稳定。当压力衰竭至5 MPa时,气相有效渗透率降低为 $5.5 \times 10^{-6} \mu\text{m}^2$,凝析油在近井地带聚集,孔喉堵塞严重,渗透率污染程度达到69.10%,反凝析污染严重。

图7为岩心发生反凝析污染前后核磁 T_2 谱。显而易见,反凝析发生后,岩心中大小孔隙均有凝析油滞留,同时从反凝析污染后信号强度可以得出,岩心内滞留凝析油量约为束缚水量的三分之二,反凝析油量高。BZ19-6低孔低渗储层反凝析将严重影响储层中气相流动能力。

4.2 解除污染效果评价

4.2.1 解除反凝析污染研究

由图8可以看出,采取3种措施都能使渗透率得到恢复,注甲醇解堵后渗透率恢复率为81%;注活性剂TC281解堵后渗透率恢复率为54%;注甲醇+活性剂体系解堵后渗透率恢复率达到84%。从污染解除

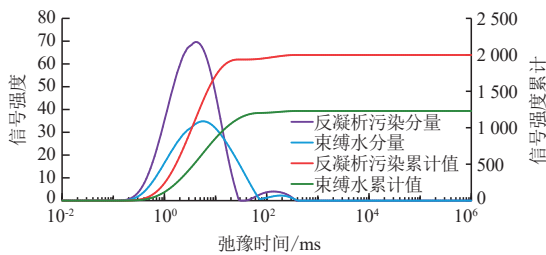


图7 反凝析污染前后核磁 T_2 谱

Fig. 7 Nuclear magnetic T_2 spectrum before and after retrograde condensation pollution

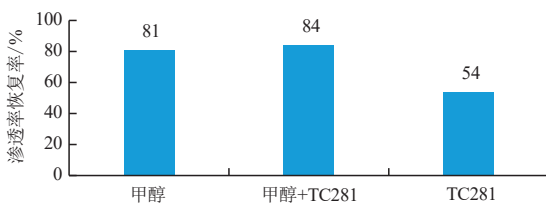


图8 渗透率恢复率对比

Fig. 8 Comparison of permeability recovery rate

效果来看,注甲醇+活性剂体系解除污染效果最好。长岩心不同解堵剂作用前后渗透率数据见表2。

4.2.2 解除反凝析+水锁综合液相污染研究

由图9可以看出,在发生反凝析+水锁污染后,长岩心渗透率下降至 $0.31 \times 10^{-5} \mu\text{m}^2$,降低为初始渗透率的0.17倍,渗透率伤害程度达到83%。采取注甲醇+活性剂体系解堵后,长岩心渗透率恢复至 $1.42 \times 10^{-5} \mu\text{m}^2$,渗透率恢复率达到80%,注甲醇+活性剂体系解除反凝析+水锁污染效果良好。

综上所述:BZ19-6凝析气田衰竭式开采反凝析污染程度严重,同时井底积液反渗吸水锁将进一步引起综合液相伤害,严重影响气井产能,注甲醇+活性剂体系对于解除反凝析污染和反凝析+水锁综合液相污染具有良好效果。

5 结论

1) BZ19-6凝析气田特低孔、特低渗储层衰竭式开采会出现反凝析污染,岩心内滞留凝析油量约为束缚水量的三分之二,反凝析油量高,反凝析污染程度达69.10%。发生反凝析+反渗吸水锁综合液相污染时渗透率伤害程度达到82.58%,反凝析+反渗吸水锁将严重影响储层中气相流动能力,影响气井产能。

表2 长岩心不同解堵剂作用前后渗透率数据
Table 2 Permeability data of long core before and after the action of different deplugging agents

解堵剂	束缚水渗透率/ μm^2	反凝析后渗透率/ μm^2	解堵后渗透率/ μm^2	渗透率恢复率(K_2/K_0)/%
甲醇	1.78×10^{-5}	0.64×10^{-5}	1.43×10^{-5}	81
甲醇+TC281	1.78×10^{-5}	0.64×10^{-5}	1.49×10^{-5}	84
TC281	1.78×10^{-5}	0.64×10^{-5}	0.96×10^{-5}	54

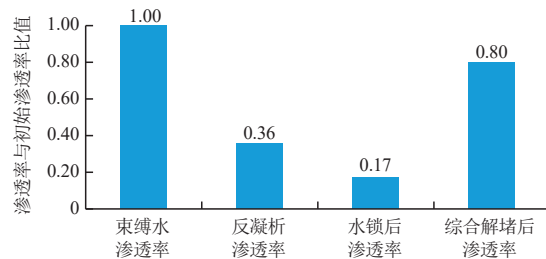


图9 综合解堵各阶段渗透率对比

Fig. 9 Permeability comparison at different stages of comprehensive plugging removal

2) 在地层温度 179 °C超高温条件下,注活性剂、注甲醇和注甲醇+活性剂 3种解除反凝析污染的方法均能有效改善反凝析污染,其中注甲醇+活性剂体系解除反凝析污染效果最好,渗透率恢复率达到 84%;注甲醇+活性剂体系解除反凝析+水锁综合液相污染时,渗透率恢复率达到 80%,从实验结果分析推荐采用注甲醇+活性剂体系解除污染。

3) 反凝析污染评价实验中,长岩心渗透率降低速率先快后慢,在 20 MPa 左右时下降速率减缓,建议在气藏开发早期采取合理的预防措施或反凝析污染解除措施。

参考文献

[1] 杜建芬,肖翠,汪周华,等. BK气藏反凝析污染评价及解除方法实验[J]. 天然气工业, 2015, 35(4): 52-56.
DU Jianfen, XIAO Cui, WANG Zhouhua, et al. Laboratory study on the evaluation and removal of retrograde condensate damage in the Baka Gas Reservoir, Tuha Basin[J]. Natural Gas Industry, 2015, 35(4): 52-56.

[2] 冯强汉,邓宝康,杨映洲,等. 致密砂岩凝析气藏反凝析伤害评价及解除方法[J]. 大庆石油地质与开发, 2020, 39(2): 139-146.
FENG Qianghan, DENG Baokang, YANG Yingzhou, et al. Evaluations and removing methods of the retrograde condensate damage for the gas condensate reservoirs in the tight sandstone [J]. Petroleum Geology and Oilfield Development in Daqing, 2020, 39(2): 139-146.

[3] 刘建仪,郭平,李士伦,等. 反凝析污染对凝析气井伤害的实验评价研究[J]. 天然气工业, 2001, 21(5): 67-70.
LIU Jianyi, GUO Ping, LI Shilun, et al. Condensate gas well damage caused by retrograde condensation contamination[J]. Natural Gas Industry, 2001, 21(5): 67-70.

[4] 高奕奕,孙笛,汤勇,等. 低渗透凝析气井反凝析、反渗吸伤害及解除方法[J]. 西南石油学院学报, 2005, 27(2): 45-49.
GAO Yiyi, SUN Di, TANG Yong, et al. Low permeability condensate gas well, retrograde condensation, reverse imbibition damage and removing methods[J]. Journal of Southwest Petroleum Institute, 2005, 27(2): 45-49.

[5] 汤勇,杜志敏,孙雷,等. 解除低渗透凝析气井近井污染研究现状及进展[J]. 天然气工业, 2007, 27(6): 88-91.
TANG Yong, DU Zhimin, SUN Lei, et al. Research status and progress of decontamination near well pollution of low permeability condensate gas wells[J]. Natural Gas Industry, 2007, 27(6): 88-91.

[6] 潘毅,孙雷,李士伦,等. 凝析气藏解除反凝析污染、提高气井产能方法[J]. 西南石油大学学报(自然科学版), 2007, 29(2): 37-40.
PAN Yi, SUN Lei, LI Shilun, et al. The method solving condensate block and improving productivity of gas condensate reservoir[J]. Journal of Southwest Petroleum University (Science and Technology Edition), 2007, 29(2): 37-40.

[7] 李小刚,谢信捷,杨兆中,等. 特低渗透凝析气藏复合解堵技术

应用[J]. 油气藏评价与开发, 2017, 7(3): 44-49.
LI Xiaogang, XIE Xinjie, YANG Zhaozhong, et al. Composite plug removal technology for ultra-low permeability condensate gas reservoir[J]. Reservoir Evaluation and Development, 2017, 7(3): 44-49.

[8] 张冲,宋宪实,汤勇. 龙凤山特低孔特低渗透凝析气藏反凝析伤害实验研究[J]. 西安石油大学学报(自然科学版), 2020, 35(2): 50-53.
ZHANG Chong, SONG Xianshi, TANG Yong. Experimental study on retrograde condensate damage of Longfengshan extra-low porosity and extra-low permeability condensate gas reservoir[J]. Journal of Xi'an Shiyou University (Natural Science Edition), 2020, 35(2): 50-53.

[9] JAMLUDIN A K M, YE S, THOMAS J, et al. Experimental and theoretical assessment of using propane to remediate liquid buildup in condensate reservoirs[C]// Paper SPE-71526-MS presented at the SPE Annual Technical Conference and Exhibition, New Orleans, Louisiana, September 2001.

[10] HAMOUD A, JACOB G, GARY A, et al. A successful methanol treatment in a gas-condensate reservoir: field application[C]// Paper SPE-80901-MS presented at the SPE Production and Operation Symposium, March 23-25, 2003.

[11] Du L G, JACOB G, GARY A, et al. Use of solvents to improve the productivity of gas condensate wells[C]// Paper SPE-62935-MS presented at the SPE Annual Technical Conference and Exhibition, Dallas, Texas, October 2000.

[12] 乐平,曾凡成,杨智帆,等. SJ低渗气藏反凝析污染评价实验研究[J]. 新疆石油天然气, 2020, 16(2): 78-82.
YUE Ping, ZENG Fancheng, YANG Zhifan, et al. Experimental study on retrograde condensate pollution evaluation of SJ low permeability gas reservoir[J]. Xinjiang Oil and Gas, 2020, 16(2): 78-82.

[13] 石德佩,李相方,刘华,等. 注甲醇解除凝析气井反凝析污染的机理[J]. 新疆石油地质, 2007, 28(2): 207-209.
SHI Depei, LI Xiangfang, LIU Hua, et al. Mechanism of eliminating retrograde condensate damage in gas condensate well by methanol injection process[J]. Xinjiang Petroleum Geology, 2007, 28(2): 207-209.

[14] 李虎,李相方,赵林. 注甲醇吞吐解除反凝析堵塞和水锁的正负面作用分析[J]. 钻采工艺, 2010, 33(1): 90-92.
LI Hu, LI Xiangfang, ZHAO Lin. Mechanism analysis of advantage and disadvantage of removing condensate and water blocking by methanol treatment[J]. Drilling and Production Technology, 2010, 33(1): 90-92.

[15] 肖丽仙,杜建芬,郭平,等. 凝析气藏反凝析污染研究[J]. 断块油气田, 2009, 16(4): 102-104.
XIAO Lixian, DU Jianfen, GUO Ping, et al. Pollution caused by retrograde condensate in condensate gas reservoir[J]. Fault-Block Oil and Gas Field, 2009, 16(4): 102-104.

[16] 严谨,张烈辉,王益维. 凝析气井反凝析污染的评价及消除[J]. 天然气工业, 2005, 25(2): 133-135.
YAN Jin, ZHANG Liehui, WANG Yiwei. Evaluation and elimination of condensate gas well damage caused by retrograde

- 与认识[J]. 油气藏评价与开发, 2023, 13(2): 173-180.
- JIN Zhongkang, SUN Xiaoqing. Evaluation and recognition of rolling expansion potential of structural lithologic reservoir in MJZ Oilfield[J]. Reservoir Evaluation and Development, 2023, 13(2): 173-180.
- [21] 杜佳, 刘彦成, 白洁珍, 等. 基于波形指示模拟的致密砂岩储层预测[J]. 地质科技通报, 2022, 41(5): 94-100.
- DU Jia, LIU Yancheng, BAI Jiefen, et al. Prediction of tight sandstone reservoirs based on waveform indication simulation [J]. Bulletin of Geological Science and Technology, 2022, 41 (5): 94-100.
- [22] 杨川, 冯鑫, 李啸, 等. 准噶尔盆地前哨地区三工河组二段沉积特征及有利储层预测[J]. 东北石油大学学报, 2022, 46(5): 1-13.
- YANG Chuan, FENG Xin, LI Xiao, et al. Sedimentary characteristics and prediction of favorable reservoir of the member 2 of Sangonghe Formation in the Qianshao Area, Junggar Basin[J]. Journal of Northeast Petroleum University, 2022, 46(5): 1-13.
- [23] 王连桥, 全钦飞, 王科朋, 等. 测井参数随机模拟在薄储层描述中的应用[J]. 复杂油气藏, 2018, 11(1): 32-36.
- WANG Lianqiao, QUAN Qinfei, WANG Kepeng, et al. Stochastic simulation of logging parameters for description of thin reservoir[J]. Complex Hydrocarbon Reservoirs, 2018, 11 (1): 32-36.
- [24] 胡玮, 张建宁, 杨江峰, 等. 地层超覆尖灭型油气藏的储层展布与厚度精确识别技术研究[J]. 地球物理学进展, 2021, 36(6): 2472-2478.
- HU Wei, ZHANG Jianning, YANG Jiangfeng, et al. Study on reservoir accurate identification technology of areal extent and thickness of overlap-denudation pinch out stratigraphic reservoir[J]. Progress in Geophysics, 2021, 36(6): 2472-2478.
- [25] 夏步余. 黄珏-马家嘴油田薄砂体预测技术应用研究[J]. 复杂油气藏, 2017, 10(3): 12-17.
- XIA Buyu. Application of thin reservoir prediction technology in Huangjue-Majiazui Oilfield[J]. Complex Hydrocarbon Reservoirs, 2017, 10(3): 12-17.
- [26] 张星, 张雅君. 海安凹陷XJ地区泰一段第二段地层圈闭识别方法[J]. 复杂油气藏, 2017, 10(2): 21-26.
- ZHANG Xing, ZHANG Yajun. Identification method of stratigraphic trap in $K_2L_1^2$ of XJ area, Hai'an Sag[J]. Complex Hydrocarbon Reservoirs, 2017, 10(2): 21-26.

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- condensate contamination[J]. Natural Gas Industry, 2005, 25 (2): 133-135.
- [17] 周小平, 孙雷, 陈朝刚. 低渗透凝析气藏反凝析水锁伤害解除方法现状[J]. 钻采工艺, 2005, (5): 66-68.
- ZHOU Xiaoping, SUN Lei, CHEN Chaogang. Development and methods of removing retrograde condensate and water blocking impairment in the low permeability condensate gas reservoir[J]. Drilling and Production Technology, 2005, (5): 66-68.
- [18] 徐兵威, 王世彬, 刘城成. 致密低渗底水气藏控水二次加砂压裂技术研究与应用[J]. 油气藏评价与开发, 2022, 12(4): 698-702.
- XU Bingwei, WANG Shibin, LIU Chengcheng. Research and application of water-control secondary sanding fracturing technology in tight low permeability bottom water gas reservoir [J]. Petroleum Reservoir Evaluation and Development, 2022, 12 (4): 698-702.
- [19] 谭先红, 梁斌, 王帅, 等. 一种低渗储层凝析气藏气井产能评价方法研究[J]. 油气藏评价与开发, 2021, 11(5): 724-729.
- TAN Xianhong, LIANG Bin, WANG Shuai, et al. A productivity evaluation method of gas wells in condensate gas reservoirs with low permeability[J]. Petroleum Reservoir Evaluation and Development, 2021, 11(5): 724-729.
- [20] 刘成川, 王勇飞, 毕有益. 中江气田窄河道致密砂岩气藏高效开发技术[J]. 油气藏评价与开发, 2022, 12(2): 345-355.
- LIU Chengchuan, WANG Yongfei, BI Youyi. Efficient development technique of tight sandstone gas reservoir in narrow channel of Zhongjiang Gas Field[J]. Petroleum Reservoir Evaluation and Development, 2022, 12(2): 345-355.
- [21] 王德英, 刘晓健, 邓辉, 等. 渤海湾盆地渤中19-6区中-新生代构造转换特征及其对太古宇潜山大规模储层形成的控制作用[J]. 石油与天然气地质, 2022, 43(6): 1334-1346.
- WANG Deying, LIU Xiaojian, DENG Hui, et al. Characteristics of the Meso-Cenozoic tectonic transformation and its control on the formation of largescale reservoirs in the Archean buried hills in Bozhong 19-6 area, Bohai Bay Basin[J]. Oil & Gas Geology, 2022, 43(6): 1334-1346.
- [22] 李文浩, 卢双舫, 王民, 等. 基于扫描电镜大视域拼接技术定量表征致密储层微观非均质性[J]. 石油与天然气地质, 2022, 43(6): 1497-1504.
- LI Wenhao, LU Shuangfang, WANG Min, et al. Quantitative characterization of micro heterogeneity of tight reservoirs by large-view FE-SEM splicing technology[J]. Oil & Gas Geology, 2022, 43(6): 1497-1504.
- [23] 袁静, 周涛, 乔俊, 等. 深层砂砾岩中的深部热流体作用及其地质意义——以渤海湾盆地东营凹陷民丰—盐家地区古近系沙河街组四段为例[J]. 石油与天然气地质, 2022, 43(4): 929-942.
- YUAN Jing, ZHOU Tao, QIAO Jun, et al. Deep hydrothermalism of deep coarse-grained siliciclastic rocks and its geological significance: A case study of the 4th member of the Paleogene Shahejie Formation in Minfeng-Yanjia area, Dongying Sag, Bohai Bay Basin[J]. Oil & Gas Geology, 2022, 43(4): 929-942.

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