



煤层气直井压裂效果及其对产能影响

马代兵 陈立超

引用本文:

马代兵, 陈立超. 煤层气直井压裂效果及其对产能影响[J]. 煤炭科学技术, 2023, 51(6): 130–136.

MA Daibing, CHEN Lichao. Hydraulic fracturing effect of CBM vertical well and its impact on productivity: a case study of Yaojie Mining Area[J]. Coal Science and Technology, 2023, 51(6): 130–136.

在线阅读 View online: <https://doi.org/10.13199/j.cnki.cst.2022-0539>

您可能感兴趣的其他文章

Articles you may be interested in

淮南矿区煤层顶板分段压裂水平井抽采技术及效果研究

Study on technology and effect of gas extraction in horizontal well with segmental hydraulic fracture in roof of coal seam in Huainan mining area

煤炭科学技术. 2024, 52(4): 155–163 <https://doi.org/10.12438/cst.2023-1937>

煤层气井液氮伴注压裂增透机制及应用研究

Study on mechanism and application of liquid nitrogen injection combined with fracturing to enhance permeability in CBM wells

煤炭科学技术. 2019(11) <http://www.mtkxjs.com.cn/article/id/a7ea770e-36a7-41b0-8c9b-4d254fcb08bb>

天然裂缝对水力压裂煤的起裂及扩展试验研究

Study on influence of natural fractures on initiation and propagation of hydraulic fracturing coal

煤炭科学技术. 2024, 52(5): 92–101 <https://doi.org/10.12438/cst.2023-0813>

渝东南地区龙潭组煤层气甜点地质评价及有效压裂工艺

Geological evaluation and effective fracturing technology of Longtan Formation CBM in Nanchuan Block, Southeast Chongqing, China

煤炭科学技术. 2023, 51(S2): 132–140 <https://doi.org/10.13199/j.cnki.cst.2022-2248>

高煤阶煤层气水平井和直井耦合降压开发技术研究

Study on technology of horizontal wells and vertical wells coupled depressurization in high rank coalbed methane

煤炭科学技术. 2019(7) <http://www.mtkxjs.com.cn/article/id/ee96d1fc-1fbf-473d-9030-66beb9633c3b>

煤层顶板间接压裂裂缝扩展机制及影响因素

Extension mechanism and influencing factors of indirect fracturing fractures on coal seam roof

煤炭科学技术. 2024, 52(2): 171–182 <https://doi.org/10.12438/cst.2023-0910>



关注微信公众号，获得更多资讯信息

地球科学与测绘



移动扫码阅读

马代兵, 陈立超. 煤层气直井压裂效果及其对产能影响——以窑街矿区为例[J]. 煤炭科学技术, 2023, 51(6): 130–136.

MA Daibing, CHEN Lichao. Hydraulic fracturing effect of CBM vertical well and its impact on productivity: a case study of Yaojie Mining Area[J]. Coal Science and Technology, 2023, 51(6): 130–136.

煤层气直井压裂效果及其对产能影响

——以窑街矿区为例

马代兵¹, 陈立超²

(1. 甘肃煤田地质局一四九队, 甘肃 兰州 730020; 2. 煤与煤层气共采国家重点实验室, 山西 晋城 048204)

摘要:煤层气藏作为典型缝控气藏, 压裂造缝规模及裂缝充填效果对气井产能具有决定性控制。为探究煤层气直井水力压裂效果对气井产能效果的影响机制, 以甘肃窑街海石湾矿区为例, 重点报道直井开发形式下煤储层压裂改造效果及其对产能制约方面认识, 结果表明: ①煤层气井破裂压力主要反馈井筒固井水泥环特征而非煤储层力学性能, 从该井压裂曲线看破裂压力不明显, 表明井筒环空固井水泥环厚度适中, 水力压裂期间固井水泥环破裂相对容易, 能量消耗低, 注入压裂液能量主要用于撑开煤岩裂缝; ②从压裂曲线看出, 该井压裂裂缝延伸压力较高, 表明地下煤储层结构较为破碎且发育煤粉源集合体, 煤粉对压裂裂缝的延展具有关键制约作用。而且在压裂曲线裂缝延展阶段出现多个波动形态特征, 指示多条次级裂缝撑开, 整体上该井压裂裂缝形态较为复杂, 推测为主干压裂裂缝两侧发育枝状次级裂缝形式; ③该井注砂后发生严重砂堵, 主要原因是煤储层压裂液滤失造成近井地带压裂裂缝内支撑剂脱砂形成楔体, 导致后续支撑剂注入困难, 同时也与煤储层原生裂缝煤粉源及少量构造煤粉源集合体发育有关; ④压裂微震监测数据显示该井煤储层主干压裂裂缝走向为 NE 50°, 其中在东北方向上煤岩微震事件更活跃, 指示该方向上煤储层天然裂隙系统更发育; 结合煤储层压裂裂缝矿井观测结果, 提出压裂裂缝有效支撑区、实际破裂区及岩体扰动区的划分方案, 认为微震监测得出的压裂裂缝半长实际为岩体扰动范围, 难以准确反映储层实际改造效果。综合该井后期产能规律及晋城矿区煤储层压裂裂缝矿井观测结果, 认为该井煤储层实际压裂裂缝半长在 20 m 以内, 有效支撑压裂裂缝半长不足 5 m, 压裂液注入液量少、压裂液滤失诱导支撑剂脱砂形成楔体以及煤粉聚集造成砂堵等是该井煤储层压裂裂缝较短的主要因素; ⑤结合煤层气产能规律, 认为该井气藏管控和排采制度较为合理, 但煤储层有效支撑压裂裂缝过短, 煤储层内煤粉运移导致近井压裂裂缝导流能力快速衰减是气井产能低下的关键制约机制, 建议后期煤储层水力压裂加大压裂液注入液量, 适当增大压裂液排量, 降低支撑剂砂比, 重点防控压裂液滤失、防止脱砂楔体形成。该区煤储层埋深大、应力高, 实现裂缝大范围加砂是煤储层压裂改造的关键。同时考虑储层干燥, 压裂液滤失严重的实际情况, 有条件可开展 CO₂ 前置压裂试验。

关键词:煤层气直井; 压裂效果; 天然裂隙系统; 压裂液滤失; 甘肃窑街矿区

中图分类号: TD712; P618

文献标志码: A

文章编号: 0253-2336(2023)06-0130-07

Hydraulic fracturing effect of CBM vertical well and its impact on productivity: a case study of Yaojie Mining Area

MA Daibing¹, CHEN Lichao²

收稿日期: 2022-05-10 责任编辑: 常 琛 DOI: 10.13199/j.cnki.cst.2022-0539

基金项目: 山西省煤层气联合研究基金资助项目 (2016012007)

作者简介: 马代兵(1969—), 男, 甘肃天水人, 高级工程师。E-mail: 673187809@qq.com

通讯作者: 陈立超(1985—), 男, 内蒙古赤峰人, 副教授, 博士。E-mail: chenlichao@163.com

(1. 149th Team, Gansu Coal Geology Bureau, Lanzhou 730020, China; 2. State Key Laboratory of Coal and CBM Co-mining, Jincheng 048204, China)

Abstract: CBM reservoir is a typical fracture-controlled gas reservoir, and the scale of fracturing and fracture-filling effect have decisive control on gas well productivity. In order to reveal the influence mechanism of the hydraulic fracturing effect of CBM vertical wells on the productivity effect of gas wells, taking the Haishiwan Mining Area of Yaojie, Gansu as an example, this paper focuses on reporting the fracturing effect of coal reservoirs under the form of vertical well development and its understanding of the constraints on productivity. the result shows: ① The fracture pressure of CBM well mainly feeds back the characteristics of the wellbore cement sheath rather than the mechanical properties of the coal reservoir. From the fracturing curve of this well, the fracture pressure is not obvious, indicating that the thickness of the cement sheath in the wellbore annulus is moderate, and the cement sheath is relatively easy to rupture during hydraulic fracturing. The energy of the injected fracturing fluid is mainly used to prop up the coal cracks; ② It can be seen from the fracturing curve that the propagation pressure of the hydraulic fractures(HF) in this well is relatively high, indicating that the structure of coal reservoir is relatively fragmented and coal fines are developed. In addition, there are multiple wave morphological features in the fracture propagation stage of the fracturing curve, indicating that multiple secondary fractures are propped up. On the whole, the HF in this well are relatively complex, and it is speculated that branched secondary fractures develop on both sides of the main HF. ③ Serious sand plugging occurred after sand injection in this well. The main reason was that the fracturing fluid in the coal reservoir was lost due to the loss of the fracturing fluid in the near-wellbore area, resulting in the formation of wedges by proppant de-sanding in the HF, which made subsequent proppant injection difficult. It is related to the coal fines of primary fractures and the development of a small amount of tectonic coal fines; ④ The fracturing microseismic monitoring data show that the main HF of the coal reservoir in this well are NE 50°, and the coal rock microseismic events are more active in the northeast direction, indicating that the natural fracture (NF) of the coal reservoir is more developed in this direction; Based on the observation results of fracturing and mineback, this paper proposes a division plan for the effective propped area, the actual fracture area and the rock mass disturbance area of HF. It is believed that the actual half-length of the HF in the coal reservoir of this well is less than 20 m, the half-length of the effectively propped HF is less than 5 m, and The small amount of fracturing fluid injected, the formation of wedges by proppant de-sanding induced by fracturing fluid-loss, and the sand plugging caused by coal fines accumulation are the main factors for the short fractures in the coal reservoir of this well; ⑤ Combined with the law of coalbed methane productivity, it is considered that the gas reservoir management and drainage system in this well is reasonable, However, the effective propped HF in the coal reservoir are too short, and the coal fines migration in the coal reservoir leads to the rapid decline of the conductivity of the near-well HF, which is the key restricting mechanism for the productivity of gas wells. It is recommended to increase the injection volume of fracturing fluid, appropriately increase the flow rate of fracturing fluid, reduce the proppant-sand ratio, and focus on controlling fracturing fluid leak-off and the formation of screenout wedges in the hydraulic fracturing of coal reservoirs in the later stage. The coal seam in this area has a large burial depth and high stress, and the realization of large-scale fracture propped is the key to coal reservoir fracturing. Meanwhile, the reservoir is dry and the fracturing fluid is seriously leak-off, the CO₂ pre-fracturing test can be carried out.

Key words: CBM vertical well; hydraulic fracturing effect; natural fracture system; fracturing fluid loss; Yaojie Mining Area in Gansu

0 引 言

水力压裂是非常规油气开发的灵魂。作为典型缝控气藏,煤层气储层压裂造缝效果包括造缝规模、裂缝形式及复杂程度、压裂裂缝内部充填效果及压裂工艺与储层改造工程属性间的适配性对气井产能具有决定性控制^[1-4]。

长期以来,煤储层压裂改造基础理论和工艺方面问题一直是行业的研究热点。大量学者和业界专家围绕煤储层压裂裂缝延展规律及影响因素^[5-9]、煤粉颗粒^[10-14]、钻完井工作液侵入^[15-17]对储层压裂裂缝延展的影响、以及非常规储层压裂物模试验方法和装置^[18-22]等问题开展了大量研究,取得了较为丰富的成果。然而,综合前期煤储层压裂改造方面的研究认识,尤其是山西沁水盆地南部废弃煤层气井

矿井回采试验现象,认为煤储层压裂改造中近井筒压裂裂缝起裂、延展及裂缝内部充填堵塞机制等是制约煤层气井长期产能效果的关键因素。而近井固井水泥浆侵入方式等对煤储层压裂裂缝延展也具有重要制约。值得指出的是,目前在包括煤储层是否存在显著破裂压力及破裂压力与气井近井结构的关系如何?压裂裂缝延展过程在压裂曲线上的反馈如何解译?利用微震监测数据如何对煤储层压裂造缝效果进行解释等问题上尚存在争议,带来的气井压裂效果的不确定性严重制约后续气井排采管控和产能分析、以及储层水力压裂方案的优化,因此亟待梳理上述煤层气井水力压裂效果分析中的几个关键问题。

针对上述需求,以甘肃窑街海石湾矿区煤层气直井(QP-01井)为例,结合气井压裂监控以及气井

产能数据,对本井煤储层压裂改造效果开展评价,并对煤储层压裂改造效果影响因素以及气井压裂效果对产能的制约机理展开初步讨论,以期为研究区煤储层压裂方案优化提供科学参考。

1 煤层气直井压裂施工情况

1.1 煤储层特征

甘肃窑街矿区是我国著名的煤与瓦斯、二氧化碳突出矿区,煤矿采掘中煤层气、二氧化碳涌出强度大,对煤矿井下安全生产安全构成严重威胁。为有效治理煤矿井下瓦斯灾害,2019 年 3 月,甘肃窑街煤电集团委托甘肃煤田地质局一四九队在窑街海石湾矿区施工首口地面煤层气直井(QP-01 井),并于同年实施水力压裂,目标层位为侏罗系窑街组(J_{2y})煤 2 层,该煤层顶深 1 197.00 m,层厚 12.00 m,从层厚角度上利于开展压裂改造。煤 2 层煤层结构相对简单,含 1~3 层夹矸,临井煤岩心显示本煤层天然裂缝系统发育,微震结果显示天然裂缝系统走向 NE50°,煤体结构相对破碎,且裂缝内部发育分散煤粉源以及少量的构造煤粉源集合体^[9]。值得指出的是,本井压裂期间曾压开井口发生溢流,从井筒返出大量煤粉浆液,表明该区煤储层内煤粉源发育。煤 2 层顶板为薄层状泥岩、碳质泥岩(伪顶)、向上过渡为砂泥岩(直接顶)及砂岩(基本顶),煤 2 层直接底板为碳质泥岩,整体上煤 2 层具有较好的围岩封闭性,能够较好地控制压裂液向围岩滤(漏)失。

据区内煤层气参数井注入/压降试井资料,本区煤 2 层地应力在 13.39~13.48 MPa,应力梯度平均 1.11 MPa/hm,裂缝闭合应力相对较高。

1.2 煤层气井近井结构特征

依据最小耗能定理及废弃煤层气井矿井回采试验现象,煤储层压裂裂缝延展主要受控于储层天然裂缝系统,尤其是近井部位储层煤体结构及天然裂缝会控制固井水泥环形态、钻完井液侵入特征,并制约后期压裂裂缝延展及造缝复杂性。结合窑街矿区微震监测资料及煤储层天然裂缝观测认识,构建了研究区煤层气井近井模式(图 1)。如图 1 所示,本井开发目标层位煤 2 层天然大裂隙走向为 NE50°,推测天然大裂隙长度大于 50.00 m,钻完井工作液沿近井天然裂缝系统侵入储层形成板片状滤饼结构,依据该井完井深度及工作液压强估算钻完井工作液侵入煤储层深度可达 5 m 以上,并在近井地带形成钻井泥浆滤饼、固井水泥浆滤饼与煤岩间的界面结构,后期压裂过程中在该界面一侧薄弱区极易开裂,诱

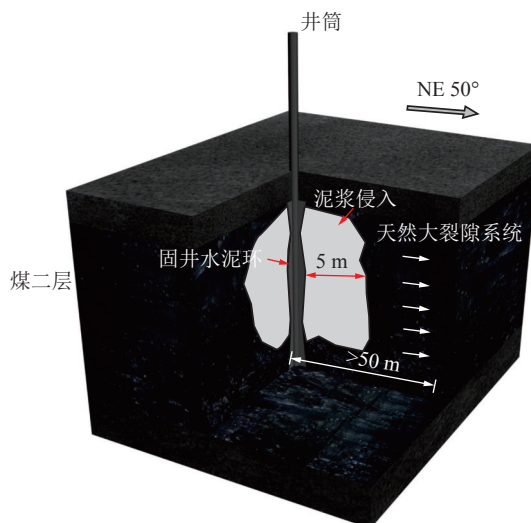


图 1 窑街矿区煤层气直井近井特征

Fig.1 Near wellbore characteristics of coalbed methane well in Yaojie Mining Area

导压裂裂缝的延展路径^[23-24]。

1.3 水力压裂施工情况

该井采用 SYD-102 型射孔枪,搭配 127 型射孔弹激发对井筒环空结构实施射孔。按照孔密 16 孔/m 分 3 段射开,为避开套管节箍少射 1 孔,每段共射 63 孔,煤 2 层段共计射开 189 孔,射孔过程中采用清水平衡压力。依据沁水盆地南部废弃煤层气井矿井回采试验现象,由于压裂加砂后期顶替效果欠佳,射孔孔眼多被支撑剂和煤粉颗粒堵塞^[9],推测该井有效畅通射孔孔眼比例不足 10%。

本井压裂液采取光套管注入,共计注入压裂液量 753.50 m³,其中前置液 450.16 m³。携砂液注入阶段砂比 3%, 6%, 9%, 12% 梯度上升,压裂中共加 20~40 目(0.84~0.42 mm)石英砂 17.40 m³。该井压裂前置液注入阶段油压相对稳定,后期加砂阶段油压快速上升,最高压力达到 34.9 MPa 发生井口脱开,施工中断,上述情况表明本区煤储层对注砂较为敏感,结合沁水盆地南部废弃煤层气井矿井回采试验认为通常这类储层通常煤体结构破碎,煤粉源集合体非常发育。

2 煤层气直井压裂效果分析

2.1 压裂施工曲线分析

裂缝型储层压裂改造本质是通过高压流体注入使得闭合的天然裂缝撑开形成油气运移通道,因此裂缝内压裂液流体能量主要用于抵抗裂缝壁面的闭合应力。在压裂裂缝延展阶段,当施工压力(延伸压力)与裂缝闭合应力平衡时,压裂裂缝稳定向前方扩展^[25-26]。

由图2中气井压裂施工曲线看出,本井破裂压力不明显,前期笔者提出异常高的气井破裂压力往往与煤储层力学性能关系不大,因为煤岩力学性能较为软弱,即使是原生结构煤其抗裂强度和断裂韧度值亦较低,例如陈立超等(2020)^[25]对内蒙古阿拉善二道岭矿区高阶煤岩断裂力学性质进行研究,得出原生结构煤断裂韧度值仅为 $0.30 \text{ MPa} \cdot \text{m}^{1/2}$,因此煤层气井压裂曲线中异常高破裂压力反应的不是煤岩断裂,而是固井水泥环的破裂方式^[20],从研究区煤层气井压裂中无明显破裂压力现象判断,本井环空水泥环厚度适中,而且钻井泥浆侵入储层深度较深。同时井径测井结果显示,煤2层段没有明显扩径,也反应出井筒环空水泥环厚度适中,这主要与钻井过程中煤2层段使用了护壁浆液有关。因此笔者认为目前过煤层段钻井采用清水或低密度钻井液方式会导致煤层段井壁塌孔、扩径,后续固井水泥环加厚,水力压裂中需要很高的能量压开厚层水泥环,导致施工压力过高造成施工风险。而选用黏度适宜的护壁型浆液能够维持井眼稳定性,保障井筒环空间隙不扩大,后期固井水泥环厚度适中,压裂中水泥环容易破裂,大部分压裂液能量能够用于拓展煤岩裂缝,尤其对深部高应力煤储层更具实际意义。因此,煤层气钻完井的重点应是维护煤层段孔壁稳定性而非防伤害。

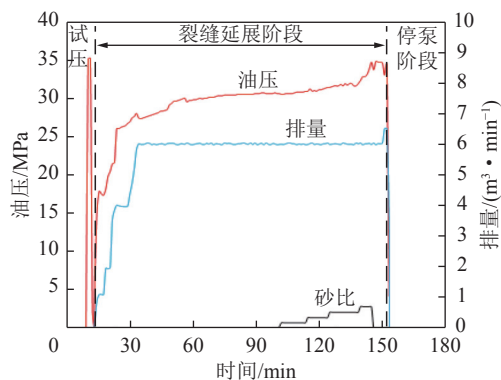


图2 窑街矿区煤层气直井压裂曲线

Fig.2 Fracturing curves of coalbed methane well in Yaojie Mining Area

由图2看出,在压裂加砂阶段,随着施工砂比增大,油压快速升高,表明前期造缝阶段主干压裂裂缝宽度尚未完全满足加砂所需,同时反映本区煤储层结构破碎,天然裂缝内发育煤粉源集合体,压裂中煤粉源和压裂液流体间发生强烈的造浆作用,注砂中煤粉颗粒极易导致砂堵,施工油压快速升高,这在新疆阜康区块部分气井表现很明显^[9]。由此推断研究区煤储层改造工程属性较为复杂,对施工方案和工

艺水平要求较高。而且有必要提及的是,由于该井压裂施工中途发生井口脱开导致施工中断,未达到压裂设计要求,压裂期间从井底返排出大量煤粉,也印证了窑街矿区煤储层具有很高的改造难度。

从窑街矿区煤层气试验井压裂施工曲线还看出,后期随着压裂液注入液量增加,施工油压逐渐升高,反映本区煤储层压裂裂缝延展难度大,与煤2层埋深大裂缝闭合应力高有关。此外在裂缝扩展过程中压裂曲线上出现多个小的波动,表明主干压裂裂缝延展中两侧部分次级裂缝开启,导致压裂流体压力上的波动。本井压裂裂缝具有复杂性,形成主干压裂裂缝两侧发育次级枝状裂缝的形式。

2.2 煤层气直井压裂微震监测讨论

微震监测是目前煤层气井压裂裂缝效果评价的主要手段,然而从沁水盆地南部废弃煤层气井压裂裂缝矿井回采试验结果看,大部分气井微震监测解释出的裂缝造缝规模与实际出入很大,通常微震监测解释压裂裂缝长度是煤储层压裂裂缝实际长度的5~8倍。如图3所示,笔者提出煤储层压裂改造范围包括近井端有效支撑裂缝、中端的煤岩实际破裂区以及远端的岩体扰动区。微震监测得出的煤储层压裂范围实际为岩体扰动半径,该值远超出煤岩实际断裂半径更大于有效充填半径,因此基于微震监测得出的压裂裂缝长度需要修正,而利用微震监测得出裂缝方位与煤储层破裂方位是一致的。

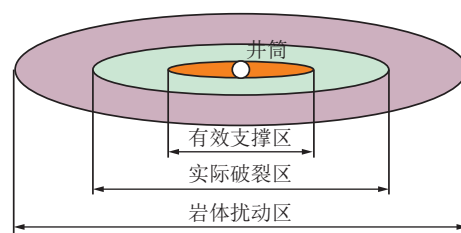


图3 煤储层压裂范围划分

Fig.3 Division of coal reservoir fracturing

2.3 煤层气直井压裂造缝效果评价

图4为研究区煤层气直井压裂裂缝微震监测结果,由图4可见本井压裂裂缝整体为北东向 50° 展布,在这一方向出现大量微震事件,其中井筒东北翼微震覆盖区域径向长度在200 m以上,宽度100 m左右,井筒西南翼微震辐射区域长度在180 m以内,宽度100 m左右,整体上在井筒北西方向上微震事件多于南东方向,这与煤储层天然大裂隙系统发育的各向异性有关^[27]。通常在煤储层天然大裂隙系统发育方向上压裂扰动半径就大,而在垂直裂缝方向上压裂过程对岩体扰动程度显然不及平行天然裂缝方

位上,笔者认为微震监测中微震事件分布能够反映煤储层天然大裂隙系统发育特征(图4中黑色虚线),对于分析煤储层原生裂缝具有很高价值。

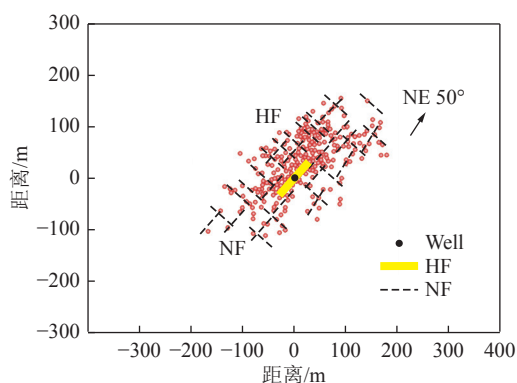


图4 窑街矿区煤层气井压裂微震监测与裂缝解释结果
Fig.4 Results of microseismic monitoring and fracture interpretation of CBM well fracturing in Yaojie Mining Area

综合认为本井压裂裂缝走向为 NE50°与储层天然大裂隙系统一致,有效扩展压裂裂缝半长 20 m 以内(图4中黄色粗线),实际充填压裂裂缝半长不足 5 m,压裂液注入液量少、压裂液滤失诱导支撑剂脱砂形成楔体以及煤粉聚集造成砂堵等是窑街矿区煤层气井压裂裂缝较短的主要因素。

3 压裂效果对煤层气井产能影响

受控于煤储层煤体结构破碎,压裂中发生了砂堵、粉堵,研究区煤层气试验井压裂造缝规模有限,且近井压裂充填裂缝的导流能力较差,影响了气藏流体的产出。而且窑街矿区煤系地层含水率较低,因此有较大比例的压裂液发生渗吸封闭,形成了吸附形式的压裂液滤失^[28],一定程度上也限制了煤储层压裂液的造缝效率。

研究区煤层气直井排采曲线如图5所示,煤层气井排采曲线整体上形态符合经典的煤层气、水产出规律,表明后期对煤层气藏排采制度设定及气藏动态管理方面较为合理。排采曲线反映整体上储层产水量较小,日产水量均在 5 m³/d 以下,这与研究区煤系地层含水率较低有关。同时煤层甲烷气产出符合先升高达到峰值后缓慢下降的规律,峰值产气出现在排采后 200 d 左右,后期气井日产气量下降至 100 m³/d 以下,表明排采初期解吸范围在近井压裂充填裂缝内,储层压降漏斗传递阻力小,气藏流体产出效率相对较高,后期随着近井资源的衰竭及压降漏斗的传递,远端未有效充填压裂裂缝两侧煤体内甲烷气开始解吸,运移过程中由于压裂裂缝及射孔孔

眼受煤粉颗粒堵塞等因素导致导流能力下降的影响,该部分甲烷气无阻流量较低,这从气井排采曲线也可以证实。由图5还可以看出,本井煤层气流体产出有明显的脉动性,同样会加剧压裂裂缝内部颗粒的堵塞程度。

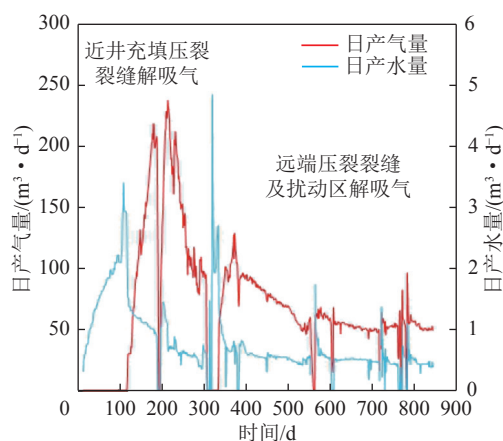


图5 窑街矿区煤层气直井排采曲线
Fig.5 Drainage curves of coalbed methane well in Yaojie Mining Area

4 结 论

1) 研究区煤层气直井破裂压力不明显,表明固井水泥环厚度适中,因而压裂过程中水泥环破裂难度低,这主要与钻井过程中采用护壁型浆液有关。煤层气钻完井的重点应是维护煤层段孔壁稳定性而非防伤害。

2) 本井压裂裂缝延伸压力高,与地下煤储层原生裂缝煤粉源及少量构造煤粉源集合体发育形成的煤粉堵塞有关。裂缝延展阶段压裂曲线出现多个顿挫表明压裂液撑开多条次级裂缝,储层压裂裂缝形式复杂。

3) 本井压裂裂缝走向为 NE50°与储层天然大裂隙系统一致,有效扩展压裂裂缝半长 20 m 以内,实际充填压裂裂缝半长不足 5 m,压裂液注入液量少、压裂液滤失诱导支撑剂脱砂形成楔体以及煤粉聚集造成砂堵等是窑街矿区煤层气井压裂裂缝较短的主要因素。

4) 有效支撑压裂裂缝过短对本井产能影响严重,建议研究区后期煤储层压裂中大幅提升压裂液注入泵量,适当增大排量延缓液体滤失防止脱砂楔体形成。针对本区煤层埋深大裂缝闭合应力高实际,实现大规模、大范围有效加砂是储层压裂改造的关键。考虑储层干燥,压裂液滤失严重的实际,有条件可开展 CO₂ 前置压裂试验。

参考文献(References):

- [1] 袁士义, 宋新民, 冉启全. 裂缝性油藏开发技术[M]. 北京: 石油工业出版社, 2004.
- YUAN Shiyi, SONG Xinmin, RAN Qiquan. Development technology of fractured reservoirs [M]. Beijing: Petroleum Industry Press, 2004.
- [2] 孙海涛, 舒龙勇, 姜在炳, 等. 煤矿区煤层气与煤炭协调开发机制模式及发展趋势[J]. 煤炭科学技术, 2022, 50(12): 1-13.
- SUN Haitao, SHU Longyong, JIANG Zaibing, *et al.* Progress and trend of key technologies of CBM development and utilization in China coal mine areas[J]. Coal Science and Technology, 2022, 50(12): 1-13.
- [3] 雷群, 管保山, 才博, 等. 储集层改造技术进展及发展方向[J]. 石油勘探与开发, 2019, 46(3): 580-587.
- LEI Qun, GUAN Baoshan, CAI Bo, *et al.* Technological progress and prospects of reservoir stimulation[J]. Petroleum Exploration and Development, 2019, 46(3): 580-587.
- [4] 王生维, 陈立超. 煤储层水力压裂裂缝延伸机制[M]. 武汉: 中国地质大学出版社, 2017.
- WANG Shengwei, CHEN Lichao. Fracture propagation mechanism of hydraulic fracturing in coal reservoirs [M]. Wuhan: China University of Geosciences Press, 2017.
- [5] 程远方, 吴百烈, 袁征, 等. 煤层气井水力压裂“T”型缝延伸模型的建立及应用[J]. 煤炭学报, 2013, 38(8): 1430-1434.
- CHENG Yuanfang, WU Bailie, YUAN Zheng, *et al.* Establishment and application of “T” shape fracture propagation model in hydraulic fracturing of methane well[J]. Journal of China Coal Society, 2013, 38(8): 1430-1434.
- [6] 傅雪海, 许行行, 王强, 等. 煤层气异常成分的界定、分布及其成因研究进展[J]. 煤炭科学技术, 2023, 51(1): 343-352.
- FU Xuehai, XU Hanghang, WANG Qiang, *et al.* Review of research on definition, distribution and causes of abnormal coalbed methane composition[J]. Coal Science and Technology, 2023, 51(1): 343-352.
- [7] 黄浩勇, 韩忠英, 王光磊, 等. 压裂中顶底板对缝高控制作用的数值模拟研究[J]. 科学技术与工程, 2015, 15(6): 181-184, 209.
- HUANG Haoyong, HAN Zhongying, WANG Guanglei, *et al.* Numerical simulation on the effect of crack height of roof and floor rock in fracturing[J]. Science Technology and Engineering, 2015, 15(6): 181-184, 209.
- [8] 高向东, 孙昊, 王延斌, 等. 临兴地区深部煤储层地应力场及其对压裂缝形态的控制[J]. 煤炭科学技术, 2022, 50(8): 140-150.
- GAO Xiangdong, SUN Hao, WANG Yanbin, *et al.* In-situ stress field of deep coal reservoir in Linxing Area and its control on fracturing crack[J]. Coal Science and Technology, 2022, 50(8): 140-150.
- [9] 程远方, 吴百烈, 李娜, 等. 煤层压裂裂缝延伸及影响因素分析[J]. 特种油气藏, 2013, 20(2): 126-129, 157.
- CHENG Yuanfang, WU Bailie, LI Na, *et al.* Analysis of hydraulic fracture extension and influencing factors in coal seam[J]. Special Oil and Gas Reservoirs, 2013, 20(2): 126-129, 157.
- [10] 蒋廷学, 卞晓冰. 深层油气藏多级迂回暂堵压裂技术研究[J]. 深圳大学学报(理工版), 2021, 38(6): 590-597.
- JIANG Tingxue, BIAN Xiaobing. Multistage circuitous-temporary plugging fracturing technology for deep oil-gas reservoirs[J]. Journal of Shenzhen University(Science and Engineering), 2021, 38(6): 590-597.
- [11] 郑新权, 王欣, 张福祥, 等. 国内石英砂支撑剂评价及砂源本地化研究进展与前景展望[J]. 中国石油勘探, 2021, 26(1): 131-137.
- ZHENG Xinquan, WANG Xin, ZHANG Fuxiang, *et al.* Domestic sand proppant evaluation and research progress of sand source localization and its prospects[J]. China Petroleum Exploration, 2021, 26(1): 131-137.
- [12] 吕明锟, 曲占庆, 郭天魁, 等. 通道压裂支撑剂团块形成过程及影响因素[J]. 西安石油大学学报(自然科学版), 2021, 36(2): 63-69.
- LYU Mingkun, QU Zhanqing, GUO Tiankui, *et al.* Formation process and influence factors of proppant agglomerates in channel fracturing[J]. Journal of Xi'an Shiyou University(Natural Science Edition), 2021, 36(2): 63-69.
- [13] 陈立超, 王生维, 何俊铎, 等. 煤粉源集合体对水力压裂效果的影响[J]. 中国矿业大学学报, 2015, 44(3): 526-531.
- CHEN Lichao, WANG Shengwei, HE Junhua, *et al.* Study of the impact of coal fines source collection on hydraulic fracturing effect[J]. Journal of China University of Mining and Technology, 2015, 44(3): 526-531.
- [14] 李瑞, 王生维, 陈立超, 等. 煤层气排采中煤粉产出量动态变化及影响因素[J]. 煤炭科学技术, 2014, 42(6): 122-125.
- LI Rui, WANG Shengwei, CHEN Lichao, *et al.* Coal powder output dynamic variation and influence factors during coalbed methane drainage[J]. Coal Science and Technology, 2014, 42(6): 122-125.
- [15] ZHANG Lufeng, ZHOU Fujian, ZHANG Shicheng, *et al.* Evaluation of permeability damage caused by drilling and fracturing fluids in tight low permeability sandstone reservoirs[J]. Journal of Petroleum Science and Engineering, 2019, 175: 1122-1135.
- [16] 陈立超, 王生维, 张典坤. 煤层气近井煤缝壁面滤饼的结构与硬度特征及工程意义[J]. 天然气工业, 2020, 40(6): 100-106.
- CHEN Lichao, WANG Shengwei, ZHANG Diankun. Structure and hardness characteristics of the filter cake-coal wall interface near a CBM well and its engineering significance[J]. Natural Gas Industry, 2020, 40(6): 100-106.
- [17] 王飞, 张士诚. 致密气储层清水压裂液侵入带动态分布及其对产能的影响规律[J]. 中国海上油气, 2015, 27(5): 93-97.
- WANG Fei, ZHANG Shicheng. Dynamic distribution of invaded zones by slick-water and its impacts on production performance in tight gas reservoirs[J]. China Offshore Oil & Gas, 2015, 27(5): 93-97.
- [18] 郭天魁, 战永平, 朱丹, 等. 多功能大尺寸真三轴储层改造实验装置的开发与应用[J]. 实验技术与管理, 2021, 38(2): 108-115.
- GUO Tiankui, ZHAN Yongping, ZHU Dan, *et al.* Development and application of multi-functional and large-scale true triaxial reservoir reconstruction experimental device[J]. Experimental

- Technology and Management, 2021, 38(2): 108–115.
- [19] 蒋廷学, 卞晓冰, 侯磊, 等. 粗糙裂缝内支撑剂运移铺置行为试验[J]. 中国石油大学学报(自然科学版), 2021, 45(6): 95–101.
- JIANG Tingxue, BIAN Xiaobing, HOU Lei, *et al.* Experiment on proppant migration and placement behavior in rough fractures[J]. Journal of China University of Petroleum(Natural Science Edition), 2021, 45(6): 95–101.
- [20] 吴峙颖, 路保平, 胡亚斐, 等. 压裂多级裂缝内动态输砂物理模拟实验研究[J]. 石油钻探技术, 2020, 48(4): 106–110.
- WU Zhiying, LU Baoping, HU Yafei, *et al.* Experimental study on the physical simulation of dynamic sand transport in multi-stage fractures[J]. Petroleum Drilling Techniques, 2020, 48(4): 106–110.
- [21] 邹雨时, 石善志, 张士诚, 等. 致密砾岩加砂压裂与裂缝导流能力实验: 以准噶尔盆地玛湖致密砾岩为例[J]. 石油勘探与开发, 2021, 48(6): 1202–1209.
- ZOU Yushi, SHI Shanzhi, ZHANG Shicheng, *et al.* Experimental modeling of sanding fracturing and conductivity of propped fractures in conglomerate: a case study of tight conglomerate of Mahu sag in Junggar Basin, NW China[J]. Petroleum Exploration and Development, 2021, 48(6): 1202–1209.
- [22] 张士诚, 李四海, 邹雨时, 等. 页岩油水平井多段压裂裂缝高度扩展试验[J]. 中国石油大学学报(自然科学版), 2021, 45(1): 77–86.
- ZHANG Shicheng, LI Sihai, ZOU Yushi, *et al.* Experimental study on fracture height propagation during multi-stage fracturing of horizontal wells in shale oil reservoirs[J]. Journal of China University of Petroleum(Natural Science Edition), 2021, 45(1): 77–86.
- [23] 陈立超, 王生维, 张典坤, 等. 固井水泥浆侵入对煤储层压裂裂缝延展的影响[J]. 天然气工业, 2019, 39(8): 74–81.
- CHEN Lichao, WANG Shengwei, ZHANG Diankun, *et al.* Impact of cement slurry invasion on the propagation of hydraulic fractures in coal reservoirs[J]. Natural Gas Industry, 2019, 39(8): 74–81.
- [24] 陈立超, 王生维, 何俊铎, 等. 煤层气井近井压裂裂缝充填特征与堵塞机制[J]. 中国石油大学学报(自然科学版), 2017, 41(6): 117–122.
- CHEN Lichao, WANG Shengwei, HE Junhua, *et al.* Filling characteristics and plugging mechanisms of hydraulic fractures near CBM vertical wells[J]. Journal of China University of Petroleum(Natural Science Edition), 2017, 41(6): 117–122.
- [25] 陈立超, 王生维. 煤层断裂力学性质对储层压裂改造的影响[J]. 天然气地球科学, 2020, 31(1): 122–131.
- CHEN Lichao, WANG Shengwei. Fracture properties of high-rank coal and its constraint on hydraulic fracturing stimulation of coal reservoir[J]. Natural Gas Geoscience, 2020, 31(1): 122–131.
- [26] 陈立超, 王生维. 煤岩弹性力学性质与煤层破裂压力关系[J]. 天然气地球科学, 2019, 30(4): 503–511.
- CHEN Lichao, WANG Shengwei. Relationship between elastic mechanical properties and equivalent fracture pressure of coal reservoir near wellbore[J]. Natural Gas Geoscience, 2019, 30(4): 503–511.
- [27] 陈立超, 王生维, 何俊铎, 等. 煤层气藏非均质性及其对气井产能的控制[J]. 中国矿业大学学报, 2016, 45(1): 105–110.
- CHEN Lichao, WANG Shengwei, HE Junhua, *et al.* CBM reservoir heterogeneity and its controlling effect on gas well productivity[J]. Journal of China University of Mining and Technology, 2016, 45(1): 105–110.
- [28] 陈立超, 王生维, 张典坤, 等. 基于渗水试验的煤岩压裂液静态滤失特征分析[J]. 中国煤炭, 2020, 46(6): 90–97.
- CHEN Lichao, WANG Shengwei, ZHANG Diankun, *et al.* Analysis of static leak-off characteristics of fracturing fluid through coal rocks based on water seepage tests[J]. China Coal, 2020, 46(6): 90–97.