

超稠油油藏油水倒置成因及含油面积圈定探析

——以埕东油田埕911-平1块馆下段为例

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摘要:埕东油田埕911-平1块馆下段超稠油油藏高部位产水或高含水、低部位产油的“高水低油”生产特征明显,存在油水倒置现象,但其成因尚不明确。基于测井、录井、实验及开发动态等资料,深入分析了该油藏油水倒置的特征及成因。该区块地面原油密度为 $1.0076\sim 1.0248\text{ g/cm}^3$,大于地层水密度,在重力的作用下,原油克服浮力和毛管压力向构造低部位发生二次运移,是造成油水倒置的主要原因,利用录井和测井等资料进一步证实了该观点。油水倒置油藏的油水分布规律与常规油藏差别较大,用于圈定常规油藏含油面积的一些原则与方法对油水倒置油藏不适用。以探明含油面积圈定为例,针对超稠油油藏复杂的油水分布关系,提出了其含油面积圈定的原则与应注意的问题。

关键词:超稠油油藏 油水倒置 成因 录井特征 测井响应 含油面积

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Genesis of oil/water inversion and delineation of oil-bearing area in super-heavy oil reservoirs: A case study of the lower member of Guantao Formation in Block Cheng911-Ping1, Chengdong Oilfield

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Abstract: The reservoir that produces water at high structure and oil at low structure maybe present phenomenon of oil/water inversion in super-heavy oil reservoir in the lower member of Guantao Formation of Block Cheng911-Ping1, Chengdong Oilfield. Its reason is not clear yet. Based on the well logging, experiment and dynamic data of development, the characteristics of oil/water inversion and its genesis were analyzed comprehensively. The ground crude oil density ranges from 1.0076 to 1.0248 g/cm^3 , which is higher than the formation water density in this area. The heavy oil migrates to the lower structure against the buoyancy and capillary force under the action of gravity, and it is the main reason of the oil/water inversion. This viewpoint was confirmed by mud logging and well logging data. The oil/water distribution law in reservoirs featured by oil/water inversion is very different from that in the conventional oil reservoir. Some principles and methods for delineation of the oil-bearing area in the conventional oil reservoir are not applicable to reservoirs featured by oil/water inversion. Taking proven oil-bearing area as an example, the corresponding delineated principle and the key points in delineation of oil-bearing area in the super-heavy oil reservoirs were proposed aiming at the complex oil-water distribution.

Key words: super-heavy oil reservoirs; oil/water inversion; genesis; mud logging characteristics; well logging response characteristics; oil-bearing area

一般情况下,由于重力分异作用,油总是聚集在圈闭的高部位,油水界面通常保持水平且具有上

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油下水的分布特点,但随着勘探开发的深入,在低渗透和超稠油等油藏的开发中,发现与经典油水分布相反的上水下油的现象越来越多^[1-8]。针对实际区域的具体情况,研究者对油藏油水倒置成因提出了各自的观点,如油藏中断层封闭性的历史性差异、构造高部位成岩遮挡或上倾尖灭砂体构造高部位岩性、物性较差可形成油水倒置^[2-3];有学者指出在一定的地质条件下,深盆油藏中可形成油水倒置现象^[4-5];泥质隔夹层发育的低充度油藏易造成生产过程中出现油水倒置的假象^[6];高密度稠油相对于边底水的二次运移,可形成油水倒置、油水并置等油水分布模式^[7],但支撑这一观点的实际依据论述较少。油水倒置油藏的油水分布规律与常规油藏差别较大,用于圈定常规油藏含油面积的一些原则与方法^[9]对油水倒置油藏不适用,如何圈定油水倒置油藏含油面积在前人的研究中也很少提及。

以埕东油田埕911-平1块为例,利用测井、录井、实验及开发动态等资料,分析该区块馆下段10砂组3小层($N_{1g_2}10^3$)油藏油水倒置的生产、流体、测录井等特征;以此为基础,对油水倒置的主要成因进行了深入分析,并利用实际资料对其进行了证实。另一方面,针对其特殊的油水分布形式,提出该类油藏探明含油面积圈定的原则及应注意的问题。准确圈定稠油油水倒置油藏含油面积对提高储量计算精度及开发方案的准确制定可打下坚实基础。

1 地质特征

埕东油田南区构造上位于济阳坳陷沾化凹陷北部埕东断裂带下降盘,北临埕子口凸起,南邻渤南洼陷,是渤南洼陷油气向埕东凸起运移的必经之路,油气资源非常丰富。埕911-平1块位于埕东油田南区,埕东断裂带的西部。 $N_{1g_2}10^3$ 油藏埋深为1580~1650 m,含油高度约为60 m,为受埕南断层及其次生断层控制的构造油藏;构造整体上呈东北高、西北低;高部位地层较陡,倾角为 $5^\circ\sim 6^\circ$;低部位地层变缓,倾角为 $4^\circ\sim 5^\circ$ ^[10](图1)。馆下段沉积时期由于可容纳空间较低,形成了一套以辫状河道为主的地层,连续叠置厚度可达100 m,主要发育辫状河三角洲—浅水湖泊沉积体系。由该区块2口探井的录井及岩心分析资料可知,储层岩性为含砾砂岩,储层层内均质性较好,孔隙度平均为26%,渗透率平均为700 mD,为高孔高渗透储层^[10]。

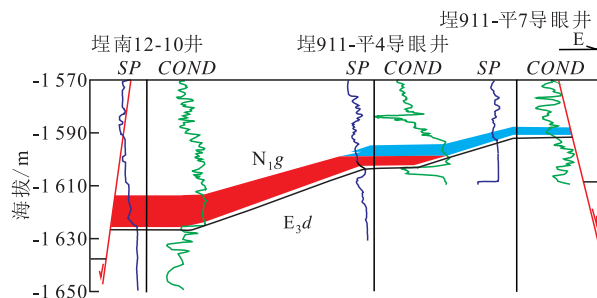


图1 埕911-平1块过埕南12-10井—埕911-平7号导眼井近东西向油藏剖面

Fig.1 Nearly E-W oil reservoir profile of Block Cheng911-Ping1 across Well Chengnan12-10-Cheng911-Ping7 in Chengdong Oilfield

2 油水倒置特征及成因

2.1 油水倒置特征

2.1.1 生产及流体特征

埕911-平1块 $N_{1g_2}10^3$ 油藏已完钻2口直井,7口水平井,水平井采用蒸汽吞吐方式开采。位于构造高部位的埕911-平7号导眼井出水。靠近构造高部位的埕911-平7井初期日产油量为5.6 t/d,含水率上升快,后因高含水关井,累积产油量为117 t,累积产水量为6899 t;其他位于构造低部位且分布较为均匀的6口水平井,均获工业油流,初期日产油量为4.1~27.4 t/d,平均日产油量为11.5 t/d,含水率较为稳定。由此可见,研究区构造高部位产水或高含水、构造低部位产油的高水低油生产特征明显,即呈现明显的油水倒置及油水并置现象。

地面原油性质分析结果表明,研究区块地面原油密度为1.0076~1.0248 g/cm³(20℃),平均为1.0165 g/cm³,原油粘度为172343 mPa·s(50℃),为超稠油油藏。根据地层水分析资料,研究区块地层水总矿化度为9939 mg/L,水型为NaHCO₃型。由于研究区块缺少原油及地层水高压物性分析资料,为了解地层条件下原油及地层水性,依据油藏相关参数,利用Vasquez-Beggs^[11]与Schowalter诺谟图^[12]方法,求得地层原油密度与地层水密度分别为1.0035~1.0206和0.9868 g/cm³,地层原油密度明显大于地层水密度,这是形成该油藏油水倒置的关键因素。

2.1.2 测井曲线响应特征

为了进一步证实油水倒置现象的存在,对该区块内油井的测井曲线响应特征(图2)进行了分析。例如,埕斜911井20号层的微电位电阻率大于微梯度电阻率,整体呈现较大正幅度差;自然电位曲线呈现明显负异常;自然伽马曲线整体呈现低值,表

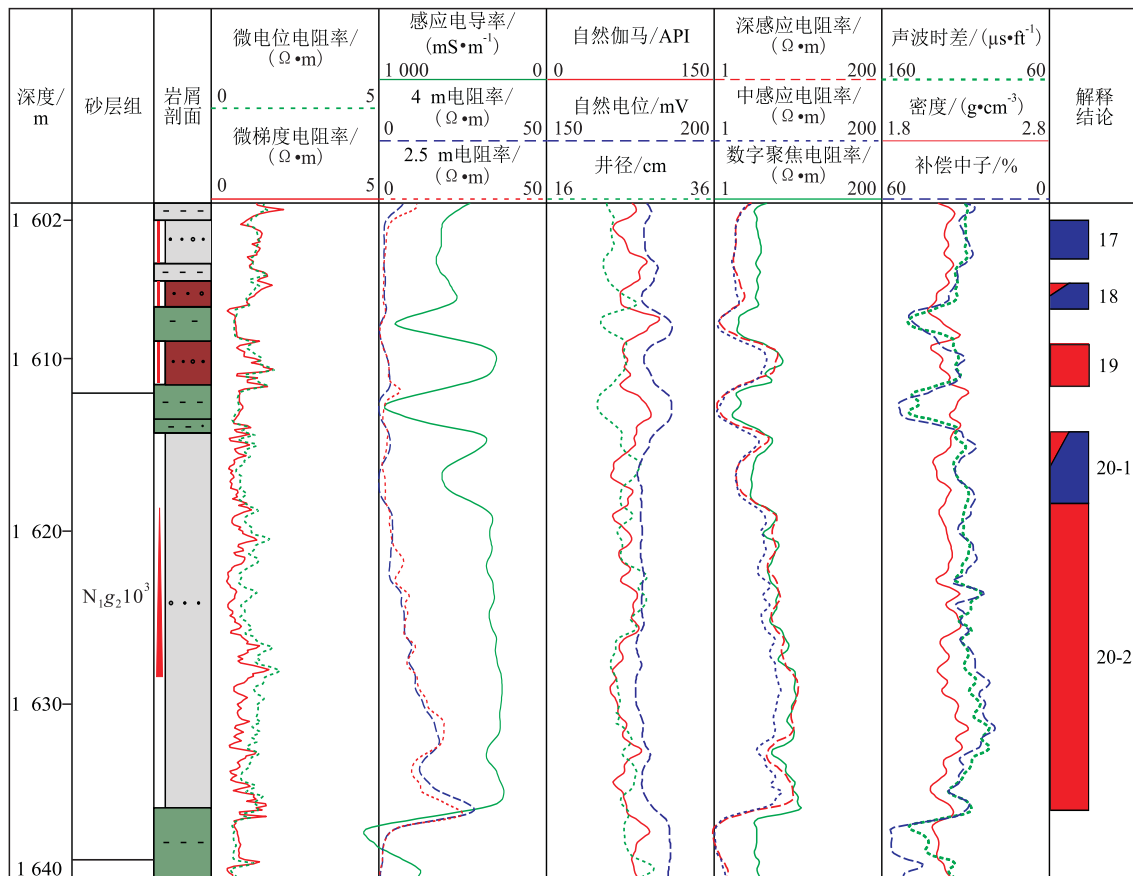


图2 埕斜911井测井解释结果

Fig.2 Well logging interpretation of Well Chengxie 911

明该套储层渗透性和均质性较好,基本不发育夹层,岩屑录井剖面也显示该套储层岩性较为稳定;但是感应电阻率测井曲线却呈现显著的上低下高特征:深度为1 616.0~1 618.5 m井段的感应电阻率为 $2.0 \Omega \cdot m$,深度为1 618.5~1 636.0 m井段的感应电阻率为 $10 \Omega \cdot m$ 。结合该区块的油水层识别标准可知:20-1号层为水层,20-2号层为油层,上水下油特征明显。同时,在20-1号层顶部1 614.2~1 616.0 m井段为含水水层,说明超稠油油藏在存在油水倒置现象的同时,由于重力分异不彻底或原油性质原因还存在油水并置现象,油水分布非常复杂。

2.2 油水倒置成因

通过录井、岩心及邻井对比发现,该区块储层层内均质性与物性均较好,故成岩遮挡为油水倒置成因不成立;另外,该油藏构造较简单,且构造低部位整体含油,分析结果表明地层水性质较为稳定,断层封闭历史性差异为油水倒置成因也不成立。

综合分析结果表明,该区块油水倒置现象的形成主要与流体性质有关。初始运移至圈闭成藏的原油应为密度小于地层水的原油,后期因生物降解、水洗、无机氧化和挥发物的损失等一种或几种作用而发生降解和稠化,逐渐形成密度大于地层水

的超稠油^[7,13-16];超稠油在重力作用下,克服浮力和毛管压力向构造低部位发生二次运移,从而改变原始的上油下水的油水分布格局,形成上水下油的油水倒置现象。

对该区块录井和测井等资料的综合分析发现了超稠油二次运移一些证据。埕斜911井 $N_{1g_2}10^3$ 油藏构造高部位20-1号水层的岩石含油性与其下部的20-2号油层的岩石含油性相当,均为油斑(图2);且在馆下段10砂组2小层($N_{1g_2}10^2$)也发现了岩石含油性为含油的17号水层及18号含油水层;这些水层或含油水层的岩石具有良好的含油性,其原因为构造高部位超稠油二次运移后留下较多的残余油,是油气二次运移的踪迹;同时,在20-1号水层顶部的含油水层,可能由于原油被稠化程度不同及其他原因导致重力分异不彻底或仍在重力分异中。

3 含油面积圈定原则及应用

3.1 含油面积圈定原则

以石油天然气储量计算规范^[9]中地质储量计算参数确定原则为基础,结合超稠油油藏油水倒置机理及其特殊油水分布形式,以探明储量含油面积为

例,提出其含油面积圈定原则:①为了便于操作,一般在油层或砂层底面构造图上圈定油水倒置油藏含油面积。②对于未查明流体界面的油水倒置油藏,应以测试证实的构造最高部位油气层(或井段)顶界,或以其有效厚度累积值或集中段高度向高部位外推来圈定含油面积。③当存在储层岩性(或物性)遮挡时,由于油水倒置油藏对应的原油密度和粘度较大,动用难度大,故应根据开发实际,用某有效厚度线或渗透储层厚度线圈定含油面积。④其他含油面积圈定原则可参经常规油水分布油藏含油面积圈定原则。

3.2 含油面积圈定中应注意的问题

由于超稠油油水倒置油藏复杂的油水分布及成因机制,高部位可能存在油水并置或正常油水分布的情况^[7,17],故在圈定含油面积时,应充分利用试油、试采、测井、测试等资料准确落实油藏油水分布特征,以免造成含油面积漏圈,低估油藏潜力。

3.3 含油面积圈定

埕911-平1块 $N_{1g_2}10^3$ 油藏地震、钻井、测井、录井、测试资料齐全,地质研究与认识程度较高,达到储量计算规范对探明储量勘探开发程度的要求。依据超稠油油水倒置油藏探明储量含油面积圈定原则并结合储量计算规范,对该油藏含油面积进行圈定。该油藏油水分布主要受构造控制,为构造油藏。以实钻井测井资料为依据,在进行地震合成记录层位标定的基础上,开展地震相层位追踪解释,并用实钻井深度进行深度校正后形成构造图,构造落实可靠,构造图比例尺均为1:10 000。

该区块 $N_{1g_2}10^3$ 油藏含油面积在其油层底面构造图上圈定(图3)。该油藏北、南、西界均为断层遮

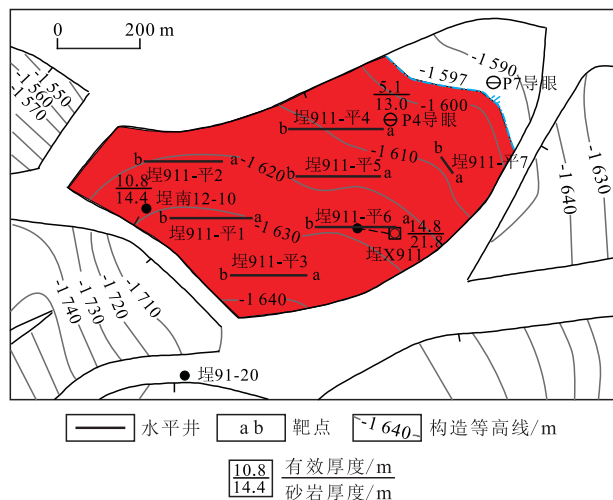


图3 埕911-平1块 $N_{1g_2}10^3$ 油藏含油面积

Fig.3 Map of oil-bearing area of Block Cheng911-Ping1 in $N_{1g_2}10^3$ oil reservoir

挡;构造高部位的埕911-平7导眼井出水,次高部位埕911-平4导眼井在 $N_{1g_2}10^3$ 底部见明显油层(13号层),油层厚度为7 m(图4),故含油面积东界为:以埕911-平4导眼井井点向构造高部位外推7 m划定为含油边界线(相当于-1 597 m构造线),据此,圈定含油面积为0.41 km²(图3)。

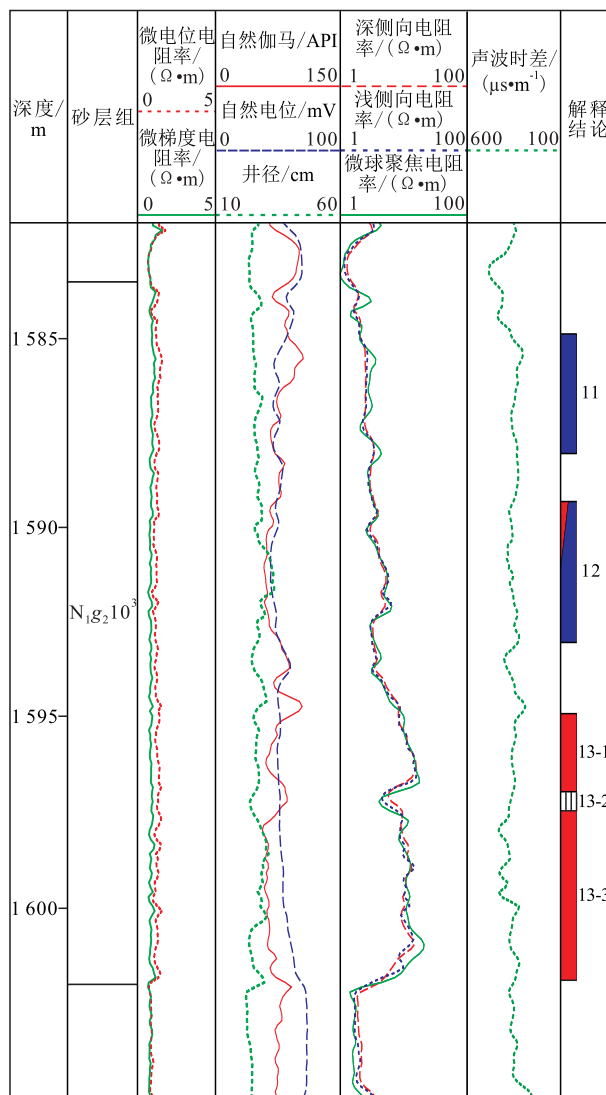


图4 埕斜911-平4导眼井测井解释结果

Fig.4 Well logging interpretation of pilot hole Chengxie911-Ping4

4 结论

通过对开发动态、录井、测井等资料分析,埕东油田埕911-平1块 $N_{1g_2}10^3$ 超稠油油藏存在油水倒置现象。该区块原油密度大于地层水密度,其在重力的作用下,克服浮力和毛管压力向构造低部位发生二次运移,是造成这一现象的主要原因,这种运移的踪迹一般会在录井、测井响应中也有所体现。

油水倒置油藏的油水分布规律与常规油藏差

别较大,用于圈定常规油藏含油面积的一些原则与方法对油水倒置油藏不适用;提出该类油藏含油面积的圈定原则及注意事项,对同类油藏的含油面积的圈定具有重要的借鉴意义,对提高其储量计算精度及开发方案的准确制定打下坚实基础。

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