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电潜泵提液采油配套技术的应用

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摘要:为了鲁克沁油田提液增产,针对其超深稠油油藏的特点和深层稠油采油技术现状进行分析,采用试验电潜泵提液井筒举升工艺,增大了油井生产压差,同时在研究和实践中,初步形成了空心抽油杆井筒掺稀油降粘、防砂电潜泵提液采油工艺配套技术。现场实施表明,单井产量大幅度提高,油田含水上升速度得到控制。该技术为超深稠油油田中高含水期实现经济高效开发奠定了技术基础,具有广阔的推广应用前景。

关键词:超深稠油;中高含水;电潜泵;生产压差;配套技术;鲁克沁油田
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前 言

鲁克沁油田自 1997 年投入单井试采,通过不断试验,确定了采用空心抽油杆泵上掺稀油降粘解决稠油井筒举升问题,并在 2000 年首先应用到油田东部埋深较浅(2 400 m)、储层物性较好的鲁 2 块的开发中,取得了较好效果,单井平均日产油达 11 t/d。该油田在近 10 a 的开发建设中,井筒举升工艺先后经历了越泵电加热井筒举升技术、空心杆泵下掺稀油降粘举升技术、空心杆泵上掺稀油降粘等举升技术,最终确定了空心杆泵上掺稀油降粘工艺作为主体的举升工艺,并逐步完善。随着油田进入中高含水开发阶段,提液增产成为油田稳油控水的主要技术对策,部分抽油泵的提液范围已不能满足油井提液采油的需求。目前鲁克沁深层稠油开采主要包括以下难点:一是稠油粘度高,地层流动能力差,单井供液能力相对较低,井筒举升过程需要配套降粘措施;二是储层胶结疏松,出砂制约了机械采油,需要采取防砂采油;三是油藏埋深大,热采工艺无法实施,冷采工艺相对复杂。为此,自 2006 年起,试验了一系列换大泵提液技术,初期起到了一定效果,但存在空心杆频繁断杆的风险。为了实现稠油的经济高效开发,2007 年集成了国内电泵高端技术开采稠油的技术方案,运用大流道、高承载泵、多级保护器、变频控制等技术解决深层稠油出砂井提液的难题。

1 稠油油藏特征分析

从采油工程角度研究,鲁克沁稠油油藏具有以下主要特点:油层埋藏深,地温梯度小。鲁克沁油藏埋深约为 2 700 ~ 3 400 m;地层压力系数为 1.02 ~ 1.05 MPa/100 m,属正常压力系统;地层温度为 76 ~ 97℃,地温梯度约为 2.5℃/100m,为异常低温系统。储层物性相对较好,为中高孔中高渗储层,但物性差异较大。油田自东向西随着埋深的增加,物性逐渐变差。储层平均孔隙度为 18.9% ~ 30.4%,平均渗透率为 $119 \times 10^{-3} \sim 694 \times 10^{-3}$ μm^2。储层胶结程度较弱,以泥质胶结为主,为强水敏储层,储层处于出砂边缘。

稠油性质研究表明,鲁克沁稠油原油具有以下特点:鲁克沁原油属普通 B 级稠油,具有高密度、高粘度、低凝固点的特点。50℃ 地面脱气脱水原油粘度为 5 972 ~ 25 570 mPa · s,地层条件下原油粘度为 526 ~ 154 mPa · s,原油密度为 0.95 ~ 0.97 g/cm^3,凝固点 19 ~ 35 ℃。原油粘温特性及流动性研究表明,鲁克沁原油粘度受温度影响较大,当温度低于 60 ℃ 后,随温度降低,原油粘度迅速增加;地层温度下,鲁克沁原油流动类型属

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屈服假塑性流体;当温度高于 90 ℃时,流动形态逐渐向牛顿流动过渡。

鲁克沁油藏特点与原油性质造成稠油在地层和井筒中均不易流动,这给稠油人工举升带来了很大难度,主要表现在:①稠油与油管及抽油杆之间摩阻大,造成抽油杆上行载荷过大,下行易发生杆漂浮现象;②油藏储层胶结输送,处于出砂边缘,加之稠油的携带能力较强,易造成地层出砂;③由于油井较深,举升管柱结构相对复杂,对各类工具及管、杆要求较高。

2　深层稠油采油技术现状分析

鲁克沁油田利用国内外最成熟的空心抽油泵越泵电加热井筒降粘有杆泵举升工艺技术[1],通过电加热降低原油粘度,减少井筒流动阻力。通过采用过泵电加热井筒举升技术,有杆泵采油泵挂深度为 1 700 m,平均日产稠油 7 m^3/d,首次将稠油成功举升到地面。其缺点是耗电量大,采油成本高,且油井深,电缆、抽油杆易断,稠油采出后不能直接集输,还要进一步采取降粘措施。

为了寻找一种经济、高效、低能耗的降粘举升方式,采用空心杆作为通道实现掺稀油降粘的举升工艺[2],首先在玉东 1 井开展试验,空心杆泵下掺稀油,有效地解决了井筒降粘问题,使原油能顺利入泵,井筒原油粘度也大幅度降低,进而减小了稠油与抽油杆、油管之间的摩阻,抽油机工况得到改善。但系统举升能力大于地层供液能力,只能采用间歇生产方式,油井不能稳定生产;掺入稀油要通过抽油泵,影响泵的排量,不利于大排量生产;泵挂深度受到限制,生产压差不能提高,油井产能得不到充分发挥。为此,在分析稠油在井筒中流动规律的基础上,对空心杆掺稀油降粘举升工艺进行改进,即减小泵径,加深泵挂,改泵下掺入为泵上掺入稀油,试验取得了突破。1998 年,尝试泵上掺稀井筒举升工艺,大幅度提高了单井产量,其中单井提高日产量达到了 17 t/d。泵上掺稀油举升试验的成功,大大提高了采油工作效率,使开井时率达到 90%以上。运用空心抽油杆泵上掺稀油降粘举升工艺,实现了 2 000 m 以上深度掺稀油降粘,降粘效果好,有利于放大生产压差,提高单井产量。

随着鲁克沁稠油泵上掺稀采油工艺的完善,基本上解决了稠油连续生产等问题,优化泵上掺稀点一般在 2 200 m 以上,初期投入开发区块油藏埋深 2 400 m,泵挂一般在 2 300 m 以上,断杆现象不严重。随着开发向西区转移,油藏深度加深,储层物性变差,单井产量较低,部分井投产后因供液不足间开生产。为解决单井连续生产问题,在采取压裂增产的同时,优化管杆结构,最大泵挂加深至 3 000 m,增产效果明显,由于放大了生产压差,大部分油井都能实现连续生产,取得了良好的效果。但加深泵挂后抽杆柱承受载荷增加,杆柱疲劳周期缩短,断杆频繁,尤其是在掺稀油量不足的情况下,易造成断杆现象,检泵周期缩短。

泵上掺稀油解决了深层稠油连续生产等问题,但受稠油流动能力差、粘度大、地层出砂及空心杆的断脱等问题困扰,开发成本较高,尤其是近年来稠油注水开发后,油井产液量大幅度增加,含水不断上升,单井产量下降,采油速度低。数值模拟研究认为,稠油油藏开发初期含水上升较快,进入中含水期后(60%)含水上升速度减缓(图 1)。稠油主要采油时间集中在中高含水期,因此中高含水期配套采油技术是提高油田开发效益的关键。

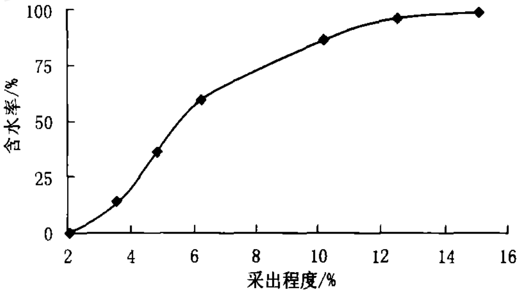

图 1　鲁克沁稠油含水率与采出程度关系曲线

3　油井提液增产技术应用及效果分析

3.1　大泵浅抽提液在深层稠油开发中的应用

鲁克沁油田开发方案设计初期采用衰竭式开发,2 a 后转水驱开发。自 2003 年起,首先在开发较早的鲁 2 块开展了注水矿场试验[3],半年后油井逐渐见效,液面及地层压力逐步回升,但随含水上升加快,需要采取措施提高油井液量及产量,降低含水上升速度。2006 年 5 月先后在鲁 2 块 4 口井采用大泵(ø57 mm)浅抽技术,实施提液措施,单井日产液达到31.5 m^3/d 以上,平均日增油大于 2.74 t/d(表 1)。大泵浅抽初期泵挂较深(1 800 m 以下),由于掺稀油量不足,出现频繁断杆现象,部分

油井继续采取小泵(ø44 或 ø38 mm)采油。针对频繁断杆现象继续优化采油配套工艺,采取2台泵掺稀油,提高泵挂深度至1 700 m左右,继续开展大泵提液试验,断杆现象大幅度减少。根据大泵提液前期试验成果,2007年在全区开展了高含水井提液增产措施[4],取得了明显效果。

表1 大泵浅抽提液效果统计

井号	施工前			施工后			对比		
	日产液/(m^3/d)	日产油/(t/d)	含水率/%	日产液/(m^3/d)	日产油/(t/d)	含水率/%	日增液/(m^3/d)	日增油/(t/d)	含水率变化/%
鲁3-5	20.40	5.58	70	32.4	7.53	75	12.00	1.95	5
鲁1-4	21.68	8.47	58	37.3	11.45	67	15.62	2.98	9
鲁2-6	17.52	7.33	55	35.6	9.93	70	18.08	2.60	15
鲁2-7	21.60	6.84	65	31.5	10.25	65	9.90	3.41	0

通过大泵浅抽试验及推广,有效地解决了部分油井液面上升、含水上升快及产油量下降等问题,尤其是部分区块油井边底水充足,利用小泵开采,排液能力明显不足,同时注水开发区块地层能量恢复后油井液面上升、含水上升、产油量下降,需要采用换大泵的方法提高单井产量。

3.2 电潜泵采油工艺在深层稠油提液中的应用

图2为鲁克沁油田吐玉克区块稠油无因次采液、采油指数变化曲线。从图2可以看出,稠油无因次采油指数随着含水增加而降低,无因次采液指数含水初期基本稳定,在中高含水期则明显增加。在中高含水期可通过提液来增加油井产量[5]。鲁克沁油藏稠油流动性较差,综合考虑各种因素,选取地层原油粘度小于550 mPa·s,油层温度小于120℃,地层供液能力较强,日产液大于40 m^3/d的油井应用电泵提液增产。

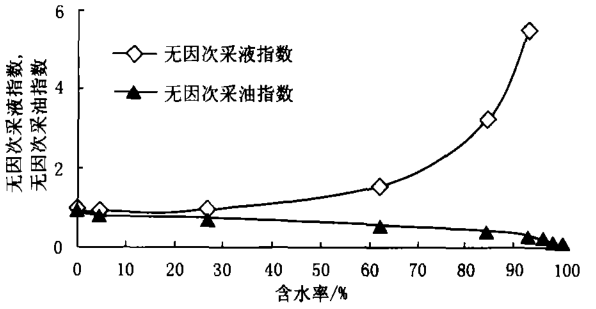

图2 鲁克沁稠油无因次采液、采油指数变化曲线

选取液面及供液能力较强的鲁3-5井进行试验。该井实施电潜泵提液前,日产液30 m^3/d,日产油5.9 t/d,含水79%,动液面为474 m,泵的沉没度达到1 326 m,生产压差仅为3.2 MPa,油井含水上升加快。为增大油井生产压差,实现控水、增产,2007年5月选取鲁3-5井进行电潜泵提液采油试验。设计电潜泵提液的技术参数:①套管外径为177.8 mm,单井产液量为40~80 m^3/d,电泵机组选138系列,排量采用变频技术控制;②根据储层性质和设计要求,电泵机组选用防砂电泵;③根据油层温度、稠油性质及电泵机组工作特点,电泵机组选用耐温大于120℃的机组;④根据鲁3-5井油层顶深为2 323 m,泵挂深度选2 200 m;⑤根据泵挂深度为2 200 m、油管外径为88.9 mm及井下原油的粘度,查管损图,管损为5%(管损为110 m)[6];⑥根据油压2 MPa的要求和保证电泵机组正常工作最低沉没度200 m的要求,考虑泵挂深度2 200 m、管损110 m及降粘效果不稳定的情况,电泵机组的扬程应不低于2 310 m;⑦根据上述计算:鲁3-5井设计产稠油40~80 m^3/d,掺稀油20~30 m^3/d,扬程不低于2 310 m。该井采用电泵生产后,日产液58.6 m^3/d,日产油10.9 t/d,含水80%,动液面为1 125 m,泵的沉没度为675 m,生产压差增大到9.2 MPa,与提液前相比增加液量28.6 m^3,增油5 t/d左右(表2),且含水较为稳定(图3)。根据取样情况,出砂相对稳定,试验初见成效。随后又开展了3口井电潜泵提液矿场试验,电潜泵提液采油的配套工艺是采用空心杆掺稀油降粘工艺(套管掺稀油工艺备用);电泵与机采井口结合,保持双翼井口;防砂工艺采用油管悬挂防砂管;泵挂位置约为2 200~2 300 m。实施后,3口井初期增油效果明显,初期平均单井日增油5.6 t/d,目前平均日增油为3.7 t/d。

表2 电泵提液效果统计

井号	施工日期	施工前			施工后			对比		
		日产液/(m^3/d)	日产油/(t/d)	含水率/%	日产液/(m^3/d)	日产油/(t/d)	含水率/%	日增液/(m^3/d)	日增油/(t/d)	含水率/%
鲁3-5	200705	30.0	5.9	79	58.6	10.9	80	28.6	5.1	1
鲁2-7	200706	21.0	6.9	65	31.0	10.0	65	10.0	3.1	0
玉东203	200708	38.0	5.4	85	95.5	8.9	90	57.5	3.5	5
鲁8-1	200709	18.6	4.2	77	64.0	15.0	75	45.4	10.8	-2

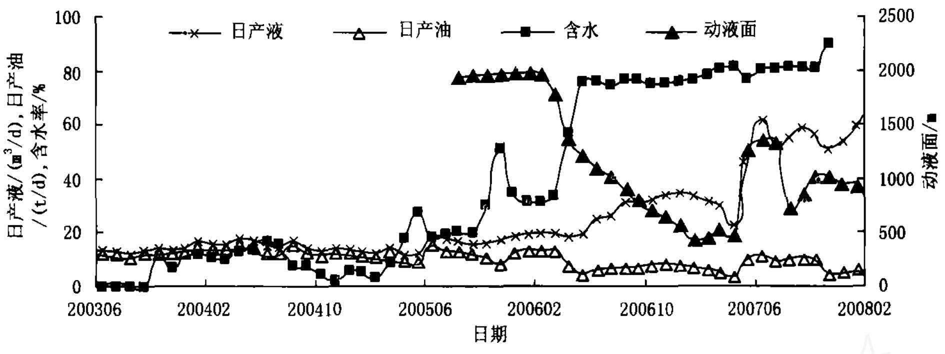

图3 鲁3-5井采油曲线

与抽油机采油相比,电泵提液日产液50 m^3/d以上,有效地解决了深层稠油开采过程中故障频繁的问题:①提液增产的同时,解决了空心杆断脱频繁问题,空心杆结蜡程度减轻,掺稀系统故障率降低,经济效益显著;②电泵抽汲力相对平稳,对地层激动小,出砂问题得到一定缓解;③运用变频技术解决了供液差、排量控制困难的问题,高温机组适应鲁克沁地温需要,空心杆泵上掺稀工艺有效地解决了井筒降粘问题。

4 结论及认识

(1)应用提液采油技术,大幅度增加了单井产能,提高了采油速度,油田含水上升速度也得到了一定的控制,对减缓油田的递减率起到了重要作用。

(2)大泵提液成本较低,适应范围广泛,效益较好,但提液量受到一定制约。电潜泵技术性能要求较高,成本大幅度增加,但增产幅度较大,生产管理方便。

(3)高含水井提液后出砂严重,治理难度大,制约了提液增产技术的推广。

(4)下一步将开展防砂技术对策研究及试验,优化油井提液采油技术,解决油井提液与出砂矛盾。

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Abstract: Polymer flooding is an effective method to improve oil recovery. Indoor and field data show that polymer flooding can further improve oil recovery by about 10% based on water flooding. Some blocks in Jiangsu oilfield are characterized by low reserves, serious heterogeneity, high formation temperature and high salinity of injected water. It is necessary to evaluate the adaptability of polymer flooding in these blocks. The effect of polymer flooding in blocks including Zhen 15 is evaluated through modern physical simulation. The result shows that polymer loading, concentration, slug composition, injection time and reservoir heterogeneity may affect polymer flooding performance. For blocks with high average permeability and serious heterogeneity, the stimulation effect of slug composition of "profile control + polymer flooding" or "polymer flooding + profile control + polymer flooding" is superior to simple polymer flooding at similar cost of chemicals.

Key words: special reservoir; polymer flooding; profile control; slug composition; physical simulation

Chemical screening and evaluation for foam - drive liquid and gas production in Well JZ20 - 2 - 3

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Abstract: The performance of the chemical for foam - drive liquid and gas production is critical to successful implementation of the process. It is important to develop a complete system for screening, evaluating and optimizing the chemicals for foam - drive liquid and gas production from Well JZ20 - 2 - 3. In this research, five chemicals are screened and evaluated in respects of compatibility, foamability, and temperature and oil resistance. As a result, Agent XXJ is selected for Well JZ20 - 2 - 3. The agent is powerful in foaming, stabilizing foams and carrying liquid under conditions of high temperature, high salinity and high oil content. The mass concentration is usually 0.3% ~ 0.5%. The result is helpful to chemical screening and evaluation in foam - drive liquid and gas production process.

Key word: offshore gas field; gas well; foam; foam - drive liquid and gas production; chemical; Well JZ20 - 2 - 3

Study on the damage of heavy oil reservoir rock by steam injection

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Abstract: In the process of heavy oil recovery by steam injection, the grain particles of reservoir rock tend to fall off, move and block up due to the alternation of heat and cold, thus affecting normal oil production. A new experimental method is designed to evaluate the damage to reservoir rock during steam injection, to determine the damage degree and the main factors causing the damage, and to define the injection rate and the bean limit causing reservoir contamination. Fractal study is conducted for the change of pore structure during steam flooding, and the reservoir damage is evaluated quantitatively.

Key words: steam injection; heavy oil reservoir; rock damage; fractal feature; Qiqihar Oilfield

Supporting techniques of lifting with electric submersible pump

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Abstract: This paper analyzes the characteristics of ultra deep heavy oil reservoirs and the present status of deep heavy oil recovery technology for Lukeqin Oilfield. Experimental electric submersible pump is applied for wellbore lifting to increase producing pressure drop. In the study and practice process, the supporting techniques have been developed, including viscosity reduction by blending light oil with hollow rod and lifting with sand control ESP. Field implementation shows that single well production has greatly improved and the tendency of water cut increasing is controlled. This technology is helpful to efficient development of ultra deep heavy oil reservoirs in medium - high water cut period and will have a promising future.

Key words: ultra deep heavy oil; medium - high water cut; electric submersible pump; producing pressure

drop; supporting technique; Lukeqin Oilfield

Analysis of sand production mechanism and influence factors of steam stimulation in shallow heavy oil reservoirs

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Abstract: This paper addresses sand production mechanism and influence factors in shallow heavy oil thermal recovery process. It is thought that the relocation of weakly consolidated silt particle, the effects of high temperature steam and pressure are among the main reasons for sand production; the diagenetic grade, depositional microfacies, crude oil quality and well location are the main geologic factors affecting sand production; and the injection – production parameters, perforation type and steam channeling are the engineering factors. This study presents basis for integrated medication of sand production problem in shallow heavy oil thermal recovery process.
Key words: heavy oil reservoir; steam stimulation; sand production mechanism; steam channeling; sand control

Integrated technology of injection – plugging – profile control in Haiwaihe Oilfield

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Abstract: The technology of integrated injection – plugging – profile control has been proposed for Haiwaihe Oilfield in accordance with the problems occurred during water flooding. With well group as flooding unit, the techniques of fracturing and block removing, stratified waterflooding, in – depth profile control, and chemical water plugging for oil and water wells are integrated and optimized to improve recovery factor. Field application has seen good result, daily oil production has sustained over 1 000 t/d for 3 years, thus realizing efficient development of the oilfield.
Key words: heavy oil; fracturing and block removing; stratified waterflooding; in – depth profile control; chemical water plugging; integration; Haiwaihe Oilfield

Adaptiveness analysis of sand dump producing technology

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Abstract: In order to remove near wellbore blocking in fine siltstone reservoirs, Shengli Oilfield analyzes solid – carrying sensitivity and the technical adaptiveness of sand dump producing technology, generalizes the result of field tests in various sanding reservoirs of Binnan, Chunliang and Gudong Oil Production Plants, studies the strategic limits of necessary sand control or no sand control, analyzes the allocation accuracy of sand retention when applying sand dump producing technology, and identifies applicable conditions. The results of field application indicate that this technology can restore original reservoir permeability and oil well productivity.
Key words: sand dump producing; solid – carrying analysis; adaptability; sanding reservoir; Shengli Oilfield

Optimization and application of fracturing process in Jishan sand body of Shanghe Oilfield

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Abstract: Jishan sand body of Shanghe Oilfield responded poorly to fracturing stimulation during earlier testing process. This paper studies earlier fracturing operation data and laboratory test data of fracturing proppant. The problems are fluid loss control with ceramic powder during fracturing has brought serious damage to the reservoirs, and improper fracturing system has resulted in high pump pressure during fracturing operation thus limited gravel input scale. Fluid loss control by adding liquid nitrogen for the full course is adopted, and a delayed crosslinker has been developed to reduce borehole friction and pump pressure. The improved fracturing process had been applied in Well Tian 303 and Tianxie 302, and oil production had been substantially improved.
Key words: Jishan sand body; fracturing; fluid loss control; delayed cross linking