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砂岩油藏高含水期封堵大孔道工艺技术研究及应用

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摘要 从文、马油田的地质特点、开发历程出发,分析了大孔道的形成因素。针对其渗透率高、孔喉半径大、油水井连通性好的特点,进行了室内堵剂种类、浓度的筛选及堵剂性能的评价,对原有调剖工艺进行了改进,并进行了现场试验,形成并逐步完善了封堵大孔道工艺技术。1997 年以来运用该工艺封堵大孔道井 25 口,累计增油 7303t,降水 29 922m³,投入产出比达 1∶3.7,有效地解决了封堵大孔道的难题。该工艺改善了层间矛盾,提高了水驱采收率,具有较大的推广应用价值。

主题词 砂岩 油藏 高含水期 高渗透储集层 封堵 工艺 研究

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中原油田采油三厂的文明寨、马寨油田均为砂岩油藏,地层非均质性严重,胶结物以泥质为主。经长期强化注水开发,地层孔隙结构变化很大,形成次生大孔道,降低了水驱波及系数,影响到水驱采收率的提高。采出程度仅为 25.37%,而综合含水高达 87.8%。1987 年开始调剖以来,不同程度地改善了吸水剖面不均的状况,但随着注水开发期的延长,堵剂施工效果变差、有效期缩短,甚至存在大剂量、连续注入时,调剖剂从对应油井抽出的情况。针对大孔道封堵的难题,1997 年通过室内研究和现场试验对原有调剖工艺进行改进,形成并逐步完善了封堵大孔道工艺技术。利用高强度堵水剂,采用间歇式、选择性注入的方式封堵注水井大孔道。

一、大孔道形成机理

1995 年以来,对应油井抽出调剖剂的现象共发现 7 口井,分析有这种现象的 9 个井组情况,发现了形成大孔道的几个因素:

1. 中高渗砂岩油藏,泥质为主的胶结方式易造成颗粒运移,从而形成大孔道 对应油井曾抽出调剖剂的文、马油田均属于中、高渗砂岩油藏,泥质含量为 8%～16%,长期注水冲刷使岩石颗粒易运移,地层孔隙结构发生很大变化。

2. 油层非均质性影响 文、马油田属于多层系、多油藏、多压力系统和多流体性质的复合型断块油气田,地层三大矛盾较为突出。渗透率变异系数为 0.4～0.85,渗透率级差 15～120。随着注水开发时间的延长,注入水易沿着高渗层突进,使这些矛盾更加恶化。目前油层渗透率是原始渗透率的 5～10 倍,形成次生大孔道。从文明寨、马寨的吸水剖面上看,强吸水层厚度小,占全井射开油层厚度的 16.3%,而相对吸水却在 60%以上。非均质性恶化,形成了大孔道。

3. 不合理的开发方式造成的影响 文、马油田自投入开发以来,一直采用强注强采、高速

开发的方式,采油速度达2%～3%,文明寨油田曾采用水力活塞泵采油,致使油田过早水淹,综合含水高达87%以上,油田已进入高含水中、后期。由于出砂、井况等因素的影响,油水井实际分层注采率一直不高,平均达35%。这些开发方式均可促使大孔道的形成。

二、封堵大孔道堵剂研究

大孔道井具有渗透率高、孔喉半径大等特点。要求堵剂具有相当的强度、适宜的固化时间、价格经济,为减少对中、低渗透层的污染还要求堵剂有合适的粒径。从对应油井抽出调剖剂的粒径在0.01～0.05mm之间,说明这些井的喉道直径至少在0.03～0.15mm。结合示踪剂试验结果,认定封堵大孔道井采用调剖剂粒径在0.05～0.15mm。

通过室内试验筛选、评价,确定了以高强度堵剂为主体的多段塞体系封堵大孔道。

1. 钙土—水泥高固化体系配方的筛选及评价

(1)钙土、水泥的比例对体系性能的影响。确定固含量,改变钙土、水泥比例,测定模拟油层温度下(75℃)固化体系性能(见表1)。

由表1可看出,随着钙土含量逐渐增大,体系初凝时间逐渐延长。

(2)固含量对体系性能的影响。确定钙土、水泥的比例,改变固含量,测定模拟油层温度下,固化体系性能(见表2)。

表1 钙土、水泥比例对固化体系性能影响试验

水泥:钙土	初凝时间 (min)	终凝时间 (h)	抗压强度 (MPa)
7:3	85	2.3	2.8
6:4	110	5.0	7.5
5:5	105	5.5	5.0
3:7	110	6.0	12.5
0:10	130	5.0	15.5

表2 固含量对体系性能的影响试验

体系固含量 (%)	初凝时间 (min)	终凝时间 (h)	抗压强度 (MPa)
20	725	—	—
30	500	36	0.6
40	230	18	1.3
50	100	5.5	1.7
60	75	2.0	3.8

由表2可看出,随着固含量的增大,初凝、终凝时间缩短,但强度增大。

(3)缓凝剂含量对体系性能的影响。确定钙土、水泥的比例及固含量,改变缓凝剂的含量,测定模拟油层温度下,固化体系性能(见表3)。

由表3可看出,随着缓凝剂含量的增大,初凝、终凝时间延长,但强度降低。

在上述单因素试验的基础上,进行了正交试验,筛选出了最佳配方:钙土22%～25%、水泥12%～15%、缓凝剂0.1%。

(4)钙土—水泥高固化体系。测定模拟油层温度下,钙土—水泥高固化体系初凝、终凝时间、抗压强度及对人造岩心的封堵效率(见表4)。

由表4可看出,其性能指标达到了现场的要求。

2. BL—D堵剂性能评价

(1)堵水剂浓度的筛选。测定不同浓度下堵剂的封堵率,发现当堵剂浓度为20%时,凝固时间适宜,封堵率较高。确定堵剂浓度为20%。

(2)温度对堵剂性能的影响。测定不同温度下堵剂的凝固时间及封堵率,发现BL—D堵剂的适宜温度在40～120℃之间。而文、马油田的地层温度为70～100℃,处于BL—D堵剂的耐

表3 缓凝剂含量对体系性能的影响试验

缓凝剂含量(%)	初凝时间(min)	终凝时间(h)	抗压强度(MPa)
0	85	2.3	1.4
0.05	100	4.7	1.6
0.1	120	5.5	1.7
0.2	175	6.5	1.8
0.3	185	6.7	2.0
0.4	200	7.5	2.8

表4 钙土—水泥高固化体系性能试验

钙土—水泥高固化体系	22%—25%钙土+12—15%水泥
初凝时间(min)	520
终凝时间(h)	12.5
抗压强度(MPa)	2.7
堵前渗透率($\times10^{-3}\mu m^2$)	2746
堵后渗透率($\times10^{-3}\mu m^2$)	54.9
封堵效率(%)	98

温性能范围之内。

(3)堵剂的封堵效率及耐冲刷性能。将20%BL—D堵剂注入人造岩心,模拟油层温度下凝固48h,进行水驱。随着注水量的增加,封堵率下降缓慢,说明堵剂在地层中具有较强的耐冲刷性能(见表5)。

表5 BL—D堵剂耐冲刷性能试验

注水量(PV)	0	1	10	30	50	100
堵前渗透率($\times10^{-3}\mu m^2$)	2858	2858	2858	2858	2858	2858
堵后渗透率($\times10^{-3}\mu m^2$)	42.8	48.5	54.3	68.6	80.0	91.4
封堵效率(%)	98.5	98.3	98.1	97.6	97.2	96.8

三、封堵大孔道及其配套工艺技术的实施

1. 堵大孔道工艺机理　注水井提前停注,降低井底压力,采用选择性注入工艺将高强度堵剂尽量挤入高渗透层,在孔隙、喉道处沉积形成桥塞,经过间歇式施工逐级减小喉道半径并加强堵水屏障,从而提高封堵效果并延长封堵有效期。

2. 选井原则

(1)从吸水剖面上看,存在从投产就一直吸水、且连续2年相对吸水在25%以上的层。

(2)示踪剂检测发现存在大孔道。

(3)曾有过对应油井抽出调剖剂现象。

(4)实测PI值小于1。

(5)注采井连通较好,动态反映明显,油井含水90%以上。

(6)对应油井有高产历史。

符合上述条件的注水井,均可采用封堵大孔道技术。

3. 现场施工工艺技术

(1)选择性注入工艺。为使堵剂更多地进入强吸水层,减小对中、低渗层的污染,采用低压、低排量,逐渐提高压力的方法注入堵剂。排量一般控制在10～15m^3/h。

(2)间歇式注入工艺。为提高封堵效果,先将一定量的堵剂挤入地层,关井候凝,让堵剂固化。使喉道半径减小并使堵剂在孔隙处充分沉积凝固。再次注入的堵剂会将原堵剂形成的封堵屏障薄弱处挤毁,重新形成新的封堵屏障。经过多次挤注,最终形成较高强度的封堵屏障。

(3)洗井工艺。为防止残留的堵剂对注水层段产生污染,先挤入一定量的石灰泥或土,注入堵剂后顶替清水,并及时控压反洗井。

4. 封堵大孔道配套技术

(1)油藏描述技术。通过测试油水井剖面,利用数值模拟等方法研究剩余油分布规律,为堵水调剖工作提供资料。

(2)注示踪剂技术。采用注水井井间示踪剂技术,落实油水井连通关系及大孔道。对示踪剂产出曲线进行数值分析处理,得出大孔道的厚度、渗透率及孔喉半径等参数。

四、现场实施及效果评价

1. 封堵大孔道整体效果分析 中原采油三厂1997年采用封堵大孔道工艺实施25口井,26井次,其中下分注管柱施工1井次,不动管柱施工25井次(原分注管柱分调6井次、统调7井次、原光油管统调12井次)。水井因调剖作业10井次,其中加深洗井4井次,换封5井次。共挤入以BL—D、钙土—水泥高固化体系为主体的高强度堵水剂7433m³,平均单井挤入286m³。共处理地层633.4m、272层,平均处理半径3.9m。单井平均启泵压力5.7MPa,最高施工压力14.3MPa,停泵压力12.7MPa。对应油井曾抽出调剖剂的5口注水井,封堵大孔道后,累计增油3530t,降水10 652m³。水井平均有效期149d。

(1)水井有效率达92.3%。封堵有效24井次,最长有效期186d。最短85d。截至1998年1月底,平均有效期149d,12口井继续有效。启动压力提高0.6～14MPa,平均提高3.16MPa,平均PI值提高2.6MPa,平均注水压力上升2.50MPa,平均注水量稳定在66.7m³/d。

(2)油井有效率达80%。对应59口油井中有效井44口。截至1998年1月底,21口井继续有效。单井平均日产油由5.3t/d上升到5.9t/d,含水由89.5%下降到88.7%,平均液面下降13.6m,累计增油7303t,降水29 972m³,平均单井增油132t,降水544m³。

2. 经济效益分析 1997年封堵大孔道25口井,26井次,水井作业10井次。投入材料费、施工费、配制费和作业费共205.1136万元,平均单井7.8889万元。25个井组,对应55口油井,累计增油7303t,累计降水29 972m³。增油价值730.3万元,降水价值29.972万元,总创价值760.272万元,投入产出比1∶3.7。

五、结论及认识

1. 中原油田采油三厂文、卫、马油田进入高含水期后,大孔道井不断出现。封堵大孔道改善层间矛盾,提高水驱动用储量和采收率,十分必要。

2. 从封堵大孔道应用效果及堵剂性能指标上看,目前的封堵大孔道技术是有效的,经济上是可行的。

3. 封堵大孔道后水井注入能力下降,高强度堵剂处理半径相对较小,一般在2～3m,若提高配注,会增加对堵层的冲刷,缩短封堵有效期,加强封堵后水井管理十分必要。

4. 对原分注管柱施工,控压洗井要及时,清水顶替量要足。

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Abstract Lignosulfonate (PS) is a new surfactant flooding appearing in recently. It extract and purify from waste liquid of paper made and have stabilization physical chemistry performance. It can reduce the viscosity of oil and the interfacial tension of oil—water. Flooding PS can enhanced oil recover. From laboratory testing, field testing and numerical simulation analysis, the oil displacement mechanism has been researched. The field experience and economic effect have obtained.

Subject heading lignosulfonate oil displacement agent displacement test laboratory testing field testing effect evaluation

EXPERIMENTAL RESEARCH ON BREAKING POLYMER GEL

by Zheng Yancheng, Zhao Xiutai, Zhao Weipeng

Abstract On the basis of investigation of breaking polymer gel with oxidizers such as H_2O_2, $K_2S_2O_8$, BH, CH, this paper uses the orthogonal test method to probe the optimized composition of gel breaking agent. Test results show that the composition of the optimized agent at 60℃ is as follows: 0.35% H_2O_2, 0.4% $K_2S_2O_8$, 0.5%BH and 0.6%CH. The compounded oxidizer can effectively break the polyarylamide gel crosslinked by hexamethylene teramine with the viscosity of 2.3×10^5 mPa·s. When the pH is 2, the percentage of gel breaking can be up to 99%, and the viscosity of the post—breaking residual fluid is low. Core test results show that the water shutoff percentage is above 98% before breaking gel, and the recovered value of permeability after breaking gel can be more than 98%.

Subject heading gel gel breaker oxidizing agent degradation core test research

DEVELOP AND APPLICATION OF POLYMER GEL PLUG REMOVER

by Du Qingzhen, Nan Qingyi, Wang Zhiqiang, Chen Fuyou, Jing Ronghua, Yu Jiliang

Abstract CHY plug removing agent is developed to solve the problem of damage to the non—target zone caused by polyarylamide chromium gel (or gel). The agent is formed by combining inorganic material (possesses no damage to the oil reservoir) with a certain amount of catalysts. It can make the viscous polymer gel to dissolve rapidly into solution with the viscosity approaching that of water. The plug removal technique has the following characteristics: strong capability of removing plug, simple and convenient construction process and so on. Field application in Mengulin Oil Field shows that the effective percentage is 85.7%, the average incremental Oil of individual well is 660 t.

Subject heading Mengulin Oil Field plug removal polyarylamide plugging application

PRACTICE AND COGNITION OF OIL RESERVOIR PROTECTION TECHNIQUE IN LONGBEI AREA

by Zhang Zhichao, Li Shuqun, Dong Jingwu, Pan Hengmin

Abstract For the development of low permeability oilfield, this paper, based on the lab test and field practice in Longbei area, Daqing Oilfield, presents the view of protecting oil reservoir during the whole stage of development. Through the reservoir sensitivity evaluation test, the inflow fluid screening test, the field test, the economic benefit analysis and so on, the oil reservoir protection technique of low permeability oilfield is practiced and studied. The view presented in the paper will be helpful for developing the similar oilfield.

Subject heading Daqing Oil Field low permeability pools water sensitivity formation damage prevention application

RESEARCH AND APPLICATION OF TECHNIQUE FOR PLUGGING LARGE PORE PATH IN SANDSTONE RESERVOIR AT HIGH WATER CUT STAGE

by Zhang Xuefeng, Zhu Minghua, Yang Shungui, Yang Jian'guo

Abstract Based on the investigation to the geologic features and development history of Wen and Ma Oil Fields, this paper analyzes the origin of large pore path. In view of the high permeability, large throat radius, good connection among injectors and producers and so on, this paper conducts screening to the sort and

concentration of water shutoff agent and evaluation on its property. The original profile control process is improved. Field test is carried out. Technique for plugging large pore path is formed and completed gradually. Since 1997, the technique has been used to plug large pore path in 25 wells. The accumulated incremental oil production is 7303 t, the accumulated water production decreased by 29 922 m^3, and the input—output ratio is 1:3.7. The problem of plugging large pore path has been solved.

Subject heading sandstone oil reservoir high water cut stage high permeability reservoir plugging technology research

HARM OF FREE HANGING OF TUBING AND ANCHORING TECHNOLOGY

by Wang Gang, Ni Guanghui, Wang Jianli, Ge Shaomin

Abstract Based on the analysis of pump detection data of a field for near 10 years, and on the investigation to the factors influencing the pump efficiency, this paper dissertates harm like elastic deformation, tubing leakage, fatigue failure, wear and so on resulted from free hanging of tubing, presents a simple and convenient tubing anchoring process and construction technology. Field application shows that good effect has been achieved. Oil producing workers should pay more attention to the technology.

Subject heading tubing suspension tubing anchor anchorage technology

RESEARCH ON OIL PRODUCTION WITH SELF—EXCITED WAVE

by Lei Guanglun, Zhang Jianguo, Fu Jitong, Zhang Huagong

Abstract When the pumping well runs normally, self—excited pressure wave can be generated at bottom hole by means of wave generator. This paper introduces the generating mechanism, theoretical calculation and lab test of self—excited wave. The frequency of the wave is small, the amplitude value of it is large, and it can produce successive surge action on the oil reservoir. Lab test shows that the amplitude value of the self—excited pressure wave is mainly related to the pump submergence, the pump setting depth, as well as the stroke and pumping speed of well pumping unit. Field application of it in 3 wells shows that the technology can improve the percolation condition of shallow stripper wells, and increase the output of oil wells.

Subject heading production well bottom hole pressure surge enhanced oil recovery technology research

RESEARCH AND APPLICATION OF PLUG REMOVAL WITH HYDRAULIC IMPACT METHOD

by Liu Hongjun

Abstract On the basis of analysis of several physical oil producing technique applied in Daqing Oilfield, this paper presents the technique of plug removal with hydraulic impact. This paper introduces the structure of hydraulic impact generator, the structure of the tubing string, the working principle and process; this paper also analyzes the surge pressure produced by the hydraulic impact generator, and presents the theoretical calculation formula used to estimate the surge pressure. Calculation results show that the generator can produce 20～40 MPa surge pressure which will not damage the casing and the tubing. Finally, this paper presents the field test results and several beneficial conclusions.

Subject heading hydraulic jetting impact pressure plug removal research

FIELD APPLICATION OF SYSTEM OF TEMPERATURE MEASURING WITH OPTIC FIBER AND PRESSURE MEASURING WITH CAPILLARY TUBING

by Xu Dong, Liu Fang, Yang Naiqun

Abstract The technique of temperature measuring with optic fiber and pressure measuring with capillary tubing is a comparatively advanced technique in field test domain at present. The technique can realize the on—line detection and location of information such as temperature and pressure at any complex environment. This paper expatiates on the principle, composition and installation method of the system of tempera-