

油田压裂用暂堵剂技术

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摘 要:随着高含水、低渗透油田开发的不断深入,对油层压裂技术的要求越来越高,施工难度越来越大。暂堵剂技术是在一定条件下向目的层中泵入暂堵剂,利用层内渗透率的差异,而改变原有液体的流入方向,达到产生新裂缝的目的。在需要增产的地层中使用暂堵剂技术可以降低压裂施工难度、减少分段工具的使用数量,还能够提高单位井段的改造效率,即在段内压出两条以上的裂缝,或使裂缝转向。该技术在提高单井产量的同时,有效降低压裂成本。

关键词:暂堵剂;压裂;增产措施;酸压

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0 前言

我国低渗透油田石油地质储量丰富,其资源量约占全国石油总资源量的30%,在已探明储量中,低渗透油藏的比例约占全国储量的2/3以上,开发潜力巨大^[1]。大多数低渗透储层在压裂改造后虽增产幅度较大,但产量仍然不高。近些年,各大油田均在压裂施工中采用段内多裂缝技术或是裂缝转向技术,加大对低渗透储层的改造力度,将储层产量最大化。此项技术中起决定性作用的一类试剂即为暂堵剂。

暂堵剂,又称转向剂(diverting agent),是一种广泛应用于油田生产中的处理剂,现已成熟应用于现场施工作业中,包括:钻井^[2]、增产措施、固井^[3]、修井^[4]、洗井^[5]等。早在1936年就有学者提出了将水溶/油溶性的CaCl₂盐作为暂堵剂应用于油田作业中^[6]的方法,解决了早期压裂中传统分段转向技术设备量大、生产费用高、作业效率低等缺陷^[7]。近年研究的适用于油田压裂的暂堵剂为:惰性有机树脂、固体有机酸(如美国使用的安息香酸)、遇酸溶胀的聚合物、惰性固体(硅粉、碳酸钙粉、岩盐、油溶性树脂、封堵小球)等^[8],其中使用最广泛的为聚合物和封堵小球。聚合物型暂堵剂得益于其牢固的化学交联网络结构,封堵效果良好。它分为地下交联型和地面一次交联型。地下交联型暂堵剂存在的问题有:小剂量达不到

所需压力,大剂量对地层造成新的伤害;虽可形成滤饼,但地下反应不稳定,达不到所需强度。地面一次交联的暂堵剂存在的问题有:黏度大、强度大,在地下很难形成滤饼,封堵效果不好,压裂液滤失量大。封堵小球的优点是封堵强度高,不易变形;但缺点是易脱落,如果嵌在炮眼处形成堵塞,还会因其不能自溶而难以解除。

1 新型暂堵剂类型

1.1 压裂酸化

压裂酸化是提高低渗透油田勘探开发水平的重要措施之一。目前,压裂酸化目的层日益复杂,因此对所需的暂堵剂要求越来越高。在压裂酸化施工中所使用的暂堵剂不但需要具有一定的抗压强度、韧性,还需具有一定的酸溶性和水溶性,使其最终可以返排出地层。

臧海宏^[9]等制备了一种水溶性压裂酸化暂堵剂,它由骨胶、磺化沥青、胍胶组成,在含水50%以上的油水混合溶液中溶解度大于90%,抗压能力达到22 MPa。此类暂堵剂不仅拥有优良的水溶性,对储层不造成污染,还对同层封堵也有着其它封堵技术不可替代的作用。相比较原有的发明专利,如CN1053631A,这种水溶性压裂酸化暂堵剂的封堵强度更高,且溶解速度更快,既可用于油井又可用于水井的压裂酸化施工。

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王稳桃^[10]等制备了一种酸化压裂暂堵剂,着重应用于油田深层长井段、跨度大的储层压裂与酸化作业。这种暂堵剂由树脂、地蜡、碳酸钙等组成,封堵率在96%以上,酸溶率98%以上,暂堵强度达50 MPa,可有效满足碳酸盐储层长井段压裂酸化暂堵分流,提高长井段的压裂酸化成功率。

张军^[11]等通过对原有专利产品的研究及改进,制备了一种油气储层裂缝暂堵剂。此类暂堵剂由超细碳酸钙、植物纤维、氧化沥青组成,对裂缝的暂堵率达99%以上,压裂和酸化反排率达80%以上,暂堵范围宽,且在暂堵结束后,用射孔和酸化可将其解除,弥补了原有暂堵剂存在的压裂酸化后不能自动解堵的缺陷。

李国锋^[12]等对ZD-10暂堵剂进行了研究,这类暂堵剂主要应用于深层、高温、长井段气层。它是在沸腾式制粒干燥机中,通过雾化喷涂作用,制备一种类似于微胶囊类型的微细固体颗粒,其外包裹材料是石油树脂和地蜡的复合物,而内部材料是酸溶性组分碳酸钙和水溶性组分无机盐组成的固体颗粒。该暂堵剂已经成功应用于普光气田,封堵率达到99%。此项研究同样还解决了暂堵剂不能解堵的缺陷,在地层温度下依靠返排液中的残酸对暂堵剂进行溶解的效率能达到99%。

1.2 自清洁

能够产生物理阻碍的暂堵剂一般分为可降解类和不可降解类,许多商业上广泛使用的球型封堵小球或是实心固体材料或是拥有一层坚固的固体外壳。射孔球密封材料为组成封堵小球的不可降解材料,它在使用中还存在一定的条件限制,只适用于有套管、且有射孔井眼的措施井,对于裸眼完井或用割缝衬管完井后的措施井并不适用^[3]。可降解材料封堵小球在压裂施工后,可从井口回收或在处理间隙排出井口,减少了施工难度、时间和资金。

Fulton^[3]等合成了一种可降解的暂堵剂。其暂堵材料是一种混合物,原料有脂肪醇、酯、蛋白质等。在配制暂堵剂时,还需加入增塑剂和脱水混合物来保证整体材料的性能。此类暂堵剂不仅具有良好的封堵性能,还具有一定的降滤失性能。

Surjaatmadja^[6]合成了一种包含可降解材料的暂堵剂,并研究了压裂液体系以及使用方法。此类压裂液的配方为:可降解的暂堵剂、基液、增稠剂、其他添加剂等。

Fu Diankui^[13]合成了一种自清洁的压井液,此压井液体系的使用方法和工作原理同样适用于压裂施工,在未来的工作中可将其引入到压裂施工中。采用VES压裂液体系作为基液、聚乳酸颗粒作为主要暂堵材料,在需要封堵的地层形成段塞来降低封堵层的渗透率。当施工结束后,聚乳酸颗粒降解释放酸液使VES破胶排出地层,此

过程较为环保。

清洁类暂堵剂对其自清理能力要求较高,Reddy^[14]等对于聚乳酸类暂堵剂自清理能力进行了深入的研究。聚乳酸暂堵剂在使用时需要添加降解加速剂缩短降解时间,常用的加速剂分为四类:乙二胺类、乙醇胺类、多胺类和聚胺类。乙醇胺类加速剂对其降解速率能起到一定的作用,研究表明,无结晶态的聚乳酸降解速度是最快的。

Allison^[15]等研制了一种可以对储层进行重复增产的可生物降解暂堵剂,将其与常用的暂堵剂进行对比,通过对所选类型暂堵剂的温度稳定性、对环境的影响、自清理性等性能的考察,得出可生物降解暂堵剂性能优良。本暂堵剂所用的携带液体系为具有一定黏度的滑溜水压裂液体系,能封堵几何结构不清的地层,降解时间12 h以上,当粒径减小10%~15%时,可完全排出。对比前面所述的自清洁暂堵剂,可生物降解暂堵剂对地层的伤害最小,不用添加任何助剂,在施工结束后的一段时间内,暂堵剂就可生物降解并最终顺利排出地层,这是未来对暂堵剂研究的一个重要方向。

1.3 交联破胶

该类暂堵剂分为颗粒型和胶塞型,通过交联的方法,得到高黏度的流体后,进行烘干、剪切、造粒形成可用于暂堵的颗粒。也可通过交联的方法形成高黏性流体,注入地层后形成暂堵胶塞。但无论是固体或液体的暂堵剂体系,由于其自身不能降解溶解于水中,都需要加入破胶剂使其破胶,进而使体系顺利返排出地层。

薛小佳^[16]等研制了一种可控破胶的水平井分段压裂用暂堵剂。组成材料包括二元醇、无机氧化增强剂、硼酸盐、碳酸氢钠、缓释微胶囊破胶剂。将该暂堵剂注入地层,在一定温度下发生交联固化,降低了泵注难度。此暂堵剂体系可承受30 MPa的压力,在施工结束后,其破胶液黏度小于10 mPa·s,最终可以全部返排出地层,具有优良的返排能力,对地层无伤害。

尹晓宏^[8]等研制了一种水平井分段压裂用的暂堵剂。主要成分为:胍胶、三氧化铝、氧化镁、微胶囊破胶剂等。在一定温度下,经候凝后,形成耐压强度超过30 MPa的胶塞。此类暂堵剂在80℃时开始交联,降低了泵注压力和施工难度。

周法元^[17]等研究了一类转向**重复压裂暂堵剂(ZF)**,主要配方为聚合物A、交联剂铬离子、二交联剂和破胶剂X。该暂堵剂有效暂堵率达98.7%,强度大,由于其具有较好的耐碱、抗盐性和一定的耐酸性,可用于酸化后的地层和一系列已经受严重污染的地层。

邱玲^[18]等人对低压气井液体胶塞暂堵技术进行了研究,此类暂堵剂是一类已成功应用于修井作业的暂堵

剂,适用于致密低孔低渗、分均质性强、纵向含气井段长、多层叠置等中浅层气藏。其所使用的暂堵胶塞是一种隔离液,它由高分子稠化剂、交联剂、氧化破胶剂等组成。在现场试验中,其抗压达到11 MPa,破胶后对地层的伤害率仅为18.9%。将此类暂堵剂应用于压裂施工中时,需向体系中加入一定材料以提高其抗压能力。

李长忠^[19]等制备了一种适用于低渗透油田缝内转向压裂暂堵剂,这是一类耐温稳定性优良、具有黏弹性的小颗粒,原料组成为:骨胶粉、苯甲酸、改性淀粉、羟乙基纤维素、含F表面活性剂、交联剂等。经过烘干、剪切、造粒后,具有良好的温度稳定性、黏附稳定性和承压能力(30 MPa)。施工结束后,暂堵剂溶解在压裂液中完全返排出地层。

1.4 吸水膨胀

吸水膨胀型的暂堵剂在早期已成熟应用于油井堵水及储层保护。将吸水膨胀类的暂堵剂注入地层后,地层中存在着地层水使得暂堵材料吸水膨胀,在裂缝周围形成有弹性的滤饼,对裂缝进行良好封堵。

赖南君^[20]等人对新型重复压裂暂堵剂CLS-1进行了实验研究。该暂堵剂由丙烯酰胺、尿素、引发剂、催化剂通过自由基共聚的方法合成。在一定条件下,暂堵剂与壁面的黏附能力好,能够承受1.5 MPa的突破压裂,施工结束后能溶解于返排液中。此类暂堵剂对比国外优秀暂堵剂存在诸多优点,如承压能力高且可调、抗剪切稳定性及热稳定性强等,但是其返排能力仍有待提高。

1.5 油溶性颗粒

油溶性颗粒暂堵剂一般只适用油井,暂堵过程结束后,不需要加入其他试剂,暂堵颗粒可以溶解于储层流体中,然后返排出地层,不会对地层造成污染。

姜必武^[21]等对压裂蜡球暂堵剂进行了研究。此类暂堵剂适用于原有多方向裂缝十分发育的低渗、低压、低产油层。基本原料为松香、全炼石蜡、沥青、氯化钾、粉陶、EVA及石英砂。该封堵蜡球是油溶性的,抗压能力达4.5 MPa。

王忍峰^[22]等对多裂缝压裂工艺中使用的暂堵剂进行研究,其中包括了三种型号的暂堵剂:CQZ-1、CQZ-2、CQZ-3,均为油溶性颗粒。这三种暂堵剂按照一定比例针对不同的油井和地层搭配使用。通过现场试验的监测结果表明,此类暂堵剂达到了创造出多裂缝并扩大油井泄流面积的目的,提高了油井的产量。油溶性颗粒在使用上具有一定局限性,考虑到其返排,只能应用于油井的压裂施工中,在今后的研究中将向暂堵剂中添加一定表面活性剂来增加体系的水溶性,使其能拥有广泛的使用空间。

2 结论

国内越来越多的油田通过加入暂堵剂达到裂缝转向以及段内多裂缝的效果,最大限度地提高储层采出率,节省施工成本。

a)酸压类暂堵剂不但适用于酸化压裂施工,还适用于单纯的压裂施工,由于其中一般都含有不溶于水的碳酸钙,而常规的压裂施工所使用的压裂液呈碱性,所以后期处理可通过射孔等方法排出。

b)自清洁类暂堵剂虽具有优良的返排性能以及良好的环境相容性能,但是它的抗压性能有待提高。不但如此,目前所提出的暂堵颗粒,如聚乳酸、聚乙醇酸、聚酯,其现成的合成产物比较稀缺、合成工艺较复杂,并且这类暂堵剂在使用上还需配合相应的携带液。

c)交联破胶型的暂堵剂适用性较广,有固态和液态两种不同存在形式,可应用于不同类型的地层。其组成与压裂液的成分类似,在压裂施工中与压裂液配伍良好。

d)吸水膨胀型的暂堵剂应用在出水的地层中更能发挥其良好性能。此类暂堵剂应用较为成熟,在堵住地层的的同时能够吸收地层多余的水分,有效降低地层滤失。

e)油溶颗粒暂堵剂目前在使用上更适用于油井,在未来的应用中可向处理液中添加一系列的表面活性剂,使颗粒溶解在后续注入地层的清理液中排出地层,将其优良的暂堵性能发挥在气井的压裂施工中。

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ABSTRACT: In abnormal high pressure gas reservoir exploitation and development, water invasion may occur often in many gas wells, which will bring about very adverse effect. It is very important to calculate the water influx during design and adjustment of gas reservoir development program. The traditional Roach water influx calculation model may involve a lot of parameters. Based on the traditional calculation model, an improved Roach curve is put forward, which combines the material balance equation with Pot model and quotes cumulative effective compressibility factor. Practical case calculation and analysis show that results obtained by this method are consistent with the actual situation. Therefore, this improved Roach curve method is convenient and intuitive and can obtain accurate results.

KEYWORDS: Abnormal high pressure; Gas well; Geological reserve; Water influx; Improved Roach curve

CORROSION AND CORROSION PROTECTION

Numerical Simulation Analysis on Corroded Casing Residual Strength

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ABSTRACT: Corrosion failure of casing is one of key problems in oil and gas field development. Current researches at home and abroad focus on casing corrosion rate and control. Less analytical investigation is conducted on corroded casing residual strength. Adopted is the numerical simulation to analyze circular arc and semilune forms after casing corrosion and analysis results show that residual tension strength increases when circular arc corrosion defect length increases, residual collapsing strength and residual internal pressure strength decrease when circular arc corrosion defect length increases, residual tension strength increases when semilune corrosion defect length increases, residual collapsing strength decreases when circular arc corrosion defect length increases, residual internal pressure strength and residual tension strength decreases linearly when semilune corrosion defect length increases and residual tension strength, residual collapsing strength and residual internal pressure strength increase when casing wall thickness increases.

KEYWORDS: Casing; Corrosion; Residual strength; Circular arc and semilune; Numerical simulation

Analysis on Factors Affecting Deep Well Anode Ground Bed Interference Range

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ABSTRACT: In order to reduce effect of deep well anode ground bed on the surrounding underground steel structures, it is necessary to make clear interference degree of deep well anode ground bed on such structures. With the method of the chart, analyzed are soil resistivity and depth, bed length and electric current applied in the anode ground bed. Generally speaking, deep well anode ground bed may be largely affected by electric current and soil resistivity applied in the anode ground bed. So, in order to reduce the interference of deep well anode ground bed, cathodic protection current shall be reduced as far as possible. If cathodic protection current can not be reduced, deep well anode ground bed shall be installed in the position with low soil resistivity.

KEYWORDS: Cathodic protection; Deep well anode ground bed; Interference

OILFIELD CHEMISTRY

New Technology of Diverting Agents Used in Oilfield Fracturing

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ABSTRACT: With continuous development of high water content and low permeability oilfields, reservoir fracturing construction becomes more and more difficult and requirements for fracturing technologies becomes increasingly strict. In

order to decrease construction difficulties and number of required segmentation tools and increase reformation efficiency of each unit well section, it is necessary to apply temporary blocking technology for stimulating the subterranean formation. This technology is designed to fracture more than two fissures in the same interval or make the fissures divert, that is, pumping the diverting agents into the subterranean formation to be stimulated and utilizing permeability differences within the formation to change flow direction of treatment fluid so as to produce new fissures. Application of this technology can increase single well yield and reduce the fracturing costs effectively.

KEYWORDS: Diverting agent; Fracturing; Stimulation; Fracture acidizing

UTILITY

Site Selection and Plot Plan Design Essentials of Liquefied Natural Gas (LNG) Plant

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ABSTRACT: In order to select liquefied natural gas (LNG) plant site reasonably, optimize plant plot plan design, reduce effect of plant facilities on external facilities and surroundings and make plot plan design be more reasonable, safe, practical and economic, it is necessary to make clear those factors affecting plant site selection in plot plan design. Conducted is analysis on general structure and technological process of LNG plant, compared are some characteristics of LNG plant with natural gas treatment plant and conducted is analysis on relative requirements specified in national or local policies and laws and regulations followed in LNG plant plot plan design and listed are such considerations in plant site selection design as LNG storage tank overflow, vapor cloud diffusion, storage tank area and flare thermal radiation range around LNG plant and transportation conditions. In addition, the following design essentials shall be considered in plot plan design: technological process, LNG tank type, cofferdam size, fire and noise prevention and tank loading type, etc.

KEYWORDS: Liquefied natural gas plant; Plant site selection; Plot plan design essentials

Application of SVG Technology in Three-phase Voltage Imbalance Treatment

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ABSTRACT: Due to the effect of traction loads of electrified railways, quality of network power supply is reduced and three-phase voltage unbalance exceeds relative standard, which results in substation protection, high alarm of reciprocating compressor motor bearing vibration, even motor bearing damage and axial cracking. Asymmetrical three-phase power network parameters are obtained through continuous on-site monitor, adopted is the SVG (static var generator) to control power supply three-phase voltage unbalance and provide reactive compensation, accordingly, power supply quality has been improved greatly.

KEYWORDS: Power quality; Three-phase unbalance; Negative sequence; SVG

ENGINEERING GEOLOGY AND SURVEY

Common Forms and Prevention and Control of Side Slope Instability in Long-distance Gas Pipeline Construction

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ABSTRACT: Elaborated are several kinds of side slope instability conditions occurred frequently during construction and operation of long-distance pipeline. Analyzed are forms of slope deformation, inducing factors, deformation mechanism and effect of side slope deformation on construction and operation of pipeline and specific, reasonable and feasible prevention and treatment measures are put forward, which will provide certain reference for prevention and control of side slope instability occurring probably during route selection and construction of pipeline.

KEYWORDS: Long-distance pipeline; Forms of side slope instability; Prevention and control