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生物酶可解堵钻井液解堵机理研究

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摘要　生物酶可解堵钻井液技术是利用现代生物技术, 将具有绿色降解能力和催化特性的复合生物酶添加到钻井液中, 使泥饼在生物酶的作用下自动降解清除, 从而达到保护油气层的目的。根据酶与处理剂之间具有对应关系、特定的酶降解特定处理剂的原理, 用黏度衰减法优选出了具有良好流变性、抑制性和润滑性并能形成渗透率几乎为零的封堵层的钻井完井液配方, 其处理剂主要包含纤维素、改性淀粉、生物聚合物处理剂等, 同时介绍了几种酶对上述几种处理剂的降解机理。采用黏度衰减法和泥饼清除、有 FA 无渗透钻井液滤失试验对比了评价钻井液加酶前后的解堵情况。结果表明生物酶可解堵钻井液能够有效解除储层封堵, 保护油气层。与常规解堵技术相比, 该泥饼清除技术对环境的污染程度更低、地层渗透率恢复值更高, 而且可以节约生产成本。

关键词　防止地层损害; 钻井完井液; 生物酶; 泥饼清除; 黏度衰减; 解堵机理

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0　引言

为了解除泥饼对地层的污染, 提高油气井产量, 一般采用酸化、氧化等化学方法清除泥饼, 有时也使用机械方法如水力喷射, 或者综合应用这几种方法来解堵。但酸化法不太适合水平井, 尤其是水平位移大的井, 因为这需要大量的酸在碳酸盐地层形成气孔, 而泥饼中的聚合物会包裹住碳酸盐颗粒, 降低了酸化效果。研究表明, 氧化法(LiOCl、NaOCl、$Na_2S_2O_8$) 对于水平井泥饼的清除效果也不显著。而且, 酸化和氧化法的化学反应非常剧烈, 所采用的化学试剂不具备特效性, 它们在清除泥饼的同时, 也会损害钻井管具、伤害地层流体, 从而降低了清除泥饼的效果。水力喷射的效果取决于立柱距离、流体速率、射流形状和喷射工具传动速度的共同作用, 主要由机械物理动力决定, 消耗的能量比较大, 成本较高。寻找高效节能环保的解堵方式是现代钻井技术的需求方向[1]。

生物酶是利用现代生物技术开发的具有催化作用的蛋白质, 是一种生化催化剂, 其化学结构复杂, 分子量在 1×10^3~ 1×10^6 之间; 催化反应范围宽, 比化学催化剂的催化反应多得多, 酶活力是非酶催化剂的 1×10^7 倍; 完全溶于水, 能降解碳氢化合物, 将它们转化为二氧化碳和水; 能快速从固体粒子表面把碳氢化合物附着物剥离; 对环境不会造成污染, 对人体无不良影响, 属环保产品。生物酶可解堵钻井液正是利用生物的酶降解能力和催化特性来清除泥饼。

1　生物酶可解堵钻井液的特点

在钻开油层前几十米, 通过在钻井液中加入复配生物酶制剂和相应的化学试剂, 可在近井壁形成一个渗透率几乎为零的护壁层, 达到稳定井壁的效果。钻进结束后, 护壁层中的钻井液材料在生物酶的催化作用下发生生物降解, 由长链大分子变成了短链小分子, 黏度逐渐下降, 先前形成的泥饼自动破除, 储层孔隙中的阻塞物消除, 从而解除对储层孔隙的封堵, 使得地下流体通道畅通, 恢复油层渗透率, 达到超低污染、低伤害、保护油气层的目的[2]。

2　生物酶与处理剂的作用特点

2.1　钻井液组成

生物酶可解堵钻井液主要由各类可生物降解处理剂以及生物酶组成。这些钻井液材料主要有: 纤

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维素、淀粉、生物聚合物、野生植物胶、多糖类聚合物等, 可以起降滤失、增黏、降黏、稳定井壁和防塌等作用[3-4]。用 DO 衰减法筛选出满足要求的主要处理剂有以下几种: HV-PAC、高、中、低黏 CMC、PAC141、LD-302、DFD-140、天然高分子包被剂、糖类抑制剂、屏蔽暂堵剂、XC。对上述处理剂用黏度衰减法进行再次优选, 最后由纤维素、改性淀粉、生物聚合物复配形成性能良好的体系, 该体系不仅具备常规钻井液完井液具有良好的流变性、抑制性以及润滑性, 还具备可生物降解性。

2.2　生物酶对处理剂的催化特点

生物酶与处理剂的作用主要存在下面 3 种方式。

1) 钻井液处理剂与生物酶结合, 在酶的催化作用下, 钻井液处理剂被氧化分解为简单的低分子物质, 同时释放能量。在该过程中, 酶分子作为一种催化剂参与反应, 其结构及活性不发生变化, 相反酶在氧化分解的同时可利用释放的能量来完成自身的新陈代谢, 不断进行生长繁殖和自我更新。

2) 钻井液处理剂与生物酶的特异部位结合, 引起酶构型的暂时变化, 使酶活性受到抑制, 但随着时间的增加, 钻井液处理剂可以毫无变化地脱离酶分子, 且对酶分子不产生任何化学损伤, 酶仍可恢复活性, 进行正常的生物降解过程。

3) 钻井液处理剂与酶的活性中心部位进行不可逆的相互作用, 从而改变了酶的化学结构和生物功能, 引起酶的化学伤害, 而且这种伤害很难恢复, 使酶的催化功能受到严重损伤, 表现出酶的活性不可恢复。

该复合生物酶与钻井液作用后, 大部分活性仍保留下来, 可以进入下次循环使用。以下针对生物酶可解堵钻井液中构成主要网架结构的处理剂, 阐述其断链降解机理。

2.3　几种酶对钻井液处理剂的降解机理

一种特异性的生物酶并不能降解所有的处理剂, 酶与处理剂之间具有对应关系, 特定的酶降解特定的处理剂[5]。

1) 纤维素酶的降解机理。钻井液中的纤维素主要用作增黏剂、抑制剂和降滤失剂。纤维素是一种直链多糖聚合物(见图 1), 由 β-1, 4-D-糖甙键将葡糖基连接在一起, 可被 β-1, 4-D-糖甙键环内水解酶有效地分解, 生成约 80% 的单糖和 20% 的二糖, 发生的化学反应是纤维素中 β-1, 4-D-糖甙键的环内水解反应。加入的挂-O-糖甙水解酶(如 β-D-糖甙葡萄糖水解酶, 也叫纤维二糖酶), 可分解末端的非还原 β-D-葡萄糖残余, 同时释放出 β-D-葡萄糖而将其余 20% 的二糖水解为单糖。

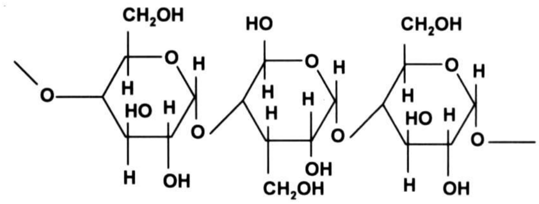

图 1　纤维素的结构式

纤维素也可被桥-木聚糖酶和挂-木聚糖酶有效地水解, 这是因为木糖的(1, 4)β 键与纤维素中的键类似。所用的酶混合物是桥-1, 4-β-木聚糖酶和挂-1, 4-β-木糖甙酶(也叫木糖二糖酶 Xylobisse) 或 2-木糖甙酶[6]。

2) 淀粉酶的降解机理。钻井液中的淀粉主要用作降滤失剂, 可被几种酶有效地水解。普通淀粉是直链淀粉(见图 2) 和支链淀粉 2 种聚合物的混合物。直链淀粉为直链 1, 4-α-D-葡聚糖。支链淀粉为支链 D-葡聚糖, 大部分为 α-D-(1, 4) 键, 约 4% 为 α-D-(1, 6) 键。最广范使用的酶是桥 α-O-糖甙水解酶和挂 α-O-糖甙水解酶, 如 α-淀粉酶、β-淀粉酶和葡萄糖淀粉酶(也叫挂-1, 4-α-D-糖甙酶)。桥 α-O-糖甙水解酶同淀粉的反应, 是通过桥解含 3 个或 3 个以上 1, 4-α-键连结的 D-葡萄糖多糖的 1, 4-α-D-糖甙键进行的。挂-α-糖甙水解酶对淀粉有特效, 因为它们水解多糖上的 1, 4-α-D 糖甙键。通过挂-α-O-糖甙酶的水解, 导致连续将麦芽糖单元从链的非还原端除去。

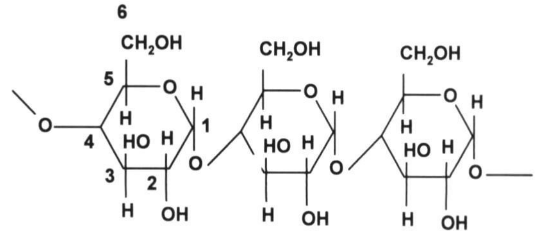

图 2　直链淀粉的结构式

3　解堵试验

3.1　黏度衰减试验

以黏度衰减法(表观黏度值) 观测钻井液中加入不同量生物酶前后黏度的降解情况, 结果见表 1。

该复合生物酶主要由淀粉酶和纤维素酶组成, 基浆配方如下。

1# 3% 膨润土+ 0. 2% LV-CMC + (0. 2%~0. 3%) 改性淀粉+ (0. 3%~ 0. 5%) 纤维素+ 0. 1% XC+ 0. 3% 双聚铵盐

表 1 不同复合生物酶加量时的钻井液表观黏度

t/d	AV/mPa·s			
	0	0.1%	0.2%	0.4%
1	26.00	22.75	17.50	9.0
2	24.50	20.00	15.00	9.0
3	21.25	19.25	15.50	9.5
4	21.75	19.25	15.25	8.0
7	19.75	18.00	13.00	8.0
11	17.25	15.75	14.25	7.5
25	9.50	10.25	9.00	7.0

由表 1 可见, 随着生物酶加量的增大, 钻井液表观黏度降解速度加快, 但是在 25 d 左右内观测, 3 个加酶钻井液与不加酶自然降解钻井液的最终降解程度是一致的, 说明加入生物酶后, 加快了钻井液的降解速度, 尤其是在初期催化作用表现更为明显; 随着生物酶浓度的增加, 钻井液的降解速度增加, 说明钻井液降解速度随生物酶浓度的增加而加快。可见通过调整处理剂和生物酶的种类及配方, 可以改变生物酶对处理剂的攻击速度, 从而达到控制钻井液降解速度的目的。

3.2 泥饼清除试验

将 1# 配方的钻井液加入中压滤失泥浆杯中, 在 0.7 MPa 压力下测试 7.5 min API 滤失量并记录, 随后再压 30 min; 将泥饼取出, 分别浸泡在酶液和清水中 0~ 10 d, 观测泥饼变化情况并拍照记录, 结果见图 3 和图 4。

图 3 1# 配方钻井液泥饼

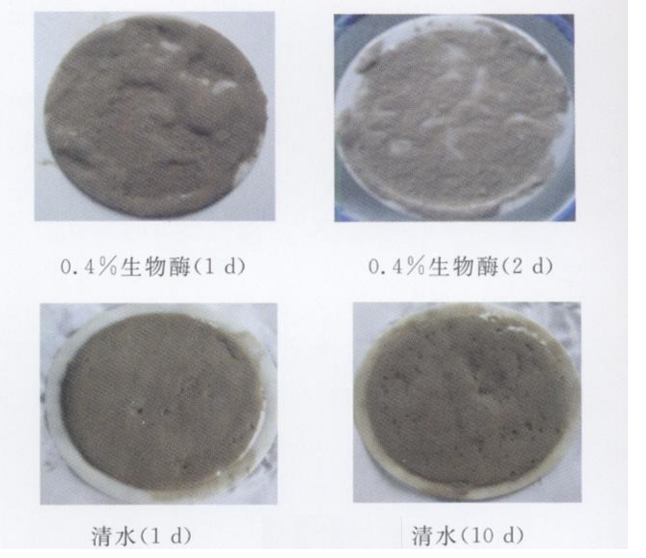

图 4 基浆泥饼浸泡在酶液和清水中不同时间的变化情况

试验结果显示, 2 d 内, 浸泡在 0. 4% 生物酶溶液中的泥饼在酶的作用下能够逐渐破除, 而浸泡于清水中的泥饼 10 d 内仍无明显变化, 可见生物酶能够有效清除泥饼。

3.3 **FA** 砂床漏失试验

使用 FA 型无渗透钻井液滤失仪, 以砂子代替常规滤纸, 观察钻井液的渗透滤失情况, 该试验不仅能直观显示泥饼的清除情况, 还能表明对渗入砂床孔隙滤液的清除效果。在滤网上将 350 cm^3 粒径为 0.45~ 0.90 mm 的砂子倒入筒状可视的钻井液杯中, 用 1 MPa 气压压实, 仪器过滤面积为(18±0. 6) cm^2 (砂子纵向高度约为 17 cm)。将 500 mL 钻井液基浆倒入杯中, 在 0.69 MPa 压力下压制 30 min, 记录基浆渗入砂层的深度(记为 H_1), 再倒出钻井液, 加入 300 mL 浸泡液, 观察浸泡液渗入砂床的深度(记为 H_2) 和滤失量, 试验数据见表 2。

表 2 砂床漏失试验数据

浸泡液	H_1/cm	H_2/cm	FL/mL	t/h
清水	4.0	4.0	0	24
清水+ 0.4% 复合酶	3.5	17.0	250	4
1# + 0.4% 复合酶液*	4.5	10.0	0	24
1#	3.5	3.5	0	120

注: * 1# + 0.4% 复合酶降解 2 h 后再做实验。

使用清水浸泡 24 h 砂床无明显变化; 使用浓度为 0.4% 的复合酶溶液浸泡 4 h 后滤液几乎全滤失; 用降解 2 h 的 1# + 0. 4% 复合酶钻井液浸泡 24 h

后, 浸泡液絮凝分层, 侵入砂层深度为 10 cm; 加压 0.5 MPa, 浸泡液瞬时渗过砂层, 清洗砂子时, 泥饼较易脱落, 无结块现象, 说明泥饼结构基本已被破坏, 但浸泡液降解后处理剂残渣堵塞了砂床孔道; 用 1# 配方钻井液作浸泡液浸泡 120 h 后观测, 发现浸泡液絮凝分层, 侵入砂层深度仍为压制泥饼时钻井液渗入砂层的深度(3.5 cm); 加压 0.7 MPa, 砂床没有明显变化, 清洗砂子时, 泥饼结块不易脱落, 表明泥饼致密, 其结构没有被破坏, 可见钻井液虽然能够自动降解, 但是却不能有效清除地层深处的泥饼。砂床漏失试验显示, 0.4% 复合酶溶液清除泥饼以及砂层孔道内滤液的效果最好, 在不加压纯浸泡的情况下, 4 h 左右复合酶溶液全渗过砂床, 其次是基浆 + 0.4% 复合酶, 此种情况下清除泥饼需要稍加压, 体系浆液即能全渗透砂床; 而清水和基浆不能有效清除泥饼。

4　结论

1. 生物酶可解堵钻井液利用生物酶的绿色降解能力和催化特性来清除泥饼, 钻进过程中能够达到稳定井壁的效果, 钻进结束后, 泥饼在生物酶的作用下能够自动破除, 该解堵技术超低污染、低伤害, 可节约生产成本。

2. 生物酶可解堵钻井液处理剂主要包含纤维素、改性淀粉和生物聚合物, 它们与生物酶结合后, 在酶的作用下断链降解, 结构破碎, 黏度下降。酶与处理剂之间具有对应关系, 特定的酶降解特定的处理剂。

3. 通过调整处理剂和生物酶的种类及配方, 可以改变生物酶对处理剂的攻击速度, 从而达到控制钻井液降解速度的目的。

4. 浸泡在生物酶溶液中的泥饼, 在酶的作用下能够逐渐破除, 而浸泡于清水中的泥饼无明显变化, 可见生物酶能够有效清除泥饼。

5. 清水和基浆不能清除泥饼, 而生物酶溶液不仅能清除泥饼, 还能清除渗透到储层孔道内的滤液残留物。

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钻至井深 5 933 m(井底温度达 233 ℃), 起钻后因钻机故障, 钻井液静止时间长达 115 h, 设备修理好后, 仍然下钻顺利, 钻进正常。

完钻后循环起钻测井温, 第一次仪器下井, 测得井温为 226 ℃, 钻井液静止时间为 17 h, 起出仪器检查后再次下入井底, 钻井液累积静止时间为 24 h, 起出后实测井温为 236 ℃。

4　认识与结论

1. 优选出的抗 220 ℃和 245 ℃高温的水基钻井液, 性能稳定, 满足了泌深 1 井四开超高温井段钻井施工任务。

2. 在超高温情况下, 该钻井液流变性能稳定、润滑性好, 具有良好的岩屑携带和悬浮能力, 摩阻系数低, 起下钻顺利, 无阻卡, 无其它井下复杂情况发生; 具有较强的抑制能力, 四开井段没有外排钻井液。

3. 井下虽有剥落掉块, 经过改善钻井液流变性能及配合工程措施, 剥落掉块问题得到有效解决, 没有造成井下复杂情况。

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Drilling Fluid Technology for Multilateral Horizontal Well Jing52-H1Z. ***DFCF*****,** 2009, 26(3): 1-4

Authors DONG Wei, YAO Lie, JIANG Wenbo, YANG Yongsheng, SONG Yonglong, SONG Dianchao

Abstract Well Jing52-H1Z, a multilateral well having 20 branch holes, has a big hole in the second interval with an interval length of 2,813 m. Downhole problems in this interval such as high hole angles, cuttings carrying in big, slant hole, wellbore stability, lubricity and reservoir protection were tackled using a low solids content drilling fluid having excellent thixotropy and flow property, as well as suspension capacity. A lubricant, LH-IX was used in place of diesel oil to render the drilling fluid good lubricity. Temporary plugging agent and other filtration control agents were added to minimize reservoir damage. In the third interval, in which 20 branch holes resided, the same problems as that in the second interval were encountered. A GOB cuttings carrying technology, was adopted to clean the 2,000 m horizontal section. The drilling fluid used was a high *YP/PV* ratio solids-free fluid, which, through field operation, was proved to be the best fluid suitable for use in this interval.

Key words Multi lateral horizontal well; Hole cleaning; Wellbore stability; Formation damage prevention; Composite film drilling fluid; Solids free drilling fluid; GOB cuttings carrying

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Drill-in Fluid Technology for Reservoir Protection in Daniudi Gas Field. ***DFCF*****,** 2009, 26(3): 5-8

Authors XUE Yuzhi, LIU Baofeng, LI Gongrang, ZHANG Jinghui, LI Haibin, ZHENG Chengsheng

Abstract A set of drill-in fluid technology was reservoir protection, such as solids-free drilling fluid, water block prevention, near or under-balance drilling using hollow glass beads as light weight additive, drilling fluid high temperature stability achieved by using potassium formate, as well as mud cake automatic removal by biological enzymes, was designed for the development of the low porosity, low permeability gas field of Daniudi. These techniques have been applied in the horizontal sections of wells DF2, DF4, DF5, DF6 and DP11. Permeability recovery achieved using these technologies was as high as 85% and above, according to filed application records.

Key words Solids free low density drilling fluid; Drill-in fluid with biological enzyme; Formation damage prevention; Water block; Potassium formate; Low porosity low permeability reservoir; Daniudi gas field

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The Ultra High Temperature Water Base Drilling Fluid Technology for Well Bishen-1. ***DFCF*****,** 2009, 26(3): 9-11

Authors SUN Zhongwei, HE Zhenkui, LIU Xia, QIU Zhengsong, QIU Jianjun, JING Guoan, CHEN Xinan

Abstract Well Bishen-1, located in Tanghe county of Henan Province, is a key exploration well with a completion depth of 6,005 m, and a Downhole temperature of 236 ℃. Two water base drilling fluids for use at temperatures of 220 ℃ and 245 ℃ were designed and used in field drilling operation. The application of these two drilling fluids was successful in the well Bishen-1 drilling operation.

Key words High temperature drilling fluid; Drilling fluid formulation; Wellbore stability; Hole cleaning; Well Bishen-1

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Mechanism Study on the Breakdown of Drilling Fluids Using Biological Enzymes. ***DFCF*****, 2009, 26(3): 12-15**

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Abstract Mud cake can be removed by adding biological enzymes into a drilling fluid, protecting reservoir permeability from being damaged. A drilling fluid was formulated through laboratory exponents, which has good rheology, inhibitive capacity, lubricity and a filtration rate of almost zero. This drilling fluid contains mainly cellulose, modified starch and biopolymer. Different biological enzymes are added to this fluid. The breakdown mechanisms of these enzymes are discussed in this paper. Laboratory experimental results showed that mud cakes can be easily removed by some specific enzymes. Compared with other mud cake removal methods, biological enzymes can remove mud cakes much more completely, thus leading to a higher permeability recovery. Furthermore, the enzymes used are environmentally friendly.

Key words Formation damage prevention; Drill-in fluid; Biological enzyme; Mud cake removal; Viscosity attenuation; Breakdown mechanism

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The Evaluation of Fracturing Cores and Reservoir Protection Technology. ***DFCF*, 2009, 26(3): 16-19**

Authors ZHANG Qilin, WANG Xueying, WEI Jun, YANG Jianjun, XU Yunyong, ZHANG Xihong

Abstract Efficient sealing of fractures encountered during drilling are generally hard to seal off because of the inaccurate understanding of the distribution and opening of these fractures, as well as the comparatively narrow distribution of the plugging particles in drilling fluids. A fracturing core evaluation method is presented to accurately measure the opening of the fractures, and a relationship between the fracture opening and formation permeability is established. Using this method, an optimized cellulosic temporary plugging agent is evaluated for its efficiency in sealing fractures. The evaluation results showed that a wide particle size distribution can prevent drilling fluids from losing into fractures more efficiently, and flow through porous media is improved, thus protecting the fracturing reservoir from being damaged.

Key words Fracturing reservoir; Formation damage prevention; Sealing and plugging agents; Core evaluation

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Borehole Stabilization of the Soft Shale Formations in Block BZ25-1. ***DFCF*, 2009, 26(3): 20-22**

Authors ZHANG Yan, WU Bin, XIANG Xingjin, LIU Ziming, MO Chengxiao, WANG Quanwei

Abstract An analysis was done on the troubles encountered in the borehole stabilization and during trip through the hole penetrated the soft formations in Block BZ25-1. It was concluded that the conventional KCl polymer drilling fluids cannot be used in drilling these soft formations, and a "soft inhibition" concept was presented in combination with an increase in membrane efficiency for borehole stabilization. An PEC drilling fluid was formulated on the basis of the analysis. the application was proved successful by field operation.

Key words Wellbore stabilization; PEC drilling fluids; Inhibitive capacity; Soft shale; Block BZ25-1

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The Application of a Filming Sealing Drilling Fluid in Block Lvda10-1. ***DFCF*, 2009, 26(3): 23-24**

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Abstract Wells A31 and A32 are two deviated wells located in Block Lvda10-1, targeted at the sloughing Dongying formation having a high porosity and high permeability. Mud losses, borehole sloughing, tight hole and pipe sticking were encountered during drilling. To avoid formation damage, a filming sealing drilling fluid (CBF) was used in two adjustment wells and the sidetrack section of well A31. Field operation showed that the percent hole enlargement of well A31 was only 3% at most. No cave-in was encountered. Hole lubricity was improved through the use of some special additives. The average ROP in the clay stone formations was as high as 10 m/h. Production rates of the two wells were both satisfactory.

Key words Filming sealing drilling fluid; Solids-free drilling fluid; Formation damage prevention; Wellbore stability; Environmental protection

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Foam Drilling Fluid Technology for Horizontal Well Drilling in Block M. I. S Iran. ***DFCF*, 2009, 26(3): 25-28**