文章编号: 1006- 6535(2009)06- 0077- 05

不同完井方式水平井表皮系数及产能评价新方法

董长银, 武 龙, 王爱萍, 张 琪
(中国石油大学, 山东 东营 257061)

摘要: 为给出带表皮系数水平井基本产能公式的统一形式, 将流体由远处地层到井筒内所经区域划分为管外环形带、射孔压实带、射孔孔眼充填带、管内充填带等几个区域, 用上述区域的特定组合来表达目前 8种主流水平井完井方式所形成的附加渗流阻力区域。根据所假设的物理模型, 重新推导了上述各区域层流和紊流压降及表皮系数的计算方法, 并给出了水平井不同完井方式下总表皮系数和产能比的计算模型。该模型可用于任何完井方式全部渗流区域的表皮系数分析及产能比预测。通过实例分析了各渗流阻力区表皮系数的相对大小, 研究了污染带、射孔参数、充填渗透率等对水平井产能比的影响规律, 并提出了提高产能比的方法。

关键词: 水平井; 砾石充填; 完井方式; 表皮系数; 产能比; 压降; 产能评价
中图分类号: TE257 文献标识码: A

前 言

水平井完井方式可分为裸眼和射孔两大系列, 根据其在井底形成的附加渗流阻力区域以及施工工艺不同又可以分为 8种。每种完井方式对水平井产生的附加表皮系数不同, 从而对水平井产能的影响程度即产能比也不同。国内外学者对不同完井方式的水平井表皮系数及产能比预测开展了大量的研究工作, 熊友明等[1, 2]以 Giger、Joshi水平井产能公式为基础, 研究了裸眼完井、裸眼砾石充填完井、射孔完井等完井方式下的表皮系数计算公式; 刘健等人[3, 4]的研究与文献 [1]、[2]非常类似, 都是针对于油井并以特定的水平井产能公式为基础。文献 [5]研究了水平井射孔几何表皮系数的计算方法, 主要是借助了垂直井射孔几何表皮系数的计算模型。在上述研究基础上, 根据新的物理模型, 推导不同完井方式形成的附加阻力区域的层流和紊流压降及表皮系数计算公式, 得到油井水平井不同完井方式下总表皮系数和产能比的计算新模型。

1 带表皮系数的水平井产能公式的统一形式

水平井基本产能公式目前多达十几种, 例如 Merkulov、Borisov、Giger、Joshi、窦宏恩等都提出了自己的油井水平井产能公式[6], 这些公式的形式各异。经过分析整理, 给出带表皮系数的水平井采油指数公式的统一形式:

$$J = \frac{q}{\$p} = \frac{2PKh}{LB[f(x) + S]} \qquad (1)$$

式中: J为水平井采油指数, $m^3/(Pa\# s)$; q为水平井产量, m^3/s; $p为生产压差, Pa; K为地层油相渗透率, m^2; L为地层原油粘度, Pa# s; B为原油体积系数, m^3/m^3; h为油层厚度, m; f(x)为计算项, 取决于不同的计算公式; S为总表皮系数。

目前不同学者提出的油井水平井产能计算公式都可以用式 (1)来表达, 各模型不同之处主要表现在分母项 f(x)的表达与计算方法不同。

2 水平井完井产能比计算

对于油井, 不同完井方式下的水平井产能比是指特定完井方式下的采油指数与裸眼完井条件下采油指数的比值。裸眼完井条件下的采油指数为:

$$J_0 = \frac{2PKh}{LBf(x)} \qquad (2)$$

特定完井方式下的采油指数为:

收稿日期: 2009- 05- 24; 改回日期: 2009- 10- 15
基金项目: 国家/ 863计划资助课题 (2006AA09Z351)、国家自然科学基金资助课题 (50704035)的部分研究内容
作者简介: 董长银 (1976-), 男, 副教授, 博士, 1998年毕业于石油大学 (华东)石油工程专业, 现主要从事采油 (气)工程、油气井防砂完井、水平井开采等方面的教学与研究工作。

$$J_1=\frac{2PKh}{LB[f(x)+S]} \qquad (3)$$

根据产能比定义,油井水平井完井产能比为:

$$PR=\frac{J_1}{J_0}=\frac{f(x)}{f(x)+S} \qquad (4)$$

式中: J_0 为自然条件下(裸眼)油井水平井采油指数, $m^3/(Pa\# s)$; J_1 为特定完井方式下油井水平井采油指数, $m^3/(Pa\# s)$; PR 为特定完井方式下水平井产能比。

根据上述分析,要计算产能比,只要计算出不同完井方式下的表皮系数即可。

3 不同完井方式表皮系数计算模型

311 水平井井底流动总压降及表皮系数

为便于推导,假设一口水平井从外到内渗流区域分别为原始地层、污染带、管外充填(或化学固砂)带、射孔孔眼压实带、砾石充填射孔孔眼、管内充填带、机械筛管等渗流带。上述渗流区域内的流动为径向流或单向流。

非线性二项式渗流方程为[7]:

$$\frac{dp}{dr}=\frac{L}{K}v+BQv^2 \qquad (5)$$

式中: p 为压力, Pa; r 为径向半径, m; Q为流体密度, kg/m^3; v为流体流速, m/s; B为紊流速度系数, m^{-1}。

根据式(5)可推导得到原始地层中径向流、地层污染带径向流、管外砾石充填(或化学固砂)带径向流、砾石充填射孔孔眼中的单向流、射孔压实带径向流、井筒内环空砾石层径向流、井筒内筛管渗滤层径向流等各区域的压降表达式。上述各区域的流动压降相加得到总压降,结合式(1)可得到:

$$\$p=\frac{qLB}{2PKh}[f(x)+S]=\frac{qLB}{2KPh}\{f(h,L,r_e,r_w,\ )+q\frac{BQKhB}{2LPL^2}\left(\frac{1}{r_d}-\frac{1}{r_{eh}}\right)+\frac{Kh}{K_dL}\ln\frac{r_d}{r_g}+q\frac{B_dQKhB}{2LPL^2}\left(\frac{1}{r_g}-\frac{1}{r_d}\right)+\frac{Kh}{K_gL}\ln\frac{r_g}{r_w}+q\frac{B_gQKhB}{2LPL^2}\left(\frac{1}{r_w}-\frac{1}{r_g}\right)+\frac{2KhL_p}{K_pL_sS_Dr_p^2}+q\frac{2hB_pQBL_pK}{LPL_s^2S_D^2r_p^4}+\frac{Kh}{K_{dp}L_sS_D(L_{dp}+2r_p)}\ln\frac{r_{dp}}{r_p}+q\frac{KhB_{dp}QB}{LPL_s^2S_D^2(L_{dp}+2r_p)^2}\left(\frac{1}{r_p}-\frac{1}{r_{dp}}\right)+\frac{Kh}{K_aL}\ln\frac{r_w}{r_a}+q\frac{B_aQKhB}{2LPL^2}\left(\frac{1}{r_a-r_w}\right)+\frac{Kh}{K_sL}\ln\frac{r_a}{r_s}+q\frac{B_sQKhB}{2LPL^2}\left(\frac{1}{r_s-r_a}\right)\} \qquad (6)$$

将 $\ln\frac{r_{eh}}{r_w}=\ln\left(\frac{r_{eh}}{r_d}\#\frac{r_d}{r_g}\#\frac{r_g}{r_w}\right)=\ln\frac{r_{eh}}{r_d}+\ln\frac{r_d}{r_g}+\ln\frac{r_g}{r_w}$ 代入上式并做适当的简化后得到总表皮系数如下:

$$S=q\frac{BQKhB}{2LPL^2}\left(\frac{1}{r_d}-\frac{1}{r_{eh}}\right)+\frac{h}{L}\left(\frac{K}{K_d}-1\right)\ln\frac{r_d}{r_g}+q\frac{B_dQKhB}{2LPL^2}\left(\frac{1}{r_g}-\frac{1}{r_d}\right)+\frac{h}{L}\left(\frac{K}{K_g}-1\right)\ln\frac{r_g}{r_w}+q\frac{B_gQKhB}{2LPL^2}\left(\frac{1}{r_w}-\frac{1}{r_g}\right)+\frac{2KhL_p}{K_pL_sS_Dr_p^2}+q\frac{2hB_pQBL_pK}{LPL_s^2S_D^2r_p^4}+\frac{Kh}{K_{dp}L_sS_D(L_{dp}+2r_p)}\ln\frac{r_{dp}}{r_p}+q\frac{KhB_{dp}QB}{2LPL_s^2S_D^2(L_{dp}+2r_p)^2}\left(\frac{1}{r_p}-\frac{1}{r_{dp}}\right)+\frac{Kh}{K_aL}\ln\frac{r_w}{r_a}+q\frac{B_aQKhB}{2LPL^2}\left(\frac{1}{r_a}-\frac{1}{r_w}\right)+\frac{Kh}{K_sL}\ln\frac{r_a}{r_s}+q\frac{B_sQKhB}{2LPL^2}\left(\frac{1}{r_s}-\frac{1}{r_a}\right) \qquad (7)$$

式中: B、B_d、B_g、B_p、B_{dp}、B_a、B_s 分别为原始地层、污染带、砾石充填带、充填炮眼、射孔压实带、管内充填带、滤砂管渗滤带的紊流速度系数, m^{-1}; K_d、K_g、K_p、K_{dp}、K_a、K_s 分别为污染带、砾石充填带、充填炮眼、射孔压实带、管内充填带、滤砂管渗滤带的渗透率, Lm^2; r_{eh}、r_d、r_g、r_p、r_{dp}、r_a、r_s、r_w 分别为井控半径、污染带外半径、砾石充填带外半径、射孔孔眼半径、射孔压实带外半径、管内充填带内半径、滤砂管内半径、井眼半径, m; L_s 为水平井射孔段长度, m; L_p 为射孔孔眼长度, m; L_{dp} 为射孔压实带长度, m; S_D 为射孔密度, 孔/m。

312 不同渗流区域的表皮系数模型

式(7)即为总表皮系数计算公式。根据式(7)以及不同渗流区域的几何特征,可分解并总结得到水平井筒附近不同渗流区域的表皮系数计算公式如下:

(1) 原始地层表皮系数。根据表皮系数定义及模型,原始地层中的层流表皮系数为 0。假设外围原始地层的内半径为 r_i,则流动表皮系数为:

$$S_{fl}=0 \qquad (8)$$

$$S_{ft}=q\frac{BQKhB}{2LPL^2}\left(\frac{1}{r_i}-\frac{1}{r_{eh}}\right) \qquad (9)$$

式中: S_{fl}为原始地层的层流表皮系数; S_{ft}为原始地层的紊流表皮系数。

(2) 管外地层中径向环形介质的表皮系数。地层中以水平井筒为轴心环形介质的渗透率为 K_o, 内、外半径分别为 r_i、r_o, 则其表皮系数为:

$$S_{ol}=\frac{h}{L}\left(\frac{K}{K_o}-1\right)\ln\frac{r_o}{r_i} \qquad (10)$$

$$S_{ot}=q\frac{B_oQKhB}{2LPL^2}\left(\frac{1}{r_i}-\frac{1}{r_o}\right) \qquad (11)$$

式中: S_{ol}为地层中环形介质层流表皮系数; S_{ot}为地层中环形介质紊流表皮系数; B_o为管外地层中环形介质紊流速度系数, m^{-1}。

管外化学固砂带、砾石充填带等区域为径向流动, 其表皮系数均可以使用式(10)、(11)计算。

(3) 砾石充填射孔孔眼流动表皮系数。

$$S_{pl}=\frac{2KhL_p}{K_pL_sS_Dr_p^2} \qquad (12)$$

$$S_{pt}=q\frac{2hB_pQBL_pK}{LPL_s^2S_D^2r_p^4} \qquad (13)$$

式中: S_{pl}为砾石充填射孔孔眼中层流表皮系数; S_{pt}为砾石充填射孔孔眼中紊流表皮系数。

(4) 射孔压实带表皮系数。

$$S_{dpl}=\frac{Kh}{K_{dp}L_sS_D(L_{dp}+2r_p)}\ln\frac{r_{dp}}{r_p} \qquad (14)$$

$$S_{dpt}=q\frac{KhB_{dp}QB}{2LPL_s^2S_D^2(L_{dp}+2r_p)^2}\left(\frac{1}{r_p}-\frac{1}{r_{dp}}\right) \qquad (15)$$

式中: S_{dpl}为射孔压实带层流表皮系数; S_{dpt}为射孔压实带紊流表皮系数。

对于新井, 射孔压实带长度可取从水泥环外算起的射孔孔眼长度; 对于老井, $L_{dp}=0$。

(5) 井筒内环形介质流动表皮系数。井筒内以水平井筒为轴心环形介质的内外半径分别为 r_i、r_o, 其表皮系数为:

$$S_{al}=\frac{Kh}{K_aL}\ln\frac{r_o}{r_i} \qquad (16)$$

$$S_{at}=q\frac{B_aQKhB}{2LPL^2}\left(\frac{1}{r_i}-\frac{1}{r_o}\right) \qquad (17)$$

式中: S_{al}为井筒内环形介质的层流表皮系数; S_{at}为井筒内环形介质的紊流表皮系数。

井筒内筛管环空充填带、管内机械筛管渗滤带的流动为径向流动, 其表皮系数均可以用式(16)、(17)计算。

(6) 水平井射孔几何表皮系数计算。该表皮系数计算可使用文献[5]的计算方法。

4 模型的应用与结果讨论

411 模型应用方法

上述模型以水平井基本产能公式为基础, 考虑了所有区域的层流和紊流表皮系数。实际应用中, 根据水平井的完井方式判断其造成的附加渗流阻力区域, 分别用式(8)~(17)计算相应的表皮系数, 用式(4)计算完井产能比。需要注意的是, 对于单纯的机械滤砂管类完井方式, 存在筛管) 井筒环空, 在投产初期, 该环空中无充填介质; 但若地层出砂, 则随着生产的继续, 环空及炮眼中可能会被地层产出砂沉积, 并充填, 形成附加阻力层, 在进行产能比评价时应考虑上述因素。

412 结果分析

某水平井水平段长度为 300 m, 油层厚度为 718 m, 控制体积宽度为 500 m, 控制体积长度为 1 500 m, 井眼直径为 240 mm。地层渗透率为 015 Lm^2, 地层原油粘度为 2167 mPa# s, 地层原油密度为 887134 kg/m^3。为了便于分析各渗流阻力区表皮系数的相对大小, 假设该井采用尾管射孔管内砾石充填完井方式, 采用 «17718 mm 套管, 砾石尺寸为 014~018 mm, 充填带渗透率为 89 Lm^2, 射孔段长度为 300 m, 孔眼直径为 14 mm, 射孔密度为 24孔 /m, 孔深为 0135 m, 射孔压实带厚度为 12 mm, 压实带渗透率取地层渗透率的 25%。采用 «90 mm 绕丝筛管, 等效渗透率为 200 Lm^2。钻井污染半径为 115 m, 污染带渗透率为 0125 Lm^2。

(1) 各阻力区域的表皮系数对比。利用上述计算模型及基础数据, 计算得到了完井后各阻力区域的表皮系数(表 1)。

表 1 各阻力区域的表皮系数计算结果

阻力区域	层流表皮系数	紊流表皮系数	总表皮系数
原始地层	/	11405@10^{-7}	11405@10^{-7}
钻井污染带	010238	21430@10^{-7}	010238
射孔几何	-010155	/	-010155
射孔压实带	010132	11628@10^{-6}	010132
砾石充填孔眼	012866	11778@10^{-3}	012884
井筒环空充填带	010003	91770@10^{-7}	010003
机械筛管	010001	11952@10^{-7}	010001
合计	013503	11778@10^{-3}	013521
完井产能比	/	/	018698

根据表 1结果, 分析认为: ¹ 对于尾管射孔管内砾石充填完井方式, 主要的表皮系数来自于钻井污染、射孔压实带和孔眼充填带; 由于射孔炮眼的流动面积最小, 流速最高, 因此砾石充填射孔孔眼的表皮系数占据了主要地位, 对于射孔类完井方式, 优化射孔参数对提高水平井产能十分重要; º 在合理的射孔参数范围内, 射孔几何表皮系数很小; 由于砾石层以及机械筛管的渗透性一般远高于地层渗透率, 其形成的表皮系数也相对很小; 它们对水平井产能的影响也比较小; » 与层流表皮系数相比, 各区域的紊流表皮系数很小, 除砾石充填射孔孔眼外, 几乎可以忽略不计, 与垂直井相比, 虽然水平井产量一般较高, 但由于向井筒的渗流面积较大, 流体在地层中的流速相对较低, 紊流影响很小; 紊流表皮系数的大小与具体的产量有关, 不便于应用, 在实际应用中, 可以不考虑紊流表皮系数。

(2) 完井产能比敏感性分析。使用上述基础数据, 对完井产能比对射孔孔眼直径及孔眼充填渗透率的敏感性进行了分析 (图 1)。

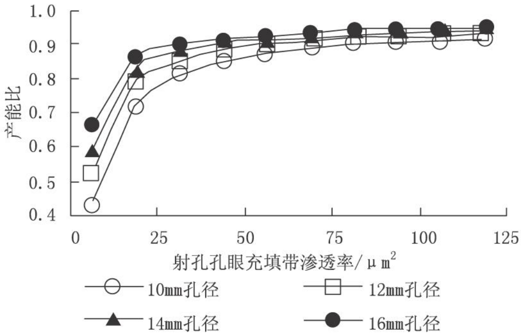

图 1 完井产能比随孔眼充填带渗透率的变化关系

由图 1可知, 射孔孔眼充填渗透率是影响射孔砾石充填完井水平油井产能比的主要因素, 尤其当充填带渗透率较低时, 影响更加明显。实际应用中应尽可能获得较高的砾石充填层渗透率。同时应尽可能采用较大的孔径和孔密以及较粗的砾石尺寸, 从而得到较小的表皮系数。

(3) 不同完井方式的产能比分析。利用上述基础数据, 分别对 8种完井方式的总表皮系数及产能比进行评价 (表 2)。

表 2 不同完井方式总表皮系数及产能比计算结果

阻力区域	总表皮系数	产能比	备注
裸眼完井	01 06567	019729	
裸眼筛管完井	01 06568	019728	
裸眼筛管完井*	01 08162	019665	产出砂沉积层渗透率取 01 8Lm^2
裸眼筛管带管外封隔器 (ECP)完井	01 06568	019728	
裸眼筛管带管外封隔器 (ECP)完井*	01 08162	019665	产出砂沉积层渗透率取 01 8Lm^2
裸眼膨胀筛管完井	01 06568	019728	
裸眼筛管砾石充填完井	01 06615	019727	
尾管射孔完井	01 06336	019737	
尾管射孔筛管完井	01 06336	019737	
尾管射孔筛管完井*	11 41120	016251	产出砂沉积层渗透率取 01 8Lm^2
尾管射孔筛管砾石充填完井	01 43310	018698	

注: * 表示环空 (及射孔孔眼)被地层产出砂沉积充填, 地层散砂堆积渗透率取 01 8Lm^2。

表 2结果显示: ¹ 对于油井水平井, 裸眼系列完井产能比较高, 即使井筒空间被地层砂散砂沉积充填后, 依然可以保持较高的产能比; º 射孔系列完井产能比相对要低一些。若不采用砾石充填, 由于地层出砂, 当井筒空间及射孔孔眼被地层散砂沉积充填后, 产能比将会明显下降; » 对于易出砂地层, 射孔砾石充填完井是一个可行的完井方式。由于井筒空间及射孔孔眼被高渗透性的砾石预充填, 避免了被地层砂充填。其产能比虽然较裸眼系列完井低, 但依然可以稳定保持一个较高的值。

5 结 论

(1) 以水平井基本产能公式为基础, 根据新的物理模型, 研究出一套系统的不同完井方式下各附加渗流区域的层流、紊流表皮系数和完井产能比计算模型, 并给出了应用方法。模型可用于任何完井方式的全部渗流区域的表皮系数分析及产能比的预测, 使用简单, 可操作性强, 对于研究影响油井水平井产能比的主要影响因素及相应的提高产能比的措施具有重要意义。

(2) 根据模型算例分析结果, 对于套管射孔砾石充填类完井方式, 主要的表皮系数来自于钻井污染、射孔压实带和孔眼充填带; 尤其是砾石充填射孔孔眼的表皮系数占据主要地位。实际应用中应尽可能获得较高的砾石充填层渗透率, 同时应尽可能采用较大的孔径和孔密以及较粗的砾石尺寸, 从而得到较小的表皮系数。而射孔几何表皮、井筒内充填、机械筛管等渗流区域的表皮系数较小, 对水平井产能比影响不大。

(3) 与层流表皮系数相比, 各区域的紊流表皮系数很小, 除砾石充填射孔孔眼外, 几乎可以忽略不计。在实际应用中, 可以不考虑紊流表皮系数。

(4) 对于油井水平井, 裸眼系列完井产能比较高, 即使井筒空间被地层砂散砂沉积充填后, 依然可以保持较高的产能比; 射孔系列完井产能比相对要低一些。如不采用砾石充填, 由于地层出砂, 当井筒空间及射孔孔眼被地层散砂沉积充填后, 产能比将会明显下降; 对于易出砂地层, 射孔砾石充填完井是一个可行的完井方式。其产能比虽然比不上裸眼系列完井, 但依然可以稳定保持一个较高的值。

参考文献:

[1] 熊友明, 潘迎德 1 裸眼系列完井方式下水平井产能预测研究 [J]1 西南石油学院学报, 1997, 19(2): 42~ 441

[2] 熊友明, 潘迎德 1 各种射孔系列完井方式下水平井产能预测研究 [J]1 西南石油学院学报, 1996, 18(2): 56 ~ 581

[3] 刘健, 练章华, 林铁军 1 水平井完井总表皮系数计算新方法 [J]1 钻采工艺, 2006, 29(2): 10~ 131

[4] 刘健, 练章华, 林铁军 1 水平井不同完井方式下产能预测方法研究 [J]1 特种油气藏, 2006, 13(1): 60~ 631

[5] 曾文广, 米强波 1 水平井射孔完井表皮系数分解计算方法 [J]1 钻井液与完井液, 2005, 22(S1): 105~ 1081

[6] 窦宏恩 1 预测水平井产能的一种新方法 [J]1 石油钻采工艺, 1996, 18(1): 76~ 781

[7] 张建国, 雷光伦, 张艳玉主编 1 油气层渗流力学 [M]1 东营: 中国石油大学出版社, 1998: 12~ 131

编辑 王 昱

(上接第 76页)

(2) 混注纤维压裂技术, 适用于低渗透油田的压裂施工, 该工艺对裂缝闭合压力无任何影响。实验结果显示, 随着纤维的降解, 人工支撑的裂缝导流能力连续升高, 最终两者差值几乎为零, 证明纤维的加入对裂缝导流能力无任何影响。

(3) 纤维压裂液体系与合适的支撑剂配合使用, 可以最大限度提高裂缝的导流能力。

(4) 加入纤维可以减缓支撑剂的沉降速度, 提高悬砂性能, 改善裂缝铺砂剖面, 提高改造效果, 且可以因此减少聚合物等增粘剂的加入量, 更有利于保护储层, 优化导流能力, 提高产量。

参考文献:

[1] 陈冬林, 张保英, 等 1 支撑剂回流控制技术的新发展 [J]1 天然气工业, 2006, 26(1): 101~ 1031

[2] Nimerikkh, McConnell, s, Samuelson1 Compatibility of resin- coated proppant with cross- linked fracturing flu2 id[C]1 SPE20639, 2009: 29~ 331

[3] Rickards M J, et al1 Proppant? We don. t need any prop2 pant[C]1 SPE38611, 1997: 5~ 81

[4] Philrace, Norbertobeig, Giler, Ginodi, Lullol New tech2 nique for proppant flow back and improved fracture con2 ductivities[C]1 SPE69580, 2001: 25~ 281

[5] Wood W D, et al1 Ultra- lightweight proppant develop2 ment yields exciting new opportunities in hydraulic fractu2 ring design[C]1 SPE84309, 2003: 5~ 81

[6] 于庆红, 王宏飞, 等 1 树脂包覆支撑剂控制回流方法研究 [J]1 石油钻采工艺, 2005, 27(1): 66~ 681

[7] 王锦生 1 地层深部纤维防砂工艺技术 [J]1 石油天然气学报, 2007, 29(3): 436~ 4381

[8] 李鹏, 赵修太 1 纤维复合防砂技术的研究及现场应用 [J]1 特种油气藏, 2005, 12(4): 87~ 891

[9] 张绍彬, 谭明文 1 实现快速排液的纤维增强压裂工艺现场应用研究 [J]1 天然气工业, 2005, 25(11): 53~ 551

[10] Engel J N, et al1 A mechanical methodology of improve proppant transport in low- viscosity fluids application og fiber- assisted transport technique in east texas[C]. SPE91434, 2004: 15~ 171

编辑 王 昱

has threshold pressure gradient, and the mobility of water-free heavy oil is closely related to pore throat size and viscosity. This ex2 periment model simulates the flow condition of heavy oil in rock pore throat, verifies the rheological property of heavy oil in under2 ground formation, and is a reference to recovery of heavy oil reservoir
Key words heavy oil; viscosity; rheological curve; threshold pressure gradient

Application of high temperature gas drive in ultra heavy oil development

MA Hong-bo
(Liaohe Oilfield Company, PetroChina, Panjin, Liaoning 124010, China)

Abstract The recovery problems exposed in the middle and late stage of cyclic steam stimulation for ultra heavy oil in Liaohe oil province have been tackled by the synergistic effect of CO_2 and other resultant of reaction generated when high temperature gas drive system is injected into formation as well as surfactant to attain the effect of improving steam swept volume and oil displacement effi2 ciency. The high temperature gas drive agent developed through study is good at foaming and viscosity reduction and is non-pollu2 tive to oil reservoir. Successful application of this technology has provided a new way of improving CSS effect for ultra heavy oil wells in later cycles and has promising application future in heavy oil recovery industry
Key words ultra heavy oil; cyclic steam stimulation; high temperature gas drive agent; high temperature foam; dissolution drive; Liaohe oil province

Numerical simulation of fracturing in water injection well for South Zhuang 74 low permeability reservoir in Shengli oilfield

QU Zhan-qing, FAN Fei, WEN Qing-zhi, HU Gao-qun, ZHANG Xiu-qin
(China University of Petroleum, Dongying, Shandong 257061, China)

Abstract Physical model and mathematical model of reservoir and fractures have been built to perform numerical simulation for hy2 draulic fracturing in a water injection well of South Zhuang 74 low permeability reservoir. The influence of input horizon permeability on water injection rate is analyzed, and fracture radius and fracture flow capacity are optimized. The optimized fracture radius is 0.30-0.35 and fracture permeability 1 000-2 000 Lm^2. Study shows that formation pressure will increase with the increasing of fracture radius and fracture permeability, and the influence of increased fracture radius on formation pressure is greater than that of increased permeability
Key words numerical simulation; fracture flow capacity; fracture radius; formation pressure; South Zhuang 74 low permeability reservoir

Fracturing by blending fiber in Hailar Oilfield

LIU Qi, LIU Miao, LI Cun-rong, ZHAO Hao-wei
(Daqing Oilfield Company, PetroChina, Daqing, Heilongjiang 163000, China)

Abstract Reservoirs in Bei 301 Block of Hailar Oilfield have problem of most proppant near wellbore flowing back during fracturing process and fractures close partially or entirely. Carbon fiber sand control technique is tested both in laboratory and on site by making ad2 vantage of fiber that is physically stable and can form spatial net structure. The study shows that the technique of fracturing by blending fi2 ber, i.e. directly blending carbon fiber into fracturing fluid, is feasible. Carbon fiber has similar sand control effect with encapsulated ce2 ramsite, moreover, it can improve sand suspension property of fracturing fluid, fracture conductivity, and stimulation result. This study provides technical support to reservoir stimulation in Hailar Oilfield and can be referred to for fracturing in similar reservoirs
Key words fracturing; proppant; back flow; encapsulated ceramsite; fiber sand control; flow conductivity; Hailar Oilfield

A new model of skin factor and productivity ratio evaluation for horizontal wells with various completion systems

DONG Chang-yin, WU Long, WANG Ai-ping, ZHANG Qi
(China University of Petroleum, Dongying, Shandong 257061, China)

Abstract This paper addresses the additional flow resistance area formed in 8 leading completion systems of horizontal wells, which is divided into several areas from distant formation to inside wellbore including outside casing annular area, perforation compaction area, perforation hole packing area, and inside casing packing area in order to give a uniform formula of horizontal well productivity with consideration of skin factor. According to an assumed physical model, the calculation method of laminar flow and turbulent flow

pressure drop and skin factor for the above areas is evolved and the calculation model for total skin factor and productivity ratio of horizontal wells with various completion styles is developed. This model can be optionally and easily used to analyze the skin factor of all flow areas and the productivity ratio of all well completions. A case study has analyzed the skin factor of each flow resistance area, the impacts of contaminated zone, perforation parameters and packing zone permeability on productivity ratio, and proposed methods of improving productivity ratio.
Key words: horizontal well; gravel pack; well completion system; skin factor; productivity ratio; pressure drop; productivity evaluation

The necessity of acid fracturing treatment for high sour gas wells

HU Jing-hong[1], HE Shun-li[1], YANG Xue-feng[2], WANG Bao-zhu[3]

(1. MOE Key Laboratory of Petroleum Engineering, China University of Petroleum, Beijing 102249, China;

2. Southwest Oil & Gas Field Company, PetroChina, Chengdu, Sichuan 610051, China;

3. Changqing Oilfield Company, PetroChina, Yan.an, Shaanxi 716000, China)

Abstract: Hydraulic fracturing and acid treatment are main stimulation measures for low permeability reservoir. For high sour gas wells, in-depth study is needed for the necessity of acid fracturing for reservoir stimulation. Numerical models of gas percolation are respectively built for acid fracturing and non-acid fracturing wells based on experiments of permeability damage due to sulfur deposit with carbonate cores of different permeability. Bottom hole pressure drawdown curves are generated for both acid fracturing and non-acid fracturing wells under fixed production. The results show that sour gas well can implement acid fracturing, which can increase gas flow conductivity, slow down pressure drop under certain quota allocation of production, delay sulfur precipitation time, and improve gas recovery ratio. This study enriches and improves the theory of acid fracturing for sour gas wells.
Key words: high sour gas well; acid fracturing; sulfur deposition; numerical simulation; pressure drop curve

Study and application of profile control process for extra-deep heavy oil reservoir

MU Jin-feng

(Tuha Oilfield Company, PetroChina, Shanshan, Xinjiang 838202, China)

Abstract: Profile control process has been studied and applied for water injection well Lu 2-5 in Lu 2 Block of Lukeqin oilfield according to reservoir characteristics, waterflooding performance and the investigation of domestic profile control process for heavy oil fields in order to control water and increase oil production. Good result of liquid reduction and oil production increment has been achieved through close follow-up of well group performance data and systematic analysis. This study pioneers subsequent design and evaluation of profile control process for water wells in Lukeqin oilfield and is promising for popularization and application.
Key words: extra-deep heavy oil; profile control process; application; result; Lukeqin oilfield

A new theory of improving oil recovery factor for oilfields in extra high water cut stage

DOU Hong-en

(Research Institute of Petroleum Exploration & Development, PetroChina, Beijing 100083, China)

Abstract: This paper examines the functions of relative permeability curve, fractional flow equation and Buckley-Leverett equation in the theory of improving oil recovery efficiency by conventional waterflood. Equations of waterflood efficiency and recovery factor are derived based on Buckley-Leverett equation and material balance relationship. It has been analyzed that the ultimate waterflood efficiency is not a constant value according to the practices of improving waterflood oil recovery for high water cut and extra high water cut oilfields in eastern China. The study shows that reservoir pore structure, porosity and permeability, and fluid parameters change with reservoir temperature and pressure at different stages of oilfield development. As the fluid is increasingly produced, the property of the fluid especially the viscosity will change a lot. It is proposed through theoretical analysis that the relative permeability curve is non-continuous during oilfield development process, the two end point values, K_{ro} and K_{rw}, change over time, and residual oil saturation is not a constant value and the limit is zero. This new theory is a challenge to traditional waterflood theory and needs to be further proved through theoretical and experimental studies.
Key words: oilfield of high water cut; improved oil recovery; displacement efficiency; relative permeability; new waterflood theory