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逆土酸增注技术在大港油田的推广与应用

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摘要 逆土酸系指氢氟酸浓度和用量高于盐酸浓度和用量的土酸,它处理地层的机理与土酸相同。在大港油田的逆土酸酸液中加入一种可以抑制氟化物沉淀或絮结成胶状物的"溶蚀剂",避免了地层酸化后新的堵塞。用高浓度大剂量的氢氟酸对泥质堵塞为主的地层解堵和在改造以粘土胶结为主的泥质砂岩地层或钻井液堵塞中的碳酸岩成分较少时,大大增强了酸液对泥质堵塞物的溶蚀能力,所以逆土酸对地层渗透性的改善程度就优于常规土酸。

主题词 高 浓度 氢氟酸 土酸 溶剂 酸化 地层 解堵

作者简介 游亨淮,1937年生。1958年毕业于重庆石油学校钻井专业,主要著作有《水力式封隔器》、《SY5468—92油管输送射孔—钻杆测试联作技术规程》、《井下作业工》(主编)等10余册,主要论文有《低压清蜡》、《管柱轴向负荷试验的初步分析》、《分层定量配水》等50余篇,现任井下作业公司副总工程师。 南守芝,1960年生。1980年毕业于天津大港石油学校采油工程专业,现从事油田化学及油层酸化研究工作。主要论文有《磁化可提高酸化效果》、《油田酸化缓蚀剂CIDS—1》、《缓蚀剂现状及今后发展》等。

改善注水井吸水剖面,提高中、低渗透层的渗透率和解除注水井因注入水水质原因造成的地层堵塞,国内外普遍采用的方法是土酸处理。土酸中的氢氟酸对砂岩中的一切成分(石英、粘土、碳酸盐)都有溶蚀能力,但它不能单独使用,而要和盐酸混合配制成土酸。依靠土酸中的盐酸溶蚀碳酸盐类,维持酸液较低的pH值;依靠氢氟酸溶蚀泥质和部分石英颗粒。这样就能较好地清除井壁的泥饼及地层中的粘土堵塞,恢复和增加井筒周围地层的渗透率。大港油田研究应用的逆土酸增注技术,对地层的解堵效果明显好于常规土酸。

一、逆土酸处理机理

逆土酸系指氢氟酸浓度和用量高于盐酸浓度和用量的土酸。它处理地层的机理与土酸相同,即用盐酸溶蚀碳酸盐,用氢氟酸溶蚀泥质、石英砂等,但由于氢氟酸的浓度和用量大于盐酸,所以对泥质堵塞为主的地层解堵酸化和在改造以粘土胶结为主的泥岩地层,或钻井液堵塞中碳酸盐类成分较小时,大大增强了酸液对泥质堵塞物的溶蚀能力,逆土酸对地层的改善程度优于常规土酸。

二、逆土酸溶蚀试验

1. 高岭土、膨润土酸蚀试验 试验条件:高岭土、膨润土试样各取4g,酸液50mL,在不同温度、常压下试验(见表1)。

由表1可知,逆土酸(3%～4%HCl+6%～8%HF)溶蚀高岭土、膨润土的能力较盐酸(20%)、常规土酸(12%HCl+3%HF),分别高出5倍以上和30%以上。

表1 逆土酸、常规土酸和盐酸溶蚀高岭土、膨润土试验数据对比

岩 石	试验条件	20%HCl	12%HCl+3%HF	3%HCl+6%HF	4%HCl+8%HF
高岭土	常温	0	20	45	55
溶蚀率	50℃	2.5	45	62.5	70
(%)	90℃	15	46.5	67.9	72.8
膨润土	常温	7.5	32	62.5	65
溶蚀率	50℃	13.8	51.3	65	72.5
(%)	90℃	20	52.3	71.3	73.0

2. 岩心酸蚀试验 取板深51井泥质砂岩岩心试样8g,酸液50mL,在常温(23℃)常压下试验,结果是逆土酸溶蚀能力比常规土酸高(见表2)。

表2 逆土酸、常规土酸对板深51井泥质砂岩溶蚀试验数据对比

板深51井泥质砂岩	12%HCl+3%HF	15%HCl+4%HF	4%HCl+6%HF
溶蚀率(%)	17.5	20.0	22.5

从上述两个试验看出,逆土酸的溶蚀泥质能力大于常规土酸。

三、逆土酸的配方选择及工艺配套技术

1. 氢氟酸能溶蚀地层中的多种矿物,亦会产生新的沉淀,堵塞地层 氢氟酸与石英(SiO_2)反应、氢氟酸与粘土反应生成的H_2SiF_6和H_3AlF_6与地层中的Na^+、K^+等离子结合,生成不溶于水的Na_2SiF_6、Na_3AlF_6、K_2SiF_6和K_3AlF_6。而H_2SiF_6和H_3AlF_6都能在水中分解成SiF_4和AlF_3,有可能产生$Si(OH)_4$和$Al(OH)_3$沉淀。所以氢氟酸能溶蚀多种矿物,亦会产生新的沉淀,堵塞地层。

2. 逆土酸配方选择试验

(1)用盐酸预处理地层以溶解注水井的堵塞腐蚀物(如氧化铁、硫化亚铁等)、碳酸盐岩(如石灰岩、白云岩等),中和地层水的Na^+、K^+等。

(2)酸液中加入"溶蚀剂"以抑制CaF_2、K_2SiF_6、Na_2SiF_6、K_3AlF_6和Na_3AlF_6等沉淀或絮结成胶状物。

①"溶蚀剂"对CaF_2的溶蚀能力试验。在8.7g溶蚀剂内加入1.5gCaF_2,在1.5h常压下,加温,观察溶蚀剂对CaF_2的溶蚀能力(见表3)。

表3 溶蚀剂对CaF_2的溶蚀能力试验数据

反应温度(℃)	8.5	20	50	70	90
溶蚀能力(g/kg)	21.1	29.6	53.2	63.4	78.0
溶蚀率(%)	11.6	16.2	29.1	34.7	42.7

试验表明,随着温度的升高,溶蚀剂对CaF_2的溶蚀能力及溶蚀率均增大。

②"溶蚀剂"对热1井灰岩溶蚀能力比较试验。分别在表4各种酸液中加入2g热1井灰岩岩样,在常温、常压下反应10min,试验其溶蚀能力。

表4 溶蚀剂对热1井灰岩溶蚀能力比较试验

酸液配方(50mL)	15%HCl	18%溶蚀剂	土酸	土酸+15%溶蚀剂	逆土酸+5%溶蚀剂
溶蚀率(%)	65.5	66.5	22.5	65.0	57.3

试验表明18%的溶蚀剂效果最好,常规土酸最差。

③“溶蚀剂”抑制 CaF_2、K_2SiF_6、Na_2SiF_6 沉淀试验。把热 1 井灰岩加入到常规土酸、逆土酸酸液中，氢氟酸中加入硝酸钾、氯化钠，使其产生 CaF_2、K_2SiF_6、Na_2SiF_6 沉淀或絮状物，然后用溶蚀剂解除，试验溶蚀剂抑制这些沉淀物的能力。试验结果表明，用 5%～10%的溶蚀剂就能达到满意的无沉淀效果。

①“溶蚀剂”与酸液中其它各种添加剂的配伍性试验。酸液中常用的添加剂有金属防腐剂(LG－1)、铁离子稳定剂(913)、助排剂(CL－606、HZ－FC3B)、粘土防膨剂(HG－5、A－25)、互溶剂、表面活性剂等，室内观察 3mL 溶蚀剂在 80℃、12h 内与 500mL 的各种添加剂配伍的情况，试验结果表明配伍性良好，均无沉淀。

⑤“溶蚀剂”与地层水的配伍性试验。地层水有不同的水型，通过溶蚀剂与之配伍性试验，在 60℃、12h 内观察结果是配伍性好，无沉淀。

上述五项试验结果表明，“溶蚀剂”既能抑制氟化物沉淀，又能与各种酸化添加剂有较好的配伍性。

(3)解除无机堵塞与有机堵塞要同时并举。根据对大港油田注水井堵塞机理研究，大港油田注水井(尤其污水回注井)有机物堵塞占 40%～60%，主要是回注污水的死油(石蜡和沥青胶质等)，它们吸附在岩石表面或充填于岩石孔隙中，使注水困难，而且在酸处理时阻止了酸液与岩石矿物和堵塞物的作用。因此逆土酸解除无机堵塞和清洗剂解除有机堵塞相结合效果最好。具体做法是：①用刮削器刮削套管内壁，用温度高于 80℃热水(在热水中加入清洗剂更好)彻底冲洗，使井筒及油层部位清洁。②在注入酸液前，先向油层注入清洗剂，清除岩石表面的有机物(如石蜡、沥青、胶质等)。

经室内多次筛选和试验，使用的 BHQ－2 清洗剂具有原油降粘、降凝和溶蜡、溶沥青性能较强的特点(见表 5、6)。

表 5 50℃下清洗剂降粘、降凝试验数据

清洗剂	井号	溶剂量(%)	原油粘度/加溶剂后粘度(mPa·s)	降粘率(%)	原油凝固点/加溶剂后凝固点(℃)	降凝率(%)
PS1	官 967	1.5	433.68/48	88.93	39/33	15.38
BHQ－2	官 967	0.5	433.68/116.76	73.08	39/34	12.82
	枣 1218	0.5			39/34	12.82
		1.0			39/31.5	19.23

表 6 50℃下清洗剂溶蜡、溶沥青试验数据(常温、常压)

清洗剂	溶蜡速度(mg/mL·min)	溶沥青速度(mg/mL·min)
HR－1	7.04	14.5
ST－3	7.15	13.6
LG－2	7.24	15.8

③针对大港油田地层特点，采取防膨、防铁离子沉淀、防乳化等措施。如枣园油田、孔东油田、自来屯油田的孔一段油层，粘土矿物中的蒙脱石、伊/蒙混层、伊利石含量很高，占 70%以上，因此酸化的同时必须采用防膨措施；而枣园油田孔二段、自来屯油田孔一段油层绿泥石含量很高，一般占粘土矿物的 20%以上，最高达 42.2%，因此酸化时要特别注意铁离子沉淀。

目前常用的防膨剂很多，经筛选，大港油田逆土酸施工中主要用 HG－5 和 A－25 防膨剂

(防膨胀率均大于95%)。所用铁离子络合剂为913(异抗坏血酸,在100℃常压下络合铁离子能力为62.5g/L)。

油、气、水井经酸化作业后,尽管油层流体通道得到扩大,但通道岩石表面性质会发生变化,此变化会对流体的流动产生阻力,严重时导致酸化不仅不能解堵,反而形成新的堵塞。因此在酸化施工中采用互溶剂与酸同时处理油层。互溶剂有3个作用:(1)能防止岩石表面润湿反转、维持地层原有的润湿性;(2)具有破乳作用;(3)能消除粘土晶格膨胀。互溶剂的这3个作用,对增大酸化效果有极大的作用。

综上所述,大港油田逆土酸的基本配方是:6%HF+4%HCl+(3%~6%)溶蚀剂,针对各施工井的特殊地质情况再加粘土防膨剂、铁离子稳定剂、油层清洗剂、互溶剂、破乳剂等。

四、现场试验情况

从1995年8月在小10-3-3井开始试验,至1996年10月底,逆土酸增注在大港油田已施工8口井,成功率100%,据可对比的6口井统计,有效率100%,与同期施工的土酸增注井比较,施工成功率及效果都比较好。如小5-3-3井枣Ⅴ油层,泥质含量14.24%~41.1%,过去虽经酸化但效果不佳,逆土酸酸化后,日增注水达157m³。小5-1井枣Ⅲ、枣Ⅳ油层,泥质含量7.15%~54.27%,过去注不进水,土酸处理后效果不好,1996年2月10日逆土酸酸化后,日增注水69m³,到1996年10月31日仍然有效,已累计增注水21 162m³。

五、结论与建议

1. 对于注水井腐蚀物堵塞的解堵和改善泥质成分含量较高的油层,逆土酸处理优于土酸处理。基本解决了大港油田注水井高含泥质地层长期不能解决的增注难题,尤其在小集油田效果非常明显,使酸处理增注措施有效率达100%。

2. 逆土酸处理的成败关键在于正确选用抑制氟化物沉淀的"溶蚀剂",否则氢氟酸虽能溶蚀多种矿物,亦会产生新的沉淀或絮结成胶状物,堵塞地层。

3. 注水井吸水能力下降原因是多方面的,逆土酸处理要结合作业井具体情况进行综合治理,包括同时解除无机和有机堵塞、防止粘土膨胀和铁离子沉淀,对于泥质含量特别高的油层还可以进行压裂闭合酸化,深部处理逆土酸可与低伤害酸组合使用。

作者附言:参加本项目研究的主要人员还有曹国玺、刘春祥、李义富、熊先齐、于庆国等,在此深表感谢。

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tion of fluid and provided the basis for the parameter design of the system. The temperature calculation is conformity with reality. The test showed that the artificial lift method had a better thermal recovery effect.

Subject heading jet pump electric submersible pump combination deep well thermal recovery temperature distribution field testing

THE CHARACTERISTICS OF CAVITATION EROSION FOR HYDRAULIC JET PUMP

by Wang Changbin, Wang Chuncui, Guo Xia

Abstract The cavitation erosion during the operation of jet pump can reduce pump efficiency and the operating life of pump, So no cavitation erosion is an important condition that the jet pump is chosen during application. In order to distinguish and predict whether cavitation erosion will occur or not during the operation, the calculating expression of ultimate flow ratio M_c which can distinguish cavitation erosion characteristics under normal conditions was derived from the Bernoulli equation, and furthermore, the calculating expression of ultimate submersion rate f_h which can guarantee against occurrence of cativation erosion during the operation was also obtained. The ultimate constant I_c of cavitation erosion was discussed by comparing the calculated result with Brown method. It was known that the theoretical value of I_c should be 1.0 and the effect of density ratio on cavitation characteristics was analyzed.

Subject heading jet pump cavitation erosion characteristics flow

RESEARCH AND APPLICATION OF COMPLEX FRACTURING TECHNIQUE

by Yang Baojun, Hui Chunlan

Abstract The complex fracturing technique is a new kind of stimulation technique .hich can combine high energy gas fracturing with conventional hydraulic fracturing. This paper discussed the fracture initiation mechanism of complex fracturing technique, gave the design criteria of it and analyzed the effect of the technique on casing and cement. And the application effect was also analyzed. The field test of 33 wells showed that the technique had advantages of less additional cost, obvious effect of stimulation and small technical risk and so on, it is an effective measure which can improve low—permeability oil—gas reservoir.

Subject heading high energy gas fracturing hydraulic fracturing synergism effect research

STUDY AND APPLICATION OF ACIDIZING TECHNIQUE IN CHUNHUA OILFIELD

by Zhang Furen, Liu Xihua, Yang Tongyu, Feng Yongyong

Abstract This paper aimed to further improve the acidizing effect in Chunhua oilfield, lower the cost and increase economic benefit. The laboratory study, comparative analysis and evaluation of acidic fluid and various additives which are currently used in Chunhua oilfield were conducted systematically in view of reservoir and flow characteristics of the oilfield. So various additives and acidic fluid which applied to the oilfield were optimized: acidic stabilizer DTE or ZJH—03, corrosion inhibitor KH—91 or LG—II, mutual solvent SCH—1; pretreatment acidic fluid: 12%～15%HCl + 0.5%NTS + 2%LG — II + 2%ZJH — 03; host acidic fluid: 25%organic acid (FAC) + 4%～5%SCH—1. The field application showed satisfactory results with 1: 6.2 input—output ratio and obvious economic benefit.

Subject heading Chunhua Oil Field formation damage acidizing additive test research

THE POPULARIZATION AND APPLICATION OF INJECTION WELL STIMULATION TECHNIQUE WITH REVERSED MUD ACID IN DAGANG OILFIELD

by You Henghuai, Nan Shouzhi

Abstract The reversed mud acid is the mud acid whose concentration and volume of hydrofluoric acid is higher than that of hydrochloric acid, its treatment mechanism is identical to the mud acid. A kind of dissolution agent that can prevent fluoride from depositing or flocculating into cement was added into the acidic fluid of reversed mud acid in Dagang oilfield to avoid new plugging after acidizing the formation. The capacity which acidic fluid dissolute shale plugging was increased greatly when the formation plugging mainly made up of shale is removed by using hydrofluoric acid with high concentration and content, the shaly sand formation which mainly consist of clay cementation is improved or there is less carbonate ingredient in mud plugging. So the reversed mud acid can improve formation permeability better than the conventional mud acid.

Subject heading high concentration hydrofluoric acid mud acid solvent acidizing formation plug removal

THE DEVELOPMENT AND APPLICATION OF HIGH — EFFICIENT VISCOELASTIC PROFILE CONTROL AND WATER SHUTOFF AGENT

by Wang Jian, Han Xianqing

Abstract The high—efficient viscoelastic profile control and water shutoff agent which applied to plug medium—low permeability reservoirs was developed on the basis of the viscoelastic mechanism of high polymer. The agent can be used to adjust the water injection profile among payzones or in different directions among payzones in order to enhance oil recovery. It has characteristics of good properties and low cost and was applied in some oilfields with the good effect of water control and oil increment. So further popularization and application are needed.

Subject heading profile control viscoelastic property water shutoff agent integration effect testing

THE PLUGGING MECHANISM OF WATER INJECTION WELLS IN CHENGBEI AND SUIZHONG 36—1 OILFIELD OF BOHAI

by Shen Yanlai, Liu Dehua, Ji Yanzhang, Chen Jianwu,

Abstract This paper introduced the physical properties of reservoir and the completion method of Chengbei and Suizhong 36—1 oilfield. The mechanism of water—sensitive plugging, acid—sensitive plugging, solid particle intrusive plugging, fine particle migration plugging, formation scale deposit plugging, sump oil plugging and formation sand production plugging in water injection wells of two oilfields was studied by cation exchange capacity determination of core, volume flow test, dynamic deposit test and theoretical prediction, the test of the effect of temperature variation on the permeability of water phase, the sensitivity test and on—site water—injection data. The main reasons resulted in plugging in water injection wells of Chengbei oilfield were water—sensitive plugging, sump oil plugging, solid particle intrusive plugging and formation sand production plugging; the reasons for Suizhong 36—1 oilfield were sump oil plugging, solid particle intrusive plugging, formation sand production plugging and scale deposit plugging. This paper provided the basis for choosing plug removal method, developing plug removal agent, choosing scale inhibitor and carrying out plug removal. It had a directive significance for water flooding in two oilfields.

Subject heading Chengbei oilfield Suizhong 36—1 oilfield water injection well plugging mechanism research

INTRODUCTION OF PRESSURE MEASUREMENT SYSTEM WITH CAPILLARY TUBING

by Gong Hengxin, Rao Wenyi, Zhu Jiahuan

Abstract It kept being a problem to monitor the downhole pressure in mechanical oil