埕岛油田海上气井排水采气工艺模式

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摘要:海上气井水淹后,排水采气工艺的选择必须考虑特定生产环境的限制。以埕岛油田埕北古 5 井为研究对象,根据不同阶段的产液情况,开展有针对性的海上气井排水采气工艺模式研究,提出了适用于海上气井经济有效的排水采气工艺。根据历史生产数据,对常用井筒温度模型和压降模型进行了拟合,筛选出基于多层圆筒壁传热机理的温降模型和修正的 Hagedorn - Brown 压降模型,以此来计算井筒气液两相沿井筒的温度和压力分布。根据选择的模型,针对埕北古 5 井对电潜泵排水采气工艺进行了设计,当油管内径为 51.8 mm,泵挂深度大于 2 233.5 m,选择泵型为 Centrilift - GC160 系列泵时,水淹气井恢复了生产,并在产液量为 152 m^3/d 的情况下保持稳定生产,该井复活后累积产气量为 170×10^4 m^3。

关键词:气井 压降模型 温降模型 排水采气工艺 埕岛油田

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与陆上气田实施排水采气工艺相比,海上平台气井受环境、空间等诸多因素限制,排水采气工艺实施的难度较大。以埕岛油田埕北古 5 井为研究对象,根据不同阶段的产液情况,开展有针对性的海上气井排水采气工艺模式研究,提出适用于埕岛油田海上气井切实可行、经济有效的排水采气工艺,以期最大限度地提高天然气采收率,为海上气井在各生产阶段采取最为适宜的排水采气工艺提供参考。

1 区域开发概况

埕北古 5 井是埕岛油田一口凝析气井,储集空间为裂缝—孔洞型,属底水凝析气藏,含气面积为 0.78 km^2,天然气地质储量为 2.55×10^8 m^3。投产初期产气量为 8.2×10^4 m^3/d,产水量为 2 ~ 3 m^3/d,后因大量出水关井,累积产气量为 $3\ 963.979\times10^4$ m^3,天然气采出程度仅为 15.4%。后对气水界面附近井段封堵后开井生产,由于层间水窜严重,气井最终水淹停产,堵水工艺未收到实质性效果。

2 排水采气工艺筛选

通过多年的改进和发展,已形成一套适合各类气藏、比较完善的排水采气配套工艺,如优选管柱、泡沫排水采气和气举等[1-5]。这些工艺都具有其自身的优点和局限性(表 1),如何根据具体井况和不同排水采气工艺的适应性,有针对性地选择适合某井或某区块的排水采气工艺成为排水采气的关键。

表 1 排水采气工艺特点

排水采气工艺	最大排液量/($m^3\cdot d^{-1}$)	最大井深/m	斜井适用情况	运转效率
优选管柱	100	4 000	适宜	高
泡沫排水采气	120	4 500	适宜	高
气举	500	4 910	适宜	高
柱塞气举	50	3 000	受限	较低
抽油机排水采气	70	4 422	受限	一般
电潜泵	500	4 752	适宜	较高
射流泵	300	2 800	适宜	较低
抽汲	50	3 000	受限	较低
气举—泡沫排水采气	>400	>3 500	适宜	一般

通过分析排水采气工艺在中国各气田的应用,结合各种工艺的可靠性和成熟性,依据埕北古 5 井的产液特点,提出了海上气井在不同开采阶段的排水采气工艺(表 2)。

埕北古 5 井关井前平均产液量为 160 m^3/d,已超过了优选管柱、泡沫排水采气、泡沫排水采气—优选管柱应用上限,故已不再适用,目前最为适宜的排水采气工艺为电潜泵。

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表 2 海上气井不同开采阶段排水采气工艺

开采阶段	产液量/($m^3 \cdot d^{-1}$)	排水采气工艺
出水前期	≤80	优选管柱
出水中期	80 ~ 120	泡沫排水采气
出水中后期	120 ~ 150	泡沫排水采气—优选管柱
出水后期	>150	电潜泵

3 井筒多相管流温降和压降模型

进行电潜泵排水采气工艺设计时，需准确计算井筒气液两相流沿井筒的温度和压力分布。

3.1 温降模型

基于多层圆筒壁传热机理[6]建立了温降预测模型，井筒流体向周围地层传热首先要克服油管、隔热层、油套环空介质、套管、水泥环产生的热阻。结合 Ramey 无因次时间函数[7]，采用哈桑—卡皮尔计算方法，得到井筒温降梯度方程为

$$\frac{dT_f}{dt}=-\frac{2\pi r_{to}U_{to}K_e(T_f-T_e)}{c_pG_t[r_{to}U_{to}f(t_D)+K_e]}-\frac{g\sin\theta}{c_p}-\frac{v}{c_p}\frac{dv}{dt}+\alpha_J\frac{dp}{dt} \quad (1)$$

式中：T_f为流体温度，K；t 为时间，s；r_{to}为油管外径，m；U_{to}为井眼传热系数，W/(m·℃)；K_e为地层传热系数，W/(m·℃)；T_e 为地层温度，K；c_p为流体的定压比热，J/(kg·K)；G_t 为气液混合物质量流量，kg/s；$f(t_D)$ 为无因次时间函数；g 为重力加速度，m/s^2，其值为 9.8；θ 为管斜角，(°)；v 为流体平均流速，m/s；α_J为焦尔—汤姆逊系数，K/Pa；p 为流体压力，Pa。

根据式(1)计算出的井口流体温度与测试值的平均绝对误差为 4.1%，说明基于多层圆筒壁传热机理建立的温降模型准确可靠。

3.2 压降模型

见水气井气液两相管流压降分布规律是分析气井自喷能力、排水采气工艺设计以及优化生产参数的核心理论。常用的两相管流压降计算方法有：Duns－Ros，Hagedorn－Brown，Orkiszewski，Aziz，Beggs－Brills，Mukherjee－Brill 等[8-9]。这些方法均是基于实验数据得到的，都有其适用条件。根据各模型的压力沿井深的变化计算了井口油压(图 1)，当井口油压测试值与计算值一致时，数据点应落在中心线上，数据点越靠近中心线，说明测试值与计算值越接近，模型计算的准确性越好。由图 1 可知，修正的 Hagedorn－Brown 方法计算的井口油压与测试值的平均绝对误差为 8.23%，能满足工程应用要求。因此，选用修正的 Hagedorn－Brown 方法，对埕北古 5 井进行排水采气工艺设计。

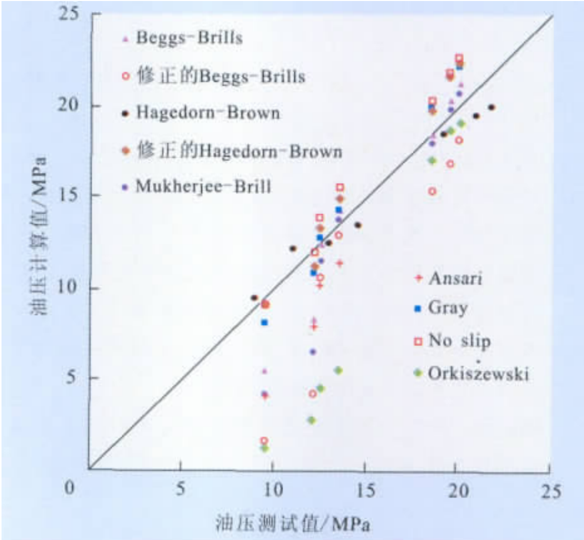

图 1 井口油压测试值与模型计算值对比

4 排水采气工艺设计与应用

根据陆上气田排水采气经验，气井复活时，电潜泵排水量为一般气井正常带水生产时产液量的1.5~2.0 倍。而气井复活生产后，其产液量可根据采液指数方法预测[10]。

4.1 油管内径选择

不同尺寸的油管具有不同的产液量，油管内径选择偏小，流体摩阻消耗大，管段总的消耗压降大；油管内径偏大，液体滑脱损失严重，举升效率下降[11-12]。气井的临界携液量为

$$Q_c = 2.5\times10^4\frac{\pi r^2 p v_c}{ZT} \quad (2)$$

式中：Q_c为气井临界携液量，10^4 m^3/d；r 为油管内径，m；v_c为携带最大液滴的最小气体流速，m/s；Z 为天然气压缩因子；T 为井底温度，K。

根据多层圆筒壁传热温降模型和修正的 Hagedorn－Brown 压降模型，可计算出不同油管内径、不同油压对应的产液量和产气量，油管内径越大，井筒的排液能力越强。

通过对不同井底流压及油管内径下临界携液量的计算可知，油管内径越小，临界携液量越小；井底流压越小，临界携液量越小，小尺寸油管有利于携液。小尺寸的油管可降低滑脱产生的压降，从而提

高井筒的自喷带液能力。

滑脱越少，产生的滑脱损失越小，气体举液效果越明显，排液效果越好。因此，优选油管内径的另一主要任务是减小气液之间的滑脱损失，减小滑脱压降。采用多层圆筒壁传热温降模型和修正的 Hagedorn－Brown 压降模型计算不同尺寸油管下的滑脱压降（表 3），油管内径越大，滑脱压降越大。

表 3　不同尺寸下油管的滑脱压降　MPa

井底流压	油管内径/mm				
	35.8	41.91	44.47	51.84	62
17.74	2.97	3.724	3.648	3.103	2.286
13		3.54	3.457	3.151	2.654
10				3.173	2.819

综合考虑油管内径对埕北古 5 井自喷能力、携液能力和因气液滑脱产生的压力损失的影响，最后推荐选用内径为 51.84 mm 的油管作为更换管柱。此油管可降低滑脱损失压降，减少携液量，提高气井的排液能力；同时不会产生较大的摩阻压降。

4.2　泵挂深度与泵型选择

利用温降与压降模型，计算整个井筒含气率，电潜泵用于辅助排水时，越靠近产层，含气率越低。泵吸入口含气率越低，可降低气体对泵的干扰[13－14]。根据大量出水后期压力分布剖面模拟计算结果，确定泵挂深度应大于 2 233.5 m。

根据气井历史生产情况，复活阶段的目标产液量为 240 m^3/d，辅助排水期产液量为 160 m^3/d，而目标产气量从复活期的 3 000 m^3/d 上升为辅助排水期的 8 000 m^3/d。泵入口的含气率上升，泵效降低，选择泵型为 Centrilift－GC160 系列泵，该泵排液量为 158.99～317.97 m^3/d，泵效大于 50%。综合考虑不同阶段的排液要求，按照复活期生产要求对泵进行设计，设计结果如表 4 所示。

表 4　泵型设计结果

生产阶段	泵级数	泵效，%	功率/kw	入口压力/MPa	出口压力/MPa	扬程/m
复活期	106	57.02	60	13.5	25.13	1 227
辅助排水期	87	50.07	44.8	13.5	25.0	1 220

埕北古 5 井 2011 年 1 月转电潜泵生产后得以复活，初期产液量为 220 m^3/d，产气量为 2 800 m^3/d，至 2011 年 10 月，平均产液量为 152 m^3/d，平均产气量为 6 500 m^3/d，累积产气量为 170×10^4 m^3。

5　结束语

通过筛选最佳的温降和压降模型来确定合理的工艺参数，电潜泵排水采气工艺能成功用于见水气井的复活，对于海上气井见水后排水采气生产具有重要借鉴和指导意义。在对油管内径进行优化过程中发现，排水采气工艺在制定开发方案时就应予以考虑，一方面可延长气井带液自喷时间，另一方面可为后续排水采气工艺的实施节约资源。

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19(2):81-83.

Abstract: Inadequate natural energy and poor transmission of pressure will give rise to deep pressure decline after putting into development in low permeable reservoir. Pressure decline will induce damages to rock physical properties and flowing character, i. e. reservoir rock presents stress sensitivity. Simulating changing process of reservoir pressure by flowing test, threshold pressure gradients at different effective overburden pressures are tested, and relationship between threshold pressure gradients and effective overburden pressures is studied. With mercury-injection test, nuclear magnetic resonance spectrometry analysis and rock mechanics test, changing mechanism for threshold pressure gradients in changing process of reservoir pressure is thoroughly analyzed. It was understood that, the threshold pressure gradients increases with reservoir pressure declines, i. e. threshold pressure gradients is sensitive to stress. It is also indicated that the lower the rock permeability, the bigger the increasing amplitude of threshold pressure gradients, which means that the stress sensitivity is stronger. It is suggested that, when calculating rational spacing between wells, it is necessary to consider the effect of reservoir pressure maintenance level on threshold pressure gradients.

Key words: low permeability; threshold pressure gradient; stress sensitivity; net overlying pressure; pore throat

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Zhang Xing, Yang Shenglai, Zhang Ling et al. Experimental study on factors of KlinKenberg permeability in low permeable gas reservoir. *PGRE*, 2012, 19(2):84-86.

Abstract: CNPC found a low-permeability gas reservoir with CO_2 in Jilin oil fields. Because the rock properties and fluid properties are unique, it is not accurate to analysis the effects of gas slippage effect on KlinKenberg permeability and penetration capacity. In view of this specificity, they are determined and analyzed by single-phase gas flow laboratory experiments. Experimental studies show that the KlinKenberg effect is found in the gas flow process in core and the influence factors are important including the core type, confining pressure, gas type and temperature. The KlinKenberg permeability of porosity core is higher than that of micro-fracture core. With the increasing of confining pressure, the slop of permeability-mean pressure curve is not changed, but the KlinKenberg permeability and its amplitude are decreased. Because of the different molecular weights, the KlinKenberg permeability of carbon dioxide (big molecular weight) is higher than that of natural gas and nitrogen gas (small molecular weight). The influence of temperature on gas flow at low temperature is greater than that at high temperature, that is, the KlinKenberg permeability of 20 ℃ is higher than that of 50, 80 and 140 ℃.

Key words: low-permeability gas reservoir; KlinKenberg permeability; gas slippage effect; influence factor; KlinKenberg effect

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Li Lianjiang. Study on drainage gas pattern for offshore gas wells, Chengdao oilfield. *PGRE*, 2012, 19(2):87-89.

Abstract: After the condensate gas wells have been flooded, the choice of drainage gas recovery plan must be considered with the specific production environmental restrictions. In the paper, according to different stages conditions of the liquid production and gas production in a condensate gas well, the approximate drainage gas process pattern for offshore gas wells is studied by the wellbore temperature and pressure drop models. And, an effective feasible and economic drainage gas technology, the electric pump drainage gas recovery scheme, is put forward. Through the implementation of drainage gas recovery scheme, the natural gas output of the well is improved. The drainage gas schemes adopted by the gas well at different production stage can also be referenced for other gas wells nearby.

Key words: condensate gas wells; pressure drop model' temperature drop model; water-out gas production technique; Chengdao oilfield

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Zhuang Li, Zhang Ling. Growth trend study of proved oil and gas reserves based on the upgrade rate of probable reserves. *PGRE*, 2012, 19(2):90-92.

Abstract: Oil and gas reserves growth trend prediction research is the key factor for the oil company to make exploration and development strategy. From the study of contribution of probable reserves to the increased proved reserves of one oil company for ten years, it shows a steady rate at about 50% in the last three years. Upgrade rate of probable reserves can be classified into yearly increased and accumulative probable reserves upgrade rate. Research shows that the accumulative probable reserves upgrade rate has more significant meaning for the prediction of the growth of incased proven reserves next year. Considering the quality of increased probable reserves is very close in the recent years, based on the relationship of increased proved reserves with the accumulative probable reserves, a formula is summarized for the prediction of increased proved reserves, with convincing results tested with actual data. This method can be used by the exploration and development decision-making departments.

Key words: controlled reserve; proved reserve; contribution of controlled reserve; upgrading of controlled reserve; reserve prediction

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Wang Shuhua, Wei Ping. SEC reserves dynamic evaluation and analysis. *PGRE*, 2012, 119(2):93-94.

Abstract: Since Sinopec's public offering in New York and London in 1999, there are great challenges to bring domestic reserves management more in line with international practice, SEC methods and concepts of oil and gas reserves evaluation are having great shock on the domestic reserves calculation and management. Based on our decade years' experiences in domestic reserves calculation, examination and SEC reserves evaluation, this paper analyzes 5 methods in SEC reserves evaluation: analogy, volume, production decline, material balance and reservoir modeling methods; herein, we present the object, basis, scope and conditions in