海上高温高压井测试技术

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摘　要　南海西部石油公司在其管辖的莺歌海、琼东南盆地中深层勘探中遇到高温高压储层,在中外专家的协助下于1994年7月在水深115 m的崖21—1构造上钻成深度4 688 m的探井,经测试地层压力为105.15 MPa,地层温度206 ℃,获得齐全准确的各项数据。在半潜式钻井平台上进行高温高压井测试是世界石油界探讨和努力解决的难题。防止意外井喷事故是测试的先决条件。对地面设备、井下工具和工艺方法的选取一切应以安全为前提,只有这样才能取全各项资料数据,确保顺利压井以及起出管柱。通过对一些测试成功井的技术总结,提出了对海上高温高压井测试技术的认识和看法,提出了目前存在的问题和今后有待于改进的方向。

主题词　莺琼盆地　油气井　高温地层　高压　半潜式钻井平台　射孔　中途测试

位于南海西部海域莺歌海、琼东南盆地的中深层油气藏,经初步测试,多为高温高压异常,故钻井工艺、完井测试难度极大。1980年对外合作勘探以来,中外方在钻探中遇地层压力系数在1.85以上的井共11口(其中8口井地层压力系数在2.0以上)。由于装备、技术等种种原因,这些井均没有钻至勘探目的层,仅东方1—1—1井和崖21—1—3井进行了(DST)测试:东方1—1—1井在2 580～2 664 m井段测得地层压力系数为2.13,地层温度127.5 ℃;崖21—1—3井在4 629.85～4 639.35 m井段测得地层压力系数2.25,地层温度206 ℃。通过测试较准确地取得了地层产能、温度和压力等数据,在异常井段的钻井、电测、固井、测试等方面积累了经验。同时也暴露出许多有待进一步探索和改进的问题。

国外海上测试技术简况

一直到1990年,国外尚没有资料表明对海上高温高压井可成功地进行测试,只是对单一的高温井或高压井进行过较为成功的测试,并有一定的认识。对高温高压气井的海上测试工作是从1991年开始的,EXPRO、HALLIBURTON、SCHLUMBERGER三家服务公司参与了该类井的施工,较成功的有如下几口井。

1) 1991年7月在挪威北海半潜式钻井平台完成测试,井深4 000 m,地层压力62 MPa,地层温度155 ℃。

2) 1992年2月挪威北海自升式钻井平台完成测试,井深4 511 m,地层压力93.4 MPa,地层温度163 ℃。

3) 1992年5月英国北海半潜式钻井平台完成测试,井深4 228 m,地层压力91 MPa,地层温度149 ℃。

目前,国外已多次在海上成功地对一些高温高压井(最大井深为4 511 m,地层压力93.4 MPa,地层压力系数2.07,地层温度163 ℃)进行了测试,并获得了一定经验。

海上测试高温高压气井存在的问题

在半潜式钻井平台上测试,其风险比在陆地和自升式平台上大,原因如下:①半潜式钻井平台因海底泥线至平台段为漂浮摆动状态,故井口防喷器组(BOP'S)安装在海床上,从防喷器组至钻台只用一层隔水导管相连,相应的各层套管都只连接至防喷器以下的井口内;②海上测试管柱必须利用防喷器组与测试管柱工具,组成完整的安全体系,将产层流体引导至平台上测试,才能完成收集各项参数的工作;③测试结束后必须压井起出测试管柱,安全封井和撤离平台。由于目前还没有成熟的标准工艺,只能由有经验的专家根据地层的特殊条件确定测试可行方案,选择可靠的设备、井下工具、测试仪表和火工

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器材,确定工艺方案,密封件受高温高压油气影响尤其突出。资料表明,还没有一家石油公司和承包商能成功地对地层压力为 103.5 MPa、地层温度为 204 ℃、地层压力系数为 2.2 的气井进行过测试。在半潜式钻井平台上对高温高压并存的气井进行测试仍是世界石油界的技术难题。世界各石油公司、服务商都在投入巨资进行研究,以求联合开发新产品来解决测试工艺技术和工具的难题。

中国海洋石油南海西部公司为解决以上难题进行了大胆的尝试,由于工艺方案、设备和工具选择合理,成功地完成了崖 21-1-3 井的两层测试施工。

崖 21-1-3 井测试工艺方案及简介

1. 测试工艺

经技术综合评价认为:崖 21-1-3 井测试应选用最简单的测试管柱结构,管柱上带有安全阀、循环阀。为防止因重复开关活动造成密封件损坏而引起泄露,全部井下阀均选用一次开或关方案;封隔器选用电缆下入式永久耐高温抗高压型,即满足 H_2S、CO_2 工作条件的 HALLIBURTON 产品;管柱带入与封隔器内孔匹配的密封总成,下部携带射孔枪串。射孔枪串通过封隔器内孔对准射孔井段,密封总成正处在封隔器内孔密封段,构成对管柱与套管环空封隔;安装好平台上的井口设备、流程,射孔和测试。这种测试管柱起下时不用携带封隔器,减低了测试管柱遇阻卡的风险。图 1 是测试管柱结构。

2. 设备、工具器材选择

(1) 井口和地面设备

按崖 21-1-3 井预测地层压力、温度,关井井口压力约为 83 MPa。若天然气流量为 450 000 m^3/d,井口温度可达 107 ℃;若为 550 000 m^3/d,井口温度达 120 ℃。测试时若天然气中混有液体,井口温度将更高。

由于防喷器组、固控设备、测试井口设备的抗温能力只有 130 ℃,测试时必须控制流量,使井口温度在 130 ℃以下。

固井泵应能在极端条件下实施强制压井,泵压在 85 MPa 时排量不应小于 15～20 m^3/h。

(2) 油管选择

采用金属对金属密封的 C-90 油管 FOX 扣型,工作压力 138 MPa,且抗 H_2S、CO_2。石油大学高德利教授组织人员对给定工况条件下的 91.44 mm 和 114.3 mm 油管进行受力分析和强度计算,认为采用 C-90 FOX 扣 114.3 mm 油管作泥线至钻井平台段测试管柱能满足要求。

(3) 地面紧急关停安全保护系统

测试时,地面压力、温度、流量等参数由人工机械和计算机连续监控。测试流程上设置压力、温度感应紧急关停系统,当流程上出现非正常压力和温度时,能自动关井,必要时还可手动操作。流程上设有压力安全阀,任何一段流程上的压力超出设定范围时按程序自动关井,该阀自动开启将天然气排放至专用管路处理。紧急关停阀包括液控海底测试树双球阀、井下防喷阀、地面液控主阀、生产翼阀等。

(4) 射孔工艺

射孔由枪、盲枪、点火头、防沉淀接头和上部管柱构成,油管携带射孔枪(TCP)负压射孔,测试联作管柱(见图 1)具有点火头选择液压/撞击双作用结构,油管加压或投棒均可引爆。

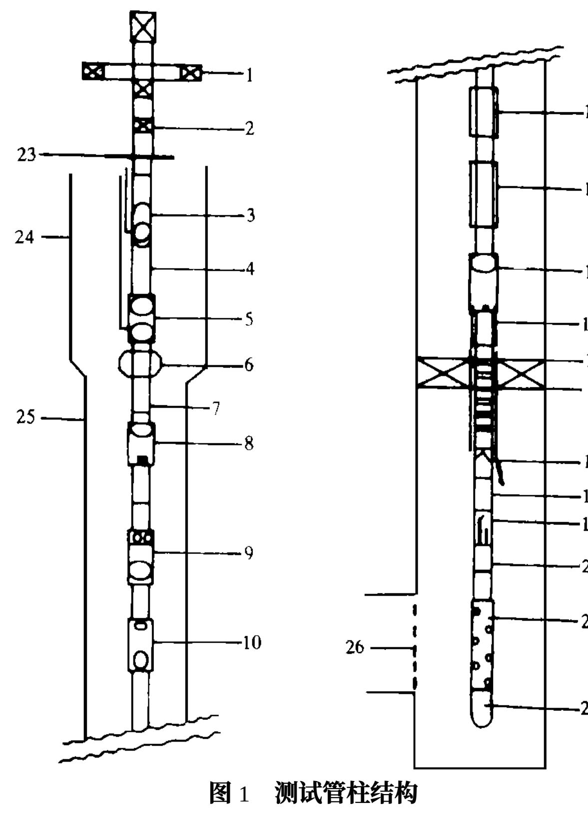

图 1　测试管柱结构

1. 地面测试树;2. 液控总阀门;3. 水下安全阀;4. 114.3 mm FOX 油管;5. 水下测试树;6. 槽型悬挂器;7. 88.9 mm FOX 油管;8. 油管试压阀;9. 单次循环阀;10. 单次安全阀;11、12. 压力计托筒;13. 油管试压阀;14. "G"止动短节;15. 177.8 mm 永久型封隔器;16. 密封总成;17. 防污染接头;18. 73.0 mm VAM 油管;19. 液压棒击两用接头;20. 盲枪;21. 射孔枪;22. 引鞋;23. 钻盘;24. 508.0 mm 隔水管;25. 177.8 mm 套管

(5) 井下测试仪表

目前适用于 176.7 ℃以上温度的电子压力计和

温度计尚不成熟,唯有AMERADA机械压力计和温度计能在210 ℃的高温下正常工作。压力计、温度计用托筒连入管柱下井,连续测量温度和压力。

3.测试成果

1)用密度为2.30 g/cm^{3}的水基钻井液作完井液完成起下测试管柱及负压射孔、下桥塞封堵等工程作业。

2)安全完成了DST_1(4 668.5～4 678.5 m)和DST_2(4 629.85～4 639.35 m)两层的测试,取得产层温度、静止压力、流动压力、恢复压力、产能等数据。DST_2测试井口温度约120 ℃,日产水760 m^3,日产天然气20 000 m^3,另外还有流动—关井、流动—恢复等全套井下连续压力、温度数据。地层压力102.6 MPa,地层温度203.5 ℃,地层压力系数2.25。

4.有待解决的问题

(1)地面设备未受全面考验

崖21—1—3井的特点是:DST_1是高温高压低产层,DST_2是高温高压高产含气水层;天然气中不含H_2S、CO_2,产天然气少,产水多,井口温度高,压力低,没有出现大节流后的低温和水化物冻结等复杂问题;应急关停、安全放空系统没有运作;求产控制容易,井下工具、地面设备没有经历极端条件考验。

(2)无固相溴化锌完井液应用失败

密度达2.3 g/cm^{2}的溴化锌完井液pH值为1。常温试验未加缓蚀剂时,其腐蚀率为0.032 mm/a,加入0.5 %B—1缓蚀剂后,腐蚀率为0.006 mm/a(由于条件限制,未做模拟井况条件下的试验)。从文献获知,每增加10 ℃,腐蚀率增加1倍,认为井温180 ℃时腐蚀率增加18倍,为0.6 mm/a,故可以满足短期测试要求。美国贝克(MILPARK)公司根据密度为2.3 g/cm^{3}的溴化锌完井液的室内试验结果,在现场采用TETRA公司CORSAF"Z"缓蚀剂进行施工,但应用显示在高温作用下分解出大量H_2S气体,为此监测器报警,被迫终止使用。此时,测试油管出现点腐蚀,密封件老化,泥浆泵凡尔密封件疏松散落,循环过程出现胶状固化物堵塞近1 000 m油管,永久封隔器损坏下滑,致使施工失败。取胶状固化物进行室内实验分析,铁总含量达12.8 %,计算的实际腐蚀率高达180 mm/a,高出室温条件下的腐蚀率6 000倍(油科院现场施工总结)。由此结论,溴化锌完井液在高温高压井况条件下对密封件的腐蚀损坏不能低估,有待研究解决。

(3)高密度水基完井液性能难掌握

以上井溴化锌完井液使用失败后,改用高密度水基钻井液作为完井液测试成功,顺利完成了下测试管柱、负压射孔、循环压井、起测试管柱、下桥塞封井等施工作业。美国贝克(MILPARK)泥浆公司提供的高温水基钻井液体系,其密度为2.0 g/cm^2。按实验室配方,膨润土含量应大于22.8 kg/m^{3}时,和其他药品配全后才能达2.0 g/cm^{3}以上比重。但地面配制性能合格后的以上完井液仍不能满足施工要求,在井内循环时,由于高温下膨润土的充分水化,使粘度不断增加,曾出现循环不动的极差状态。为改进这种情况,经半个月在井内反复循环调配,48 h静止观察,用泥浆泵进行井下循环测试启动压力和循环压力,最后选定循环出口样品性能指标为:pH值11,漏斗粘度37 s,塑性粘度18 MPa·s,屈服值30 Pa,动切18 MPa,终切23 Pa,密度2.2 g/cm^3,膨润土含量17.12 kg/m^3。应用如上性能的完井液,最后顺利完成了该井的两层测试施工。

(4)射孔工艺问题

在半潜式钻井平台上,若采用电缆射孔,无法解决高压防喷问题。油管携带射孔枪(TCP)射孔是在管柱下完且安装好井口设备后,在严格控制下进行引爆射孔的,安全有保障。目前使用的防沉淀接头、点火头还不能有效克服高密度泥浆和高温影响。另外,沉淀物堵塞点火头,高温高压影响致使机械动作不准确等多项问题仍有待解决。

(5)固井、封井注水泥技术尚不成熟

在固井和封井注水泥时,水泥浆、前置液、后置液密度均比压井液(钻井液)密度小,由此如何防止施工过程高密度压井液被稀释沉淀和卡钻,以及如何在高温高压下安全施工有待进一步解决。

几点体会

通过现场实践认识到,高温高压井的成功与否,与如下几点有直接的关系。

1.组织落实及时

西部公司为完成高温高压井测试,抽调技术骨干成立项目组,进行技术方案调研。测试期间召开专门会议进行组织分工,成立测试现场指挥组和后勤支持组,24 h值班支持。测试开始后启动应急力量,开通平台至基地专用通讯线路,为安全测试提供了坚实的保障。

2.技术准备充分

1)广泛进行国内外高温高压气井测试的调查研究。通过多种形式了解、分析已有测试井的成败经验,制订测试可行方案。

崖城 21 —1 —3 井钻井技术

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摘　要　南海西部石油公司自营钻探成功的崖城 21 —1 —3 井 ,井深 4 688 m ,是一口高温高压并存的天然气深探井。测试证实 ,地层孔隙压力达 104. 70 MPa ,井底温度为 206 ℃,压力梯度为 22. 76 kPa/ m ,地温梯度达 4. 42 ℃/ 100 m。崖城 21 —1 —3 井是在对同构造上的 1 井和 2 井的认识基础上 ,应用成熟、实用的先进技术 ,克服了施工中出现的复杂情况钻成的。通过分析总结 1 井和 2 井的资料 ,在充分认识地层压力和地层破裂压力的基础上 ,共提出 4 套井身结构方案 ,经过充分比较 ,采用方案四 ,并针对该方案的不足之处 ,采取相应的技术措施 ;在施工过程中遇到了严重的套管磨损问题 ,通过修补回接更换部分套管和对套管进行保护 ,保证了 Ø244 mm 套管下到设计井深 ;通过评估 ,选择了 Milpark 公司的 Pyro —drill 高温水基钻井液体系 ,在实际使用中 ,通过严格控制膨润土含量 ,钻井液显示出良好的高温热稳定性 ;在密度为 1. 33 g/ cm^3 的钻井液中固 Ø178 mm 尾管 ,技术难度较高 ,固井获得成功 ,为以后积累了经验。在回顾这口井从设计、作业准备到现场施工的基础上 ,总结了这口井使用的技术 ,并对适应于高温高压深探井的钻井技术进行分析探索。

主题词　南海地区　高温　高压　天然气　探井　井身结构　钻井液　固井

在南海西部莺琼盆地同时存在高温高压 ,给钻井工程带来了极大的困难和风险。从 1984 年 3 月以来 ,在该地区钻的 11 口高温高压探井中 ,只有南海西部公司自营钻探的崖城 21 —1 —3 井进行了完井测试。该井的论证、设计和钻前准备用了近两年时间 ,钻井周期达 266. 30 d ;使用的井身结构及采取

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2) 对平台现有设备进行测试流程系统的全面检查、试压、测厚、修理和整改 ,购买必要的管阀并安装 ,使之达到要求。

3) 按当地恶劣海况条件和半潜式平台工况进行油管极限承载能力校核。

4) 进行无固相完井液研究及现场实验与应用。

5) 进行无固相溴化锌高密度完井液的防腐蚀研究。

3. 选用可靠装备

经过评价对比 ,选用 EXPRO 公司的井下一次性开关和环空加压打开的循环阀、环空超压关井安全阀、油管试压阀、海底测试树、防喷阀、地面测试井口、高压软管、测试油嘴管汇、液控动力、安全控制系统、资料收集自动化系统。选用 SCHLUMBERGER 公司 TCP 射孔电测校深。选用 AMERADA 机械压力计和温度计。选用 HALLIBURTON 的‘NWB’电缆下入式、密封孔直径为 120 mm、底部带蝶型阀的永久型封隔器。该永久型封隔器具有抗高压差、高温(210 ℃) 、耐 H_2S 及 CO_2 的能力。

4. 精心检查落实把关

派员到承包商、供应商所在地参与启运前的检查 ,试压和出厂检验。甚至进行井况条件下模拟试验和监督以确保施工顺利。

5. 制定规程和措施

崖 21 —1 —3 井主要程序和措施有 : ①半潜式钻井平台气井测试安全操作规程 ; ②测试期间安全应急程序 ; ③压井和起测试管柱安全措施 ; ④测试工艺设计方案和操作程序 ; ⑤测试施工程序和预测进度安全。

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70 ,1/ 25/ 99. (ISSN 1000 - 0976 ; **In Chinese)**

ABSTRACT: The complex gas bearing formations in Yinggehai Qiongdongnan Basin refer to what are difficult to be identified by conventional interpretation methods under present logging techniques. Restricted by the conventional interpretation techniques ,such as the shaly fine sand and siltstone are usually recognized as mudstone or dry formation. The principle of this technique is that so long as some amount of natural gas is contained in this formation ,there must have a certain effect on the results of acoustic ,density and neutron logging. Formations with relatively high gas saturation ,present distinct characters of low density, low neutron value , high interual transit time and high resistivity. Formations ,with relatively low gas saturation ,however ,do not present those characters obviously ,and so are often ignored by people. In this technique ,the generality of three kinds of porosity (from neutron ,density and interval transit curves ,respectively) in water layers and the anisotropism in gas bearing formations are taken fully into account. Resolution capability of these three kinds of porosity curves can be improved by use of the multiple computation of elasticity modulus ,synthetic interval compressional transit time ,slopes from interval transit time ,density and neutron curves and acoustic impedance ,and those information amplified through computer. As a result ,the gas bearing formations can be shown in a direct way.

SUBJECT HEADINGS: Nanhai Basin , Yingqiong Basin , Complex reservoir , Reservoir , Well logging , Technique , Application ,Analysis

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A STUDY OF THE DRILLING TECHNIQUES OF HIGH TEMPERATURE AND HIGH PRESSURE WELLS IN YING-QIONG REGION OF SOUTH CHINA SEA

Zhang Yong (Drilling Engineering Department of Nanhai West Corporation , CNOOC) . *NATUR. GAS IND*. v. 19 , no. 1 , pp. 71～75 , 1/ 25/ 99. (ISSN 1000 - 0976 ; **In Chinese)**

ABSTRACT: It is proved by drilling that the high temperature and high pressure coexist in the medium-and deep-lying strata in the Ying-Qiong region of South China Sea. Through practice it is shown that the difficulty and risk caused by high temperature and high pressure formation for drilling operation are much larger than those caused by normal temperature and normal pressure or high temperature and normal pressure or normal temperature and high pressure formation for the operation. In accordance with the problems encounting in drilling the high temperature and high pressure wells in the research region ,the personnel of Nanhai West Corporation had investigated the operating conditions of drilling such wells at home and abroad and primarily found and approved some techniques for drilling such wells in the research region. On the basis of introduing the operating conditions of drilling such wells in the research region ,the investigation results are primarily summarized in the paper ,including the formation pressure predication ,casing program ,casing wear , casing protection and downhole complex condition treatment as well as the high-density drilling fluid suitable for the high temperature condition and the equipment and tools of the drilling and cementing ,etc.

SUBJECT HEADINGS: Yingqiong Basin , High temperature , High pressure ,Drilling , Technique ,Offshore drilling

Zhang Yong *(senior engineer)* , born in 1960 ,graduated in drilling engineering from the Southwest Petroleum Institute in 1982 and has been always engaged in the offshore drilling work. He was appointed drilling intendant ,drilling superintendent ,and director of the Technical Research Office of the Drilling and Production Technology Research Institute ,early or late. Currently he is the chief engineer of the Drilling Engineering Department. Add : POB 11 , Potou District , Zhanjiang , Guangdong (524057) , China Tel : (0759) 3901964

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HIGH TEMPERATURE AND HIGH PRESSURE WELL TESTING TECHNIQUES

Liang Mingxi (Nanhai West Corporation , CNOOC) . *NATUR. GAS IND*. v. 19 , no. 1 , pp. 76～79 , 1/ 25/ 99. (ISSN 1000 - 0976 ; **In Chinese)**

ABSTRACT: High temperature and high pressure reservoirs were found in exploring the medium-and deep-lying formations in Yinggehai and Qiongdongnan Basins administrated by Nanhai West Corporation. With the assistance of domestic and foreign experts ,an exploration well with a depth of 4 688 m had been drilled in Ya 21 —1 structure with a submerged depth of 115 m in July 1994 , and a suit of accurate data had been achieved through well testing ,the formation pressure being 105. 15 MPa and the formation temperature 206 ℃. The high temperature and high pressure well test carried out on a semisubmersible drilling platform is still a difficult problem which the petroleum circles in the world are discussing and taking great effort to solve. It is a prerequisite for testing to guard against the well blowout accident. The safety should be considered first, when the surface equipment, downhole tools and testing technology are chosen and only under the premise of safety, can the data be fully acheived, the well killing be smoothly carried out and the piple string be pulled out. Through a technologic summarization of some wells being successfully tested, an understanding of the testing techniques of offshore high temperature and high pressure wells, their existent problems and improvable trend in the future are proposed in the paper.

SUBJECT HEADINGS: High temperature formation, High pressure, Semisubmersible drilling platform, Perforation

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WELL YA 21—1—3 DRILLING TECHNIQUES

Duan Yisheng (Drilling and Production Technology Research Institute of Nanhai West Corporation, CNOOC). *NATUR. GAS IND.* v. 19, no. 1, pp. 79～82, 1/25/99. (ISSN 1000 - 0976; **In Chinese)**

ABSTRACT: The Well Ya 21—1—3 successfully drilled to a depth of 4 688 m by the Nanhai West Corporation by way of raising funds independently is a deep gas explortion well with both high temperature and high pressure. By means of well testing it is proved that the formation pore pressure is 104.70 MPa, the bottom hole temperature 206 ℃, the pressure gradient 22.76 kPa/m and the thermal gradient 4.42 ℃/100 m. Based on the understanding of Wells Nos 1～2 drilled on the same structure, the Well Ya 21—1—3 was successfully drilled through adopting the mature, practical and advanced techniques and overcoming the complicated conditions encountered during operating. By way of analyzing and summarizing the data on Wells Nos 1～2 and on the basis of fully understanding the formation pressure and fracture pressure, four casing program plans are proposed, Plan 4 being adopted through well comparing. The relevant technical measures were used for remedying the deficiencies of the plan, i.e. because the serious casing wear problem was always encountered in the process of operating, through the patching, tieback and replacement of the casing and protecting the casing against wear, it was ensured to run the Ø244 mm casing to the designed setting depth; through evaluation, the high temperature water-base drilling fluid system (Pyro-drill) developed by Milpark Co. was choosed and in practice, a good thermal stability of high temperature was showed by means of strictly controlling the bentonite content in the drilling fluid; it was difficult in technology to cement Ø178 mm liner in the drilling fluid with a density of 2.33 g/cm^3, but the well cementing was still successful, by which some experiences were accumulated for the future. On the basis of the review from well design, preparation to spot operation, the techniques used for this well are summarized and the drilling technology suitable for the deep exploration well with high temperature and high pressure is analyzed in the paper.

SUBJECT HEADINGS: High temperature, High pressure, Natural gas, Exploration well, Casing program, Drilling fluid, Well cementing

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WELL COMPLETION TECHNOLOGY APPLIED TO YA13—1 GAS FIELD

Du Tao and Chen Guocai (Nanhai West Corporation, CNOOC). *NATUR. GAS IND.* v. 19, no. 1, pp. 83～84, 1/25/99. (ISSN 1000 - 0976; **In Chinese)**

ABSTRACT: Ya13—1 gas field is located in the Nanhai Sea waters at a distance of 100 km from Sanya, Hainan Island, Gas field area being 54 km^2, mean gas reservoir effective thickness 93.9 m and gas reserves 889 $\times 10^8 m^3$. It is the largest offshore gas field found up to now in China, being of the properties of high formation temperature and high formation pressure. It is required that the individual-well production must be high so as to stably supply gas of 29 $\times 10^8 m^3/a$ to Hongkong and 6 $\times 10^8 m^3/a$ to Hainan Province; the Ø711.2 mm gas pipeline to Hongkong, Ø355.6 mm oil & gas pipeline to Hainan Province, Hongkong acceptance station and Hainan processing station must be constructed; and the stable production period must be twenty years. The well completion technology design is relatively strict, which demands that all gas wells must be normally put into production and it is necessary to do the workover treatment without shutdown or by a short-term shutdown. In the paper, the characteristics of the well completion technology in the field are simply in-