第三届中俄测井国际学术交流会

2004(乌法)

论文集

陆大卫 主编

CHINA & RUSSIA

2004

目 录

注硼中子寿命测井技术及其在油田开发中的应用

陆大卫　赵培华

（中国石油天然气股份公司勘探与生产分公司）

摘要：本文介绍了注硼中子寿命测井技术原理和在中国华北、冀东、大港等油田的应用实例。实际应用表明，该项技术为油田水淹层评价和剩余油挖潜提供了一种行之有效的测井方法。

一、引 言

注硼中子寿命测井技术是近几年来发展起来的一项新的水淹层测井技术，是测—注—测技术在中国的发展。目前在中国很多油田得到推广应用，测井工作量也逐年增加，不完全统计，已累计测井 2000 多井次，目前中石油年测井工作量在 200 井次左右。该项技术在准确判断高含水层位和窜槽层位，为堵水等挖潜措施提供依据方面见到显著效果，同时在发现未动用层、评价地层的封堵效果、分析套管腐蚀、监测产层剩余油饱和度变化、了解油田剩余油饱和度纵横向分布等方面也具有较好辅助作用。

二、测井原理

注硼-中子寿命测井是在中子寿命测井技术基础上发展起来的。中子寿命测井是通过测量中子源发出的中子射线在地层中经过多种核反应所放出的次生伽马射线强度来反映地层俘获截面的大小的一种测井技术，适用于高矿化度地层水的油田。对于低矿化度地层水的油田，由于油层和水层俘获截面相近，无法用中子寿命测井区别油水层。于是由此产生了注硼-中子寿命测井想法，即用俘获截面较高的注入液作为示踪剂，使地层水“咸化”，增大地层水俘获截面，区分出油水层。由于硼元素的俘获截面大约是氯元素的 23 倍，且硼酸易溶于水而不溶于油，向井筒灌注适当浓度的硼酸溶液，用中子寿命测井仪进行“测一渗一测”或“测一注一测”施工，根据注硼前后两次测量地层俘获截面值的变化评价地层水淹级别，评价地层剩余油的分布状况（如图 1 所示）。

注硼-中子寿命测井基本过程为：首先测一条地层俘获截面基线Σ_1，然后根据施工井的产层厚度、孔隙度、岩性、压力、温度等参数，设计硼酸浓度、注入量和注入压差，将硼酸溶液低速注入或渗入目的层段，以使地层水“咸化”，再测一条地层俘获截面曲线Σ_2，将这两条曲线重叠就可判断地层含水情况。由于两次测井之间，地层的孔隙度、泥质含量、饱和度等对地层俘获截面值有影响的因素基本未变，改变的只是地层水的俘获截面值，因此两条俘获截面曲线幅度差大小就可以定性的反映出地层含水的多少。地层中含水越多，进入的硼酸量越多，幅度差值越大。

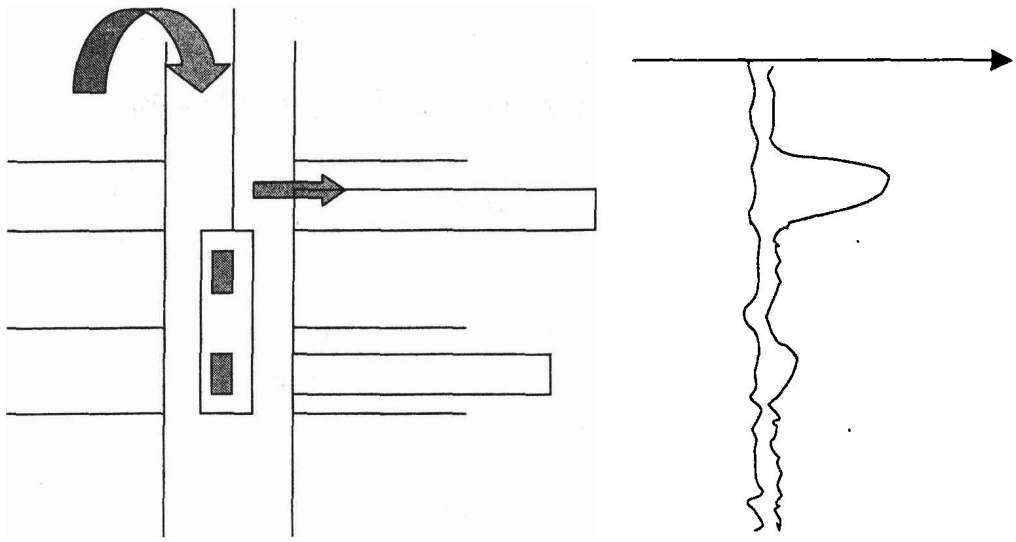

图 1 注硼中子寿命测井原理示意图

三、应用实例

1．识别油井内以产水为主的的出水井段，为堵水调剖等井下措施提供依据

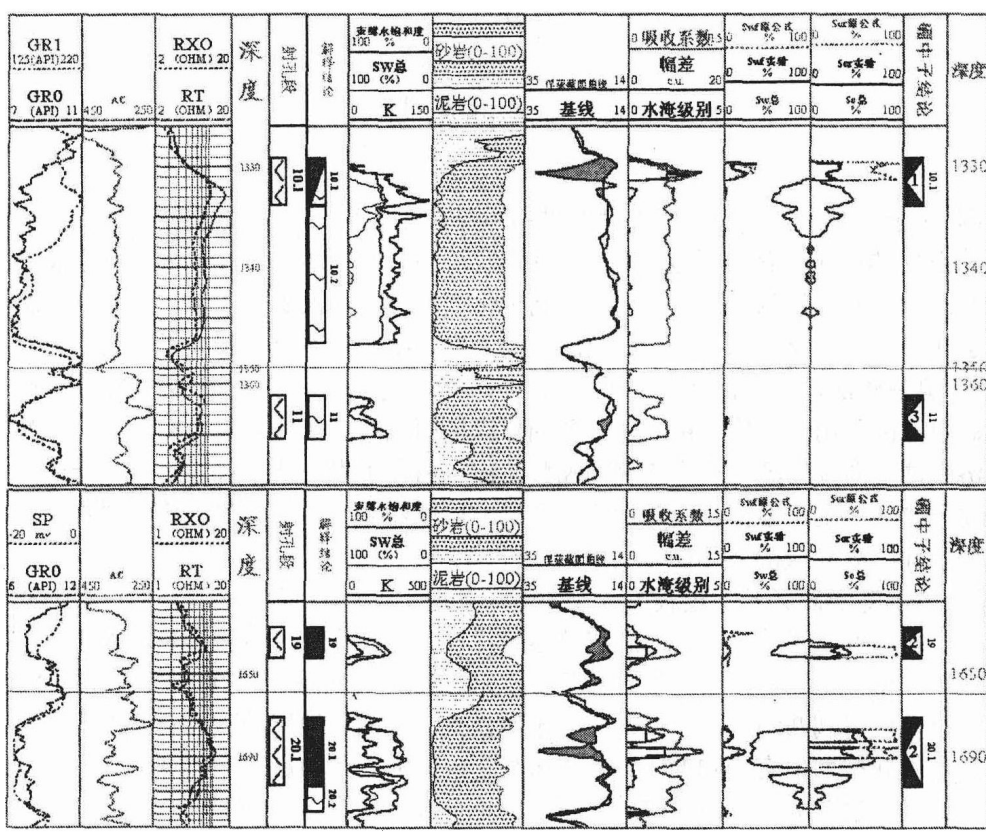

图 2 华北油田路某井注硼中子寿命测井成果图

图 2 为华北油田路某井注硼中子寿命测井处理成果图，该井于 1988 年 9 月 3 日 10、11、19、20 号层合采，2000 年 7 月，日产液 53.4 吨，日产油 1.8 吨，含水 96.6%。该井于 2000 年 6 月测产液剖面，测试结果该井日产液 48.7 吨，日产油 16.7 吨，含水 65.7%。测试的含水结果与地面计量相差悬殊。为了解目前各射孔井段的剩余油分布情况，于 2000 年 7 月 27 日对该井进行了硼-中子寿命测井，解释 10 号层为强水淹层；11 号层为弱水淹的水层；19 号层为中水淹层；20 号层呈中水淹特征。依据解释成果本井于 2000 年 8 月 2 日实施了卡水作业：措施后日产液量下降至 33.2m3，日产油量增至 9.7t，含水率下降到 71%，日增油 7.9 吨，累积增油 1221 吨。同时，经硼中子测试及措施验证，证实了该井原解释二类层 11 号层为油层，据此并结合构造、测井响应情况推断邻井路 XXX 井连通层 12 号也应为油层（原解释为油水）。于 2000 年 6 月进行补孔后也见到了很好的增油效果。措施前因高含水自 1997 年 4 月一直关井（液 41、含水 100%），措施后日产油量 11.7t，含水 2%。

图 3 为冀东油田某井注硼中子寿命测井成果图，该井射开 7 号、8 号 2 层，射开厚度 9.1 米，措施前日产液 16.2 方，日产油 3.2 吨，综合含水 80.4%。测井解释成果表明 9 号层是主要出水层，依据测试结果实施化堵 9 号层。措施后，日产液 28.6 方，日产油 12.9 吨，综合含水下降到 51.8%，取得显著效果。

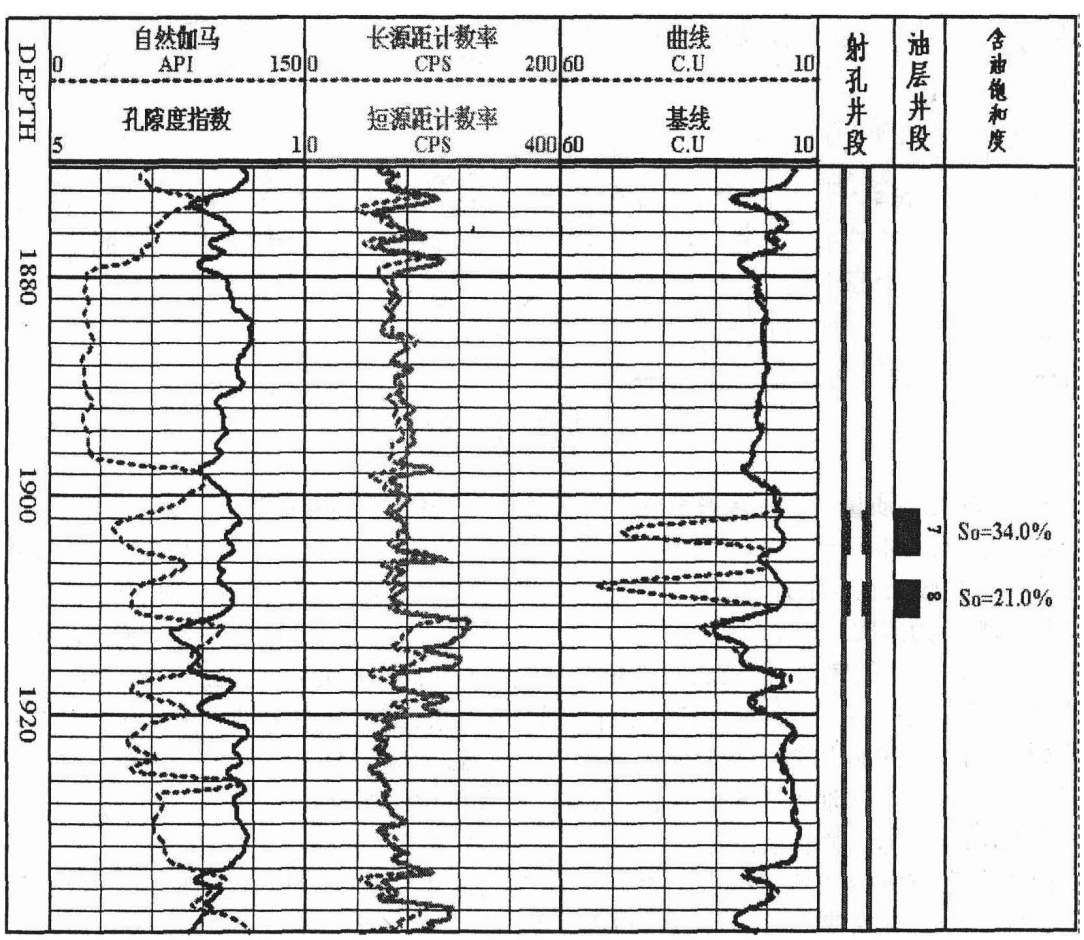

图 3　冀东油田 G115-4 井注硼中子寿命测井成果图

2．为深化油藏认识和剩余油挖潜提供依据

华北二连地区阿北油田安山岩主要是气孔-杏仁状安山岩，储层类型为孔隙微裂缝型，部分井投产初期产量较高，但产量下降很快，含水迅速上升，只好关井停止生产。分析认为其地下油、水分布规律很可能将发生因裂缝窜流而暴性水淹的油井，在关井后纵向上将发生重力分异作用，油向上运移后将使剩余油重新聚集。为了证实这一观点及认识，对其中阿 X1 井进行了注硼中子寿命测井，如图 4 所示，7 号、8 号和 10 号层水淹并不严重，仍有恢复生产的可能。根据这种认识，对该区域长期关井的 7 口油井，进行了转抽恢复工作。这 7 口井全面恢复后，初期日增液达 157t/d，日增油达 99t/d，综合含水率仅 38.6%。这些井的成功恢复，不仅使阿北油田的低效区块开发局面得到了有效改善，形成了老油田的二次开发，而且可为其他低效区块的治理提供依据和借鉴方法。

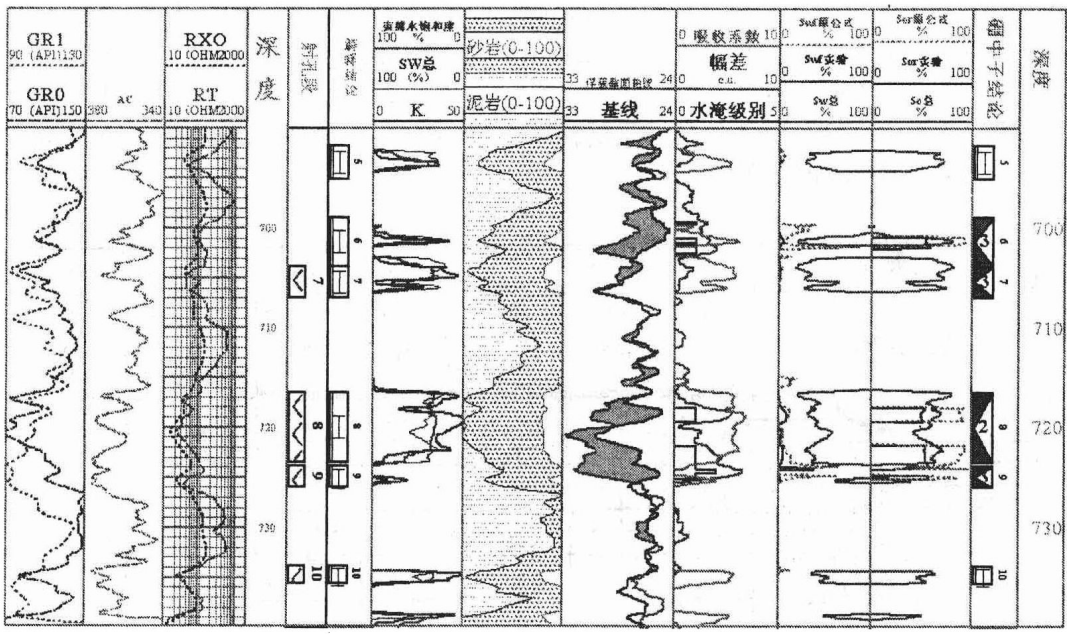

图 4　华北阿 X1 井硼中子数字处理成果图

3．检验固井质量，识别窜槽层段，为窜槽封堵措施实施提供依据

图 5 为大港油田一口 2000 年 9 月完钻井，投产初期射开 13、14 和 21 号层，自投产以来，含水一直较高且呈上升趋势，测注硼中子寿命测井以前，日产液 72.4 吨，油 2.2 吨，含水达 97%。为落实这三个射孔层中出水的主要原因，决定进行注硼中子寿命测井，测井结果如图所示，14 层的底部以下 884.4m-893m 井段未射孔而有较大的曲线离差，表明有硼酸沿 14 号射孔层窜入该层，综合固井资料分析，判定该层第二界面上部窜槽。据此，决定对该井窜槽处（884.4—893m）挤水泥打塞面，作业后，用 7mm 油嘴恢复生产，措施后日产液由 72.4 吨降到 21.6 吨，日产油由 3.5 吨增至 9.2 吨，含水由 95.1%降到 57.4%，年增油 2052 吨，年降水 93732m^3，降水增油效果显著。

图 6 为冀东油田某井注硼中子寿命测井成果图。该井在测井温找水时发现 9 号小层与 10、11、12 号小层存在窜槽。对 10、11、12 号小层进行封堵后，生产效果仍没有得到改善，因此决定利用注硼中子寿命测井对封堵效果进行进一步检验,结果证实只有 9 号层产液，原封窜效果仍有效。进而分析认为主要是出砂造成生产效果差，故进行防砂措施，日增油 3 吨，累

计增油 1270 吨。

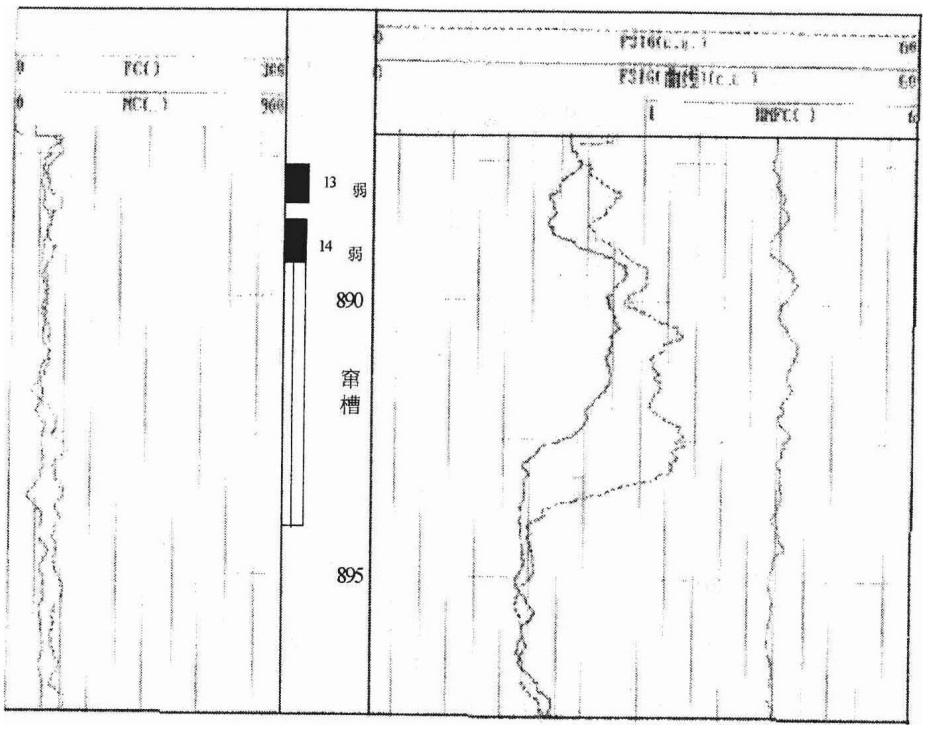

图 5 大港油田一口注硼中子寿命测井成果图

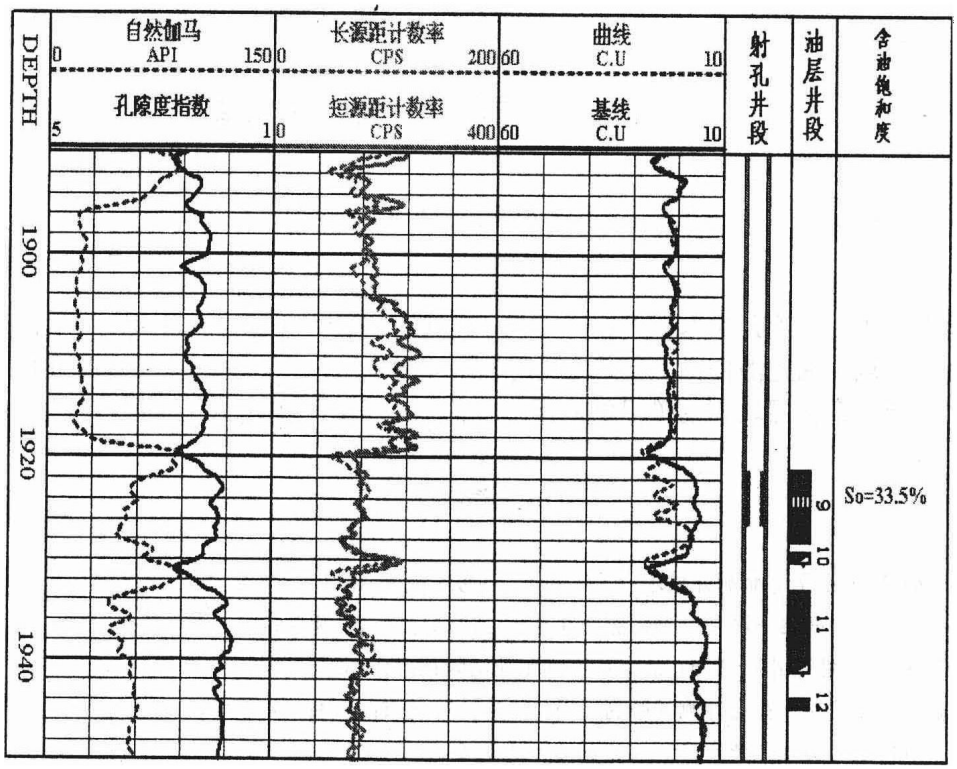

图 6 冀东油田某井注硼中子寿命测井成果图

4. 计算油层剩余油饱和度，确定剩余油分布，为区块开发方案调整提供依据

通过对区块不同井点有计划地进行硼—中子寿命测井，对区块剩余油的分布可有进一步的认识。图 7 为冀东油田某区块注硼中子寿命测井井点分布图，根据单井水淹评价结果对该区块剩余油分布潜力有了新的认识。由于储层层内、层间非均质性严重，剩余油在纵向上的差异显著。纵向上 12 小层剩余油饱和度大于 13#小层。因此，油井在纵向上挖潜的潜力较大。

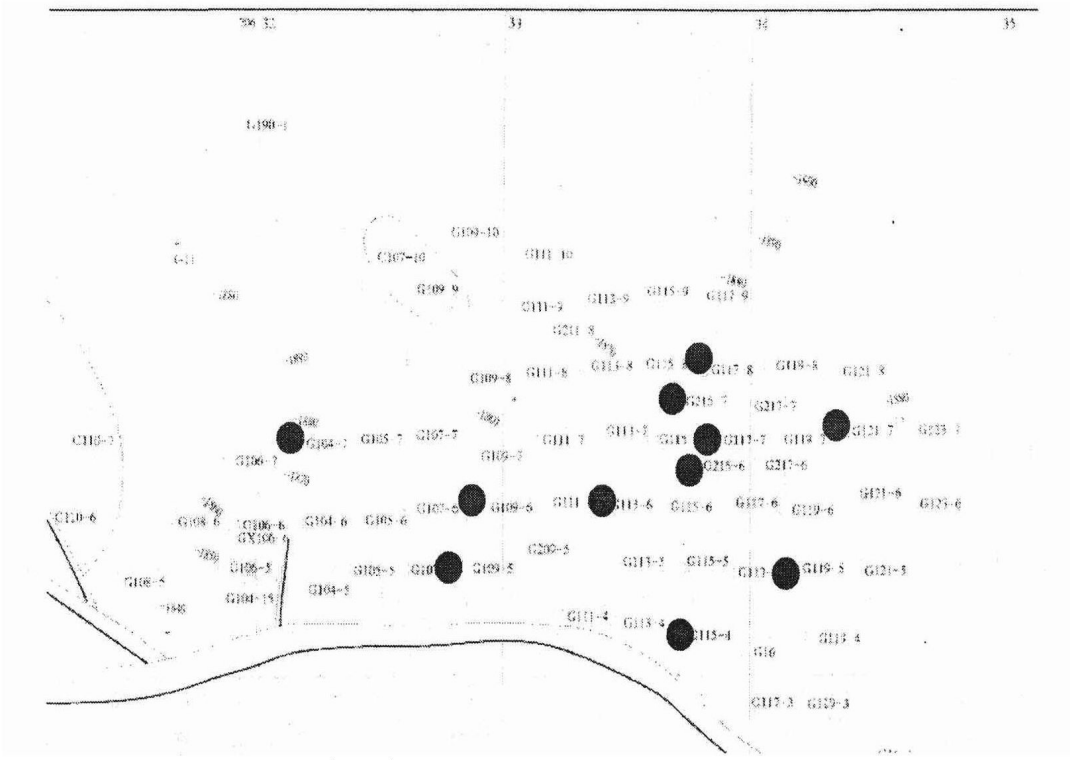

图 7　高 104-5 区块硼中子测试井点分布图

四、结论

注硼中子寿命测井技术在华北、冀东、大港等油田的应用实例表明，该项技术为油田水淹层评价和剩余油挖潜提供了一种行之有效的测井方法，同时注硼中子寿命测井技术也为固井质量检验，窜槽层段识别等提供依据。

参考文献

[1] 赵培华. 硼—中子寿命测井技术应用综述[J]. 测井技术，2001, 25(3).

[2] 郑希科 等. 测－渗－测中子寿命测井在大庆油田的应用[J]. 测井技术，2003, 28(Suppl).

[3] 黄隆基. 放射性测井原理[M]. 北京：石油工业出版社，1985.

[4] 魏振球 等. 放射性在石油测井中的应用与防护[M]. 北京：石油工业出版社，1985.

[5] 测井新技术应用[M]. 北京：石油工业出版社，1998.

Boron Injection Neutron Life Logging Technology and Its Applications in Oilfield Development

Lu Dawei Zhao Peihua
(PetroChina Company Limited)

Abstract: This paper introduces the theory of Boron Injection Neutron Life Logging technology and its application examples in Huabei, Jidong, Dagang and other oilfields in China. The applications illustrate that this technology provides a feasible and effective logging method for oilfield watered out zone evaluation and residual oil potential tapping.

Introduction

Boron Injection Neutron Life Logging is a new logging method for watered out intervals developed in recent years, it is the development of Logging-Injection-Logging in China. At present, it is applied in many oil fields in China, the logging service job increases year by year, according to the uncompleted statistics, the accumulated logging jobs have reached 2000, the logging service jobs of PetroChina are around 200 every year. This technology has obtained obvious achievements in the aspects of accurately locating the intervals with high water-cut and channeling to provide basis for plugging water and tapping oil production potential. At the same time, it also plays an auxiliary role very well in determining the non-producing intervals, evaluating the sealing effectiveness of formation, analyzing casing erosion, monitoring residual oil saturation variation, understanding the vertical and horizontal distribution of oilfield residual oil saturation.

Theory

Boron Injection –Neutron Life Logging is developed from Neutron Life Logging. Neutron Logging is to measure the formation capture cross-section by measuring the second gamma ray density emitted from the neutron ray produced in neutron source after many nuclei reaction in formation, the technology is suitable in the oilfield with high salinity. For the oilfield with low salinity formation water, Neuron Life Logging cannot distinguish oil intervals from water intervals because the capturing cross section of water intervals and oil intervals are similar. It is this point inspirits the logging method of Boron Injection-Neutron Life Logging. The method is using the injection fluid with high capture cross section as the tracer to make the formation "salinitified", so the capturing cross section of formation water is increased and water interval can be distinguished

from oil intervals. Because the capture cross section of Boron is about 23 times of chlorine, and Borate is easy to dissolve in oil rather than in water. Borate solution with suitable density is injected into borehole, "logging-infiltration -logging" or "logging-injection-logging" is run with neutron logging tool, the formation capture cross section varieties of two runs before and after boron injection are used to evaluate formation watered out degrees and formation residual oil distribution (See Fig.1).

The basic process of Boron Injection- Neutron Life Logging is: first measure a reference line of formation capture cross section$\sum_1$, then design the borate density, injection amount and injection pressure difference according to the thickness of the producing interval, porosity, litholgy, pressure, temperature and other parameters, after that, inject or infiltrate the solution at a very low speed to make the formation "salinitified ", measure another formation capture cross section curve$\sum_2$, the formation water-cut condition can be determined by overlapping these two curves. Because there is no change of the basic elements that affect the values of formation capture cross section, such as porosity, shale content, saturation, and etc., the only change is the value of cross section of formation water, so the value of the amplitude difference between the two capturing cross section amplitude qualitatively reflects the water-cut of the formation. The bigger the water-cut is, the more borate enters into the formation, and the bigger is the amplitude difference.

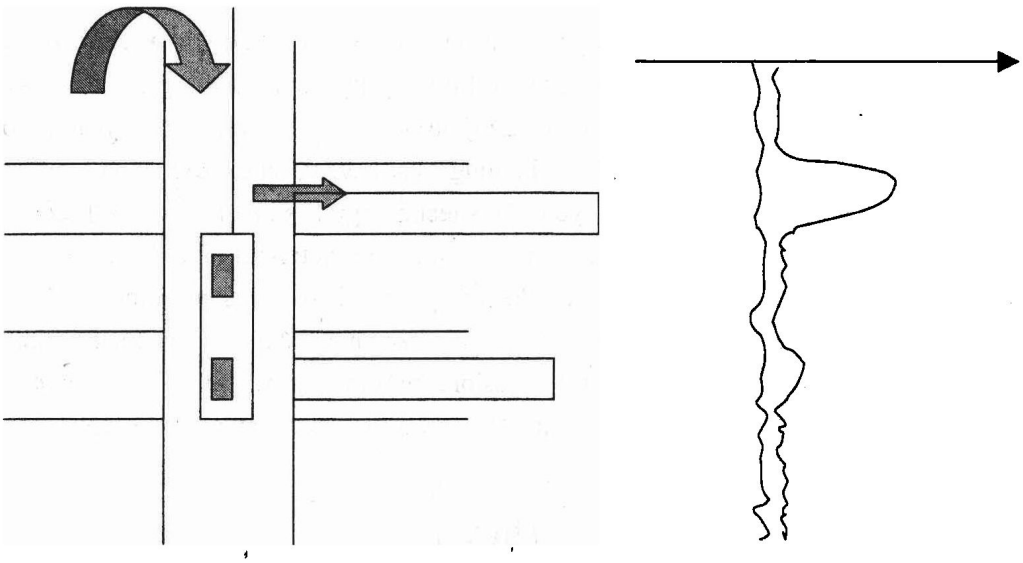

Fig.1 The sketch map of the theory of Boron Injection Neutron Life Logging

Application Examples

1. Identify the water producing intervals in which the main production is water to provide basis for the down hole measures such as water plugging and profile adjusting

Fig. 2 is a logging result of Boron Injection Neutron Life Logging in Well LuX of Huabei Oilfield. Since 3rd, September of 1988, the general production is from intervals No.10, 11, 19 and No.20 together. In July of 2000, the metering at the wellhead showed that the fluid output was

53.4t/d，oil output was 1.8t/d with 96.6% of water-cut. the result of production profile logging run in June of 2000 showed that the fluid output was 48.7t/d，oil output was16.7 t/d with 65.7% of water-cut. The water-cut from logging is quite different from the metered one at wellhead. In order to make clear the residual oil distribution at the perforated intervals at present , on 27th, July of 2000, Boron Injection- Neutron Life Logging was run in this well, the interpretation results indicate that Interval No. 10 is serious water out, No. 11 is slight watered out, No. 19 is medium watered out, No. 20 is characterized as medium watered out. Based on this result, water plugging was applied to this well on 2nd, August of 2000, after the treatment, the fluid output reduced to 33.2m^3/d，oil output increased to 9.7t/d，water-cut reduced to71%，oil production increased by 7.9t/d，the accumulated oil production increased 1221t. At the same time, both the Boron Neutron Logging and the treatment being taken verified that Interval No. 11 was an oil payer, which used to be mistaken as the second-class oil payer. According to this and combining the conditions of borehole structure and logging response, it was assumed that Interval No.12, which is connected with the neighboring well, was also an oil payer(it used to be interpreted as oil-water layer). The reperforation was applied in June of 2000 in the neighboring well and it obtained a very good oil enhancing effect. The well has been shut off since April of 1997 because of high water-cut (fluid out put was 41t/d with 100% of water-cut). After the treatment, the oil output is 11.7t/d with only 2% of water-cut.

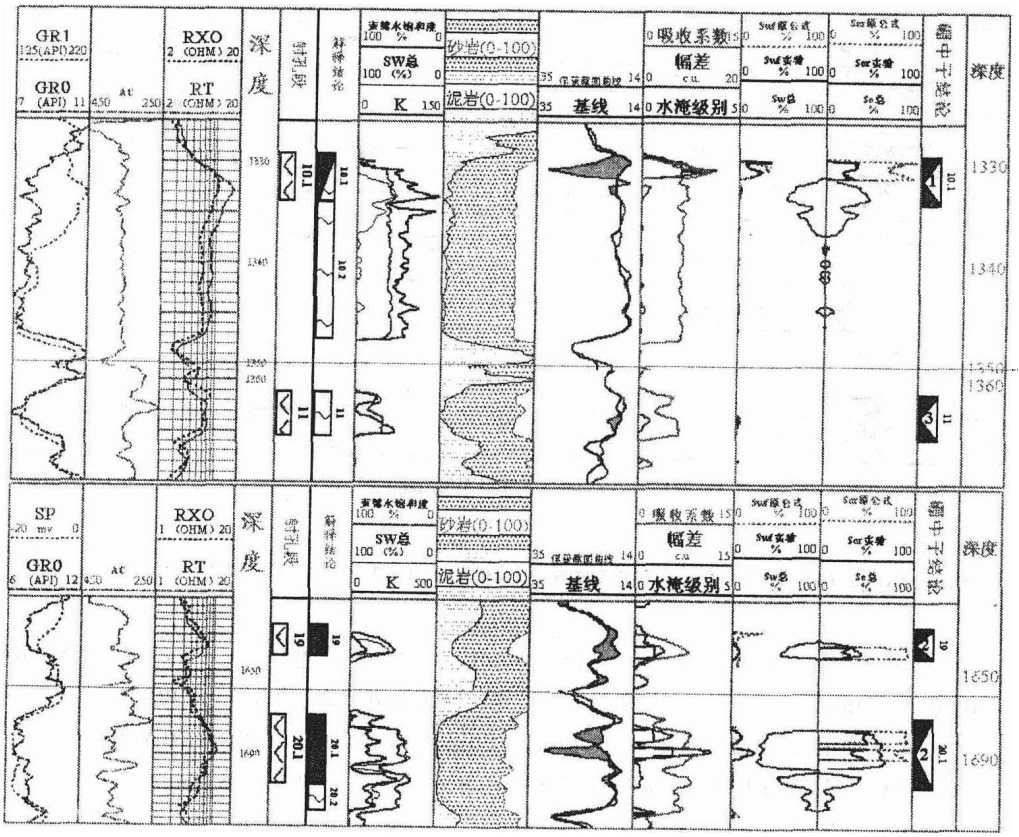

Fig.2 Logging Example of Boron Injection Neutron Life Logging in LuX Well of Huabei Oilfield

Fig. 3 is a Boron Injection Neutron Life Logging Result obtained in Jidong Oilfield, two layers Numbered 7 and 8 were perforated; the perforated interval thickness is 9.1 meters. Before being taken measures, the fluid output was 16.2 m^3/d, oil output was 3.2 t/d, resulting water-cut was 80.4%. The interpretation result indicates that Layer 9 is a major water producer. Chemical plugging was taken to Layer 9 according to the logging result. After the treatment, the fluid output became 28.6 m^3/d, oil output became12.9t/d, the resulting water-cut reduced to 51.8%, the effect is obvious.

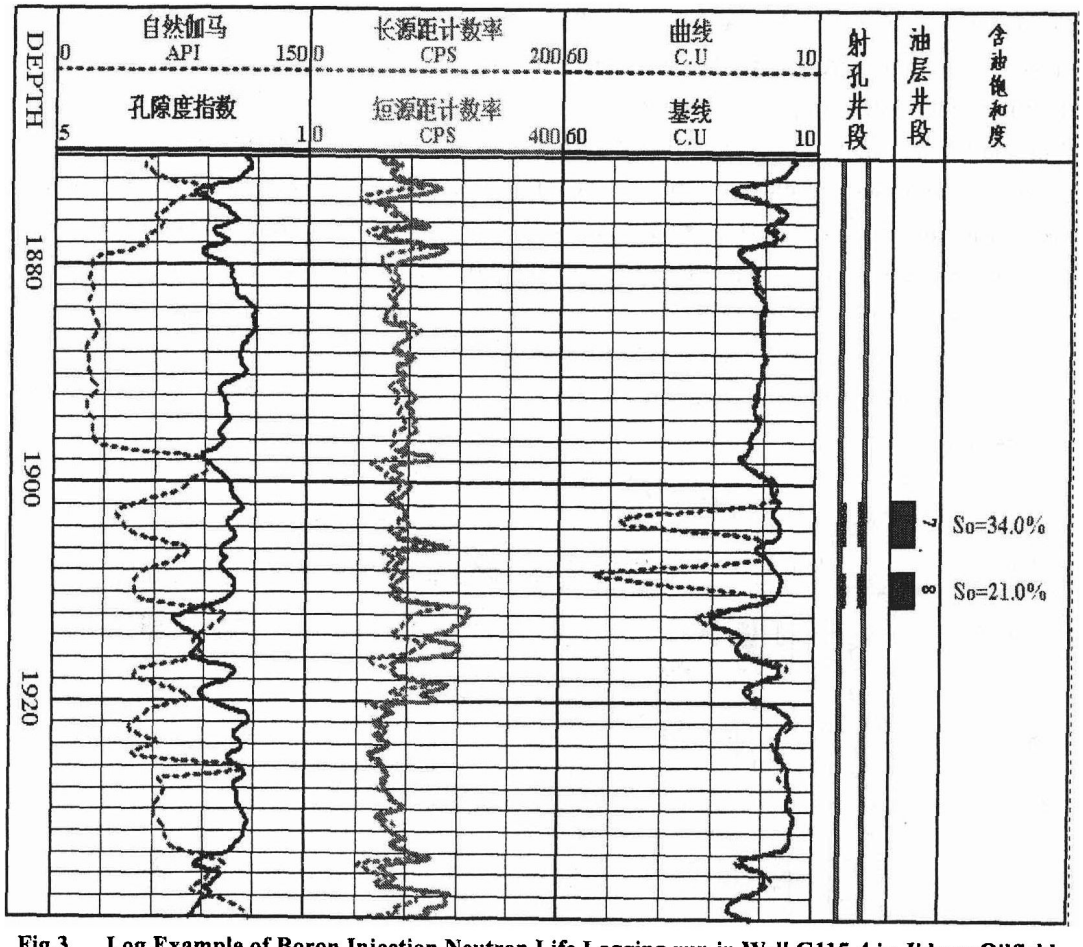

Fig.3 Log Example of Boron Injection Neutron Life Logging run in Well G115-4 in Jidong Oilfield

2. Provide basis for further understanding reservoir and taping residual oil production potential

The andesite of A'bei Oilfield located in Erlian Region of Huabei is mainly pore-amygdaloidal andesite, the reservoir type is porous-micro fractural, the output of some wells is high at the early stage of production, but the output decreased dramatically with water-cut increasing fast, the well had to be shut off. The analysis for this phenomenon got the following conclusion, in this kind of sudden watered out wells because of fracture channeling, according to the rule of underground water and oil distribution, vertical gravity separation will happen after shut

off, so the oil will move upward to make the residual oil accumulate again. In order to prove this point and understanding, Boron Injection Neutron Life Logging was run in Well A'X1 in this block. As shown in Fig.4, the watered out in Layer No.7, 8 and 10 is not serious; it is possible to restore the production in these wells. Then, the 7 wells that have been long-term shut off were restored production. At the early stage of production restoration, the fluid output reached 157t/d, oil output reached 99t/d with total water-cut of only 38.6%. The successful restoration of these well not only improves the low efficient development in some blocks of A'bei Oilfield and forms the second development of the old oilfields, but also provides the basis and references for the treatment of other low efficient blocks.

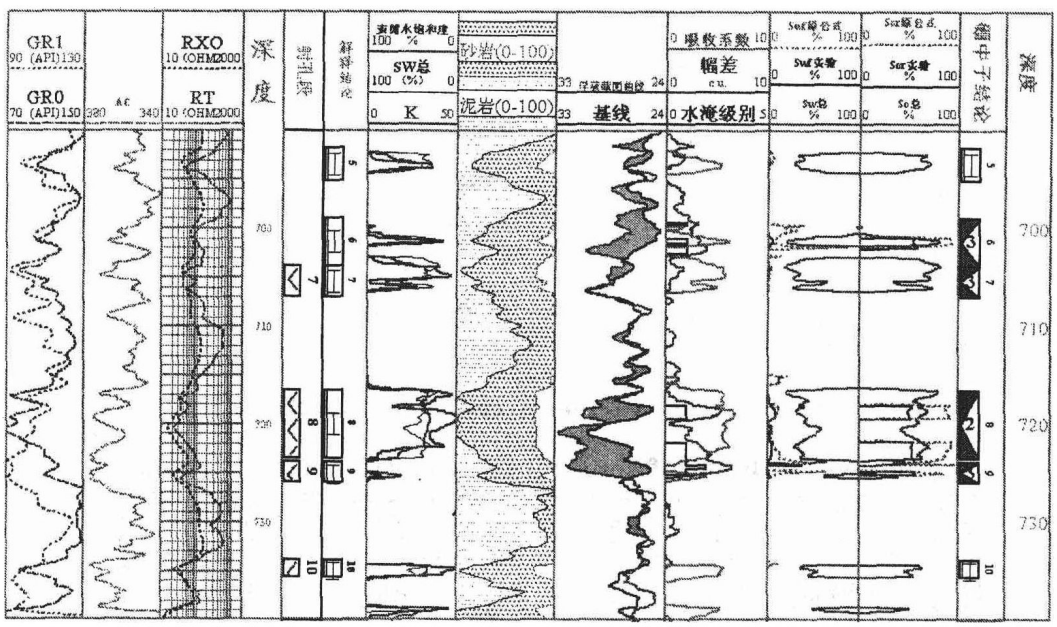

Fig.4 Digital Processed Result of Boron Injection Neutron Life

3. Evaluate cementing quality, identify channeling interval, and provide basis for plugging the channeling

The well in Fig.5 is completed in September of 2000 in Dagang Oilfield, Layer No.13, 14 and 21 were perforated at the early stage of production. Since it was put into production, the water-cut has been increasing all the time. Before Boron Injection Neutron Life Logging was run, the well produced at fluid 72.4t/d, oil 2.2t/d with water-cut 97%. In order to find out the main reasons for water production in these three perforated intervals, Boron Injection Neutron Life Logging was decide to be run in this well. The log result is as shown as in Fig.5, the curve of Interval 884.4m-893m under Layer 14 has a big deviation, which means borate flows into this interval along perforated Layer 14. The analysis of combining the data with cementing data finds out the channeling in the upper part of the second interface. Based on this analysis, cement squeezing treatment was carried out in the channeling part of this well (884.4－893m). after the treatment, 7mm mandrel was used to restore the production, the liquid output reduced from 72.4t/d to 21.6t/d, oil output increased from 3.5t/d to 9.2t/d, water-cut reduced from 95.1% to 57.4%, the oil

production increases 2052 every year， water production reduces 93732m^3 every year, the effect of increasing oil and reducing water is very obvious.

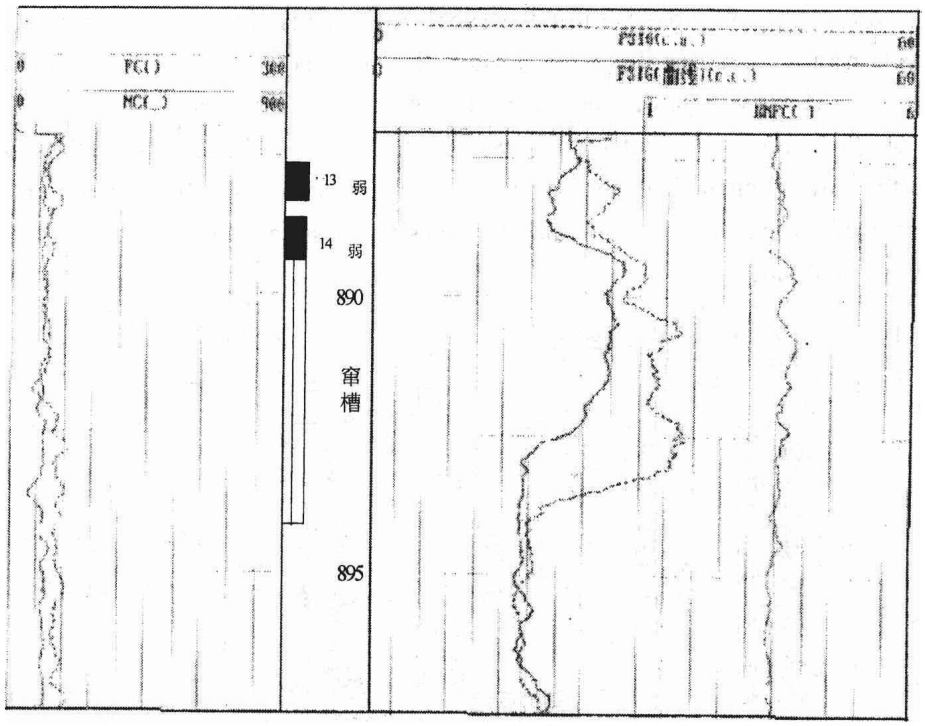

Fig.5 Log Result of Boron Injection Neutron Life Logging run

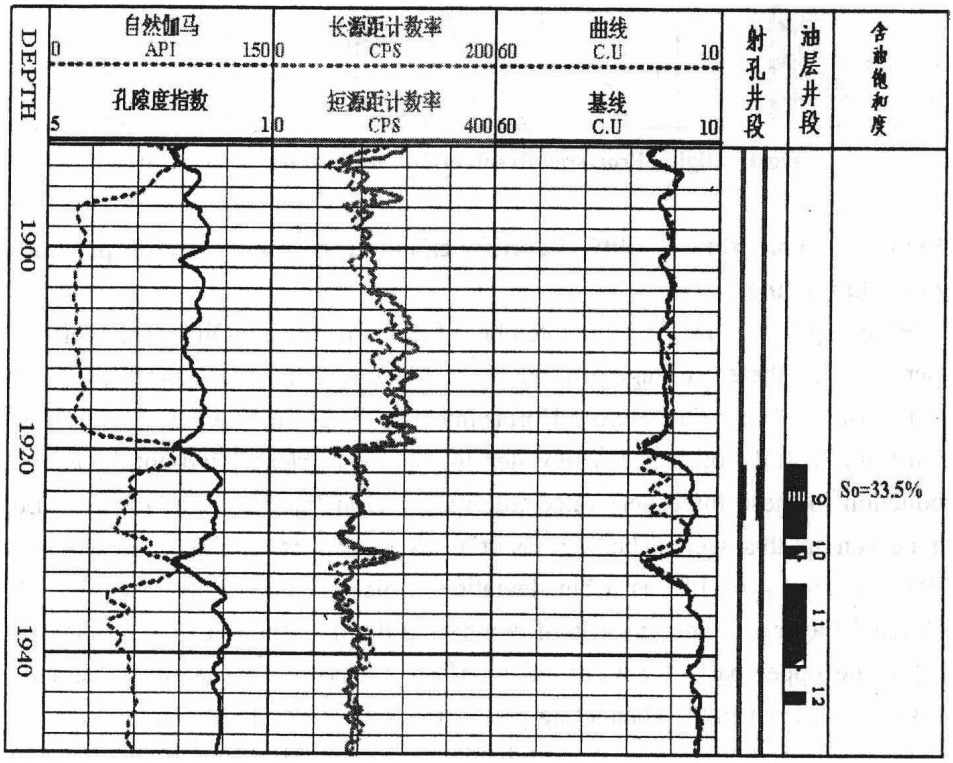

Fig. 6 Boron Injection Neutron Life Logging Result run in Jidong Oilfield

Fig.6 is a Boron Injection Neutron Life Logging Result run in Jidong Oilfield. Temperature Water Locating Logging found out that Layer 9 has channeling connected with Layer10, 11 and 12. The production effect is not improved by water plugging Layer10, 11 and 12. So it is decided to use Boron Injection Neutron Life Logging to do further examination for water plugging effect. The logging result shows that only Layer 9 produces fluid, the original channeling plugging effect is still effective. The further analysis assumes that sand flowing causes bad production effect, so sand flowing preventing measures were taken, the result is daily oil enhancement is 3 tons, and the accumulated oil enhancement is 1270 tons.

4. Calculate reservoir residual oil saturation, determine the distribution of residual distribution to provide basis for adjusting block development plan

A further understanding to the block can be made by carrying out the planed Boron—Neutron Life Logging in different well patterns of the block. Fig.7 is a Sketch Map of the Wells Being run with Boron Neutron Life Logging in a certain block of Jidong Oilfield, the evaluation result for single well watered out gives a new understanding to the residual oil distribution. Because of the serious intra-layer and interlayer heterogeneity, distribution difference of residual oil saturations in vertical direction is prudent. In the vertical direction, the residual saturation of Layer 12 is bigger than that of Layer 13. So, the oil production potential in the vertical direction is huge.

Conclusions

The applications of Boron Injection Neutron Life Logging in Huabei, Jidong, Dagang and other oilfields show that, this technology provides a feasible and effective logging method for evaluating oilfield watered out zone and tapping residual oil production potential. It can also provide basis for cementing quality evaluation and channeling interval identification.

References

[1] Zhao Peihua, Overview on Application of Boron—Neutron Life Logging Technology, Well Logging Technology, Vol.25,No.3, 2001

[2] Zheng Xike, etc., The Applications of Logging—Infiltrating—Logging Neutron Life Logging In Daqing Oilfield, Well Logging Technology, Vol.28, Supplement, 2003

[3] Huang Longji, Radioactive Logging Theory, Petroleum Industry Publishing House, 1985

[4] Wei Zhenqiu, etc., The Application and Prevention of Radioactivity in Well Logging, Petroleum Industry Publishing House, 1985

[5] The Applications of New Well Logging Technologies, Petroleum Industry Publishing House, 1988