

Evolution Of Wireline Well-Logging Technique (The Eye Of Oil Industry) In India And Advances Beyond 2000

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Abstract

Well-logging plays a very important role in the petroleum industry. It is an eye of oil industry as it provides detailed geological information of drilled holes which is very cost effective. It enables quantitative estimation of hydrocarbon reserves through its openhole services. The cased hole and production logging services are of immense help during exploitation and development stages of oil/gas fields. The geophysical well logging technique has also wide applications in subsurface mineral, geothermal and ground water exploration. Of late it has found application in 'Coal-Bed Methane' (CBM) exploration, which has opened up new opportunities. Because of its immense importance in subsurface hydrocarbon and mineral exploration the geophysical well-logging technique has seen tremendous development in the field of instrumentation and interpretation. This has become possible due to the advancement in science and technology aided by computerisation. The present paper (deals with the initiation of well-logging technique that has seen tremendous development in the field of instrumentation and interpretation. It also covers the initiation of well-logging services in India and the present state-of-the-art. Its future application is briefly discussed.

Key Words : Well Logging, Sp, Resistivity, Gamma Ray Neutron, Density, Induction, Laterolog, Sonic, Formation Tester, Dipmeter, EPT, F-0, a.m.n., Saraband, Coriband, Elan, FMS, FML, CAST, AIT, LWD, MWD, MDT, RST, CMR, MRIL, FDT.

Introduction

Historically the term "well-logging" had a wider meaning and application with the genius and innovative ideas of Schlumberger brothers, Conrad and Marcel who recorded the first electrical log in a Patchelbronn oil well in north eastern France on 5th September, 1927.

The wireline logging services, the eye of oil industry, constitutes an important branch of geophysics. Of late, the geophysical well-logging technology has led to enormous developments in down hole data acquisition and interpretation techniques due to advances in science and technology particularly in the field of electronics and computerisation. In the west, the logging companies are equipped with diversified advanced logging systems. In India too, these advances have found applications in oil/gas as well as in ground water, coal and other mineral exploration.

An attempt has been made here to depict the application of well logging in oil exploration in India and the scenario 2000 ahead. Also a brief account is given on its use in other fields like ground water, coal and other mineral exploration. Since the users are many and applications are wide, no claim is made to cover all spheres of applications.

What is Well-Logging

The world logging means recording of any information with respect to depth or time. The term 'well-logging' had a wider meaning and application in borehole geophysics, ever since its adaptation.

Well-logging is a wirehole study of different formations encountered in a well. We, in oil exploration, are mainly interested in identification of porous and permeable formation, their thickness and extent, and geometry of the

reservoir. Well logging is exactly such a device which aims at acquiring these informations, by measuring various physical, chemical and lithological properties of the formations. This information when supplemented with other informations available from core analysis, seeks to give depth, formation, its nature, fluid type, extent of fluid contact, porosity, permeability, mobility of hydrocarbon the flow rate, formation pressure and a score of other details with a high degree of precision. The advancement in electronics and instrumentation and the advent of computers have found their wide applicability in well-logging. Thereby the well-logging has entered into the field of high technology and modernization. The transmission of downhole data through wireline cable has opened a new era in well-logging offering the scope of recording vast amount of information in the sense of real time data acquisition. Thus, presently the data acquisition and data interpretation through application of computers in well-logging has made new vistas for hydrocarbon exploration and exploitation.

Evolution of well-logging

Oil exploration is age old, since the drilling of the first oil well in 1859 by Col. Drake, it advanced in leaps and bounds. As mentioned earlier, the concept of well-logging was introduced by famous Schlumberger brothers Conrad and Marcel. When they recorded the first Electrical log by a three-electrode resistivity device in Patchelbronn in France on 5th September 1927. This simple event transformed the course of the oil industry. It led to the production of million tons of oil throughout the world. In 1929, Electrical resistivity logging was introduced on a commercial basis in Venezuela, USA, Russia and soon in the Dutch East Indies.

The existence of Spontaneous Electrical Potential (SP log) in the well was established by the Schlumberger engineers during their logging in Rumania in 1931. In 1931, schlumberger brothers perfected method of continuous recording and the first pen recorder was developed. The Photographic recorder was introduced in 1936, though pen recording continued for a few decades.

The following is the chronology of development of well logging:

(1927- 1980)	by M/s. Schlumberger.
1927	First Electrical logging using 3 electrode system.
1931	S.P. (Self Potential)
1931	Gamma Ray log.
1936	S.P. Short Normal, Long Normal and Lateral Resistivity curves called "Electrical Logs". This continued till early 60's in oil wells. (For mineral surveys it is continuing till date)
1937	Side wall coring
1943	Dip meter (S.P. curves) with photo inclinometer.
1946	Dip meter with resistivity curves
1949	Induction log tool.
1951	Laterolog tool.
1956	Sonic log tool.
1957	Formation Tester tool.
1962	Side wall Neutron Porosity tool (SNP)
1963	Dual Induction tool.
1964	Formation Density compensated tool (FDC)
1970	Compensated Neutron tool (CNL)
1978	Electromagnetic propagation tool (EPT)
1980	Stratigraphic High Resolution Dip meter tool (SHDT)

The suite of logs enabled data acquisition for detailed and accurate formation evaluation. Subsequent development in logging tools enhanced data acquisition which will be mentioned while describing advanced logging systems.

The Indian Scenario (Early Days)

In India, the well logging technique was first adopted by Assam Oil Company (AOC). Mr. C.R. Jagannathan³, Chairman OIL writes, "The AOC which was a subsidiary of Burmah oil company (BOC) drilled its first oil well in Digboi, Assam in the year 1889. To solve the geological correlation problems of beds, the Board of BOC adapted a resolution at its Head Quarters at London in 1933 to invite the French Electrical Coring Company - M/s. Schlumberger to Digboi for conducting some electrical surveys. The Digboi well No. 269 was the first well logged

by M/s. Schlumberger in India when Raymond Sauvage ran a resistivity and SP log on 21st October 1933. By 1934 - 36 it was found that the method identified sand and shale and distribution of oil and water. Within 15 years, Schlumberger survey put correlation into a firm footing, provided delineation of underground structures and development of Digboi Field." Since then well logging continued in Digboi by AOC and later in Nahorkatia and Moran by BOC/OIL (Oil India Limited).

Oil and Natural Gas Commission (ONGC) was established in 1956 by the decision of Govt. of India. The first well drilled was Jwalamukhi well No. 1 in 1958 for prospecting hydrocarbon. The first electrical survey in this well was carried out at a depth of 600 feet by a logging unit of Geological Survey of India (GSI) in 1958 and a detailed lithological description was made by late Mr. S.C. Sinha⁴, senior Geologist of GSI.

For carrying out logging survey at deeper depth in Jwalamukhi-1 well, ONGC meanwhile imported its first logging unit AKC. L-3 from USSR with three core logging cable⁵. Two more logging units of type OKC - 56 with single core logging cable were procured from the same source and logging bases were established at Cambay in Gujarat and Sibsagar in Assam⁶.

The State-of-Art of well logging services (till mid 70's).

The state-of-art in well logging during the initial period was very rudimentary in nature. The initial well logging survey included recording of SP, Resistivity, Micrologs. Radio active logs (Gammas ray log and Neutron log, non-calibrated), Caliper, well deviation survey (Inclinometer) and Temperature -log. The set of resistivity logs offered determination of true resistivity (Rt), which was the prime criteria in distinguishing hydrocarbon from water bearing zones. Resistivity interpretations were made for 2 layer (non invasion) by BKZ charts and 3 layer cases (invasion zone) by MKZ charts. The electrical and radioactive logs provided log correlation of different wells⁷. Archi's equation was the basic equation for determination of hydrocarbon saturation⁸.

The status of log interpretation was though very much qualitative in nature, empirical relations using various techniques like Dewette's, Poupon's, Itenburg's methods etc. were utilized for evaluation of shaly sands⁹. Detailed core studies were undertaken for determination of F- ϕ relation and a,m,n values for producing formations in different oil/ gas fields in the country¹⁰. Waxman-Smidt model and Simandu equations for shaly sands were utilized. The departmental logging services were supplemented by Contractual logging services of M/s. Schlumberger to provide induction/Latero resistivity logs. Formation density. Neutron and Sonic logs on limited basis due to constraint of

Foreign Exchange (FE). The methodology adapted helped in discovery of oil and gas as well as for estimation of oil/gas reserves.

The departmental logging services in late 60's were also strengthened from U.S.S.R. by procurement of new generation of resistivity devices (USP) and radioactive devices (NGGKT) which had higher temperature ratings. Also new logging units AKCL-7 with photographic recording system were procured along with new tools. This improved quality of data acquisition as well as data interpretation.

The scenario Mid 70's onward till 80's

The next important chapter in well logging services in the country came in with the availability of Foreign Exchange (FE) when both ONGC and OIL decided to go for procurement of well logging units from western sources. In 1975, two open hole logging units and two cased hole production-logging units from M/s. Gearhart Owen Ltd, USA, along with down hole tools were procured by ONGC¹¹. These were analog type. OIL also made similar procurement. These helped in more detailed data acquisition with introduction of Induction/Latero, sonic, Density, Neutron, Dipmeter tools for openhole logging. Cased hole and production services were also updated. On one hand this up gradation saved F.E. expenditure reducing dependence on contract logging services for which payment was in F.E. on the other hand the technological skill was up gradated for the sophisticated system by the personnel both in ONGC and OIL. Along with open hole and cased hole services perforation kits and explosive charges were procured from western sources hence forth.

Later on by mid 80's Direct Digital Logging Units (DDL) from Gearhart Industries were inducted which introduced computers for data acquisition. Downhole data acquisition was still in analog form¹². The units were procured by ONGC and OIL. By late 80's due to advancement in technologies there was enhancement in downhole transmission of data to the surface from multiple tools recording large number of log data simultaneously. This saved rig down time and brought in efficiency and economy in logging services. New tools were introduced like stratigraphic High Resolution Dip meters (SHDT). Induced Gamma Ray spectroscopy tool (GST/C-0 logging). Natural Gamma Ray spectroscopy Tool (NGS) etc by M/s. Schlumberger¹³. While M/s. Schlumberger introduced MAXIS logging unit¹⁴. M/s. Halliburton logging services introduced EXCELL - 1000¹⁵. Both systems upgraded open hole, production logging, cased hole services. Also the systems had well-site post processing facilities of the log data acquired for carrying out well-site interpretation.

Simultaneously there had been enormous improvement in log data interpretation. This was due to computer application and software developments. M/s. Schlumberger

developed in 70's SARABAND, CORIBAND, DUAL WATER MODEL etc. Which brought in a quality change in log-data interpretation¹⁶ Within ONGC, log interpretation software were developed in-house. While at KDMIPE ONGC, SPILD^{17,18} software was developed, LACOR¹⁹ was developed in BOP (Bombay Offshore Project). Both were upgraded time to time to suit the new challenges in log interpretation using magnetic log data tape. These were adopted in the regional computers in later days to meet the interpretation needs.

In early 80's M/s. Schlumberger introduced GLOBAL software which was later updated to ELAN20 a more versatile log interpretation software. Gearhart Industries / Halliburton introduced ULTRA²¹ software. While ONGC had the facility to utilize these softwares on contract basis, it has developed the OPTIMISING TECHNIQUES using multi mineral models^{22,23}. The methodologies adapted along with enhancement in core laboratory studies helped in reserve accretion of oil and gas in the country.

There has been more Geological Application of Well-logs such as ELECTROFACIES, Faciologs etc. using Dipmeter and other log data both through the logging companies²⁴ and in house²⁵

The Scenarios in 90's

Due to improvement in data transmission, a new array of borehole imaging tools were developed by logging companies to gather information from a large coverage of the borehole surface to obtain detailed geologic information. The High Resolution Dipmeter Tool (SHDT) was updated to Formation Micro Scanner (FMS). FORMATION MICRO IMAGER (FMI) by M/s. Schlumberger. Halliburton developed circumferential Acoustic scanning Tool (CAST). There was improvement in the Vertical Seismic Profiling (VSP) technique in borehole seismic data acquisition. Other new tools like Dipole sonic. Array Sonic, Azimuthal Resistivity Imager (ART)²⁶, Array Induction Imager (AIT)²⁷ etc. were introduced by M/s. Schlumberger. The Dipole Sonic. Array Sonic tools²⁸ were useful in determining rock strength and rock properties. Many of these tools were utilized through contract services in ONGC.

In Bombay offshore, as an aid in advanced drilling programs. Tool pusher logging opened the door for quality logging information in very high angle drill holes. Logging while drilling (LWD) provided necessary back up. Production logging was widely taken up for monitoring producing and injection wells. Special log evaluation techniques had been used for evaluation of open hole and production logs in horizontal wells. The services had been provided by both Schlumberger and Halliburton systems. Schlumberger introduced a new Reservoir Saturation Tool (RST). One of its main applications is enhanced

C/o Saturation measurement.

Halliburton provided EXCELL - 2000 logging systems²⁹. For onland operations, a state-of-the-art integrated logging platform that delivers accurate, high quality data and provides powerful post processing workstation capabilities. New tools and software currently in development can be efficiently operated. It provides increased power and speed in data acquisition and processing. Complete open hole cased hole and production logging services are provided with it along with data processing applications including latest image processing facilities. The system is available for ONGC and OIL for procurement.

What is Ahead of 2000

Halliburton has introduced Polaris array induction called High Resolution Array Induction (HRAI) tool. Its features include 10, 20, 30, 60, 90 and 120 inch depth of investigation results with invasion profiling and bed thickness resolution to 1 ft. Schlumberger has introduced extreme high temperature, high pressure suite of 4 in - OD wireline logging tools for hostile environments rated to 500° F and 25 Kpsi.. Also it has developed a series of enhancement to its array induction Imager tools (AIIT).

Nuclear magnetic Resonance tools include schlumberger's combinable Magnetic Resonance (CMR)³⁰ and Halliburton's magnetic Resonance Imaging Log (MRIL)³¹.

Computalog has introduced a new dipole array sonic tool for vertical and deviated wells. The Monopole Dipole Array (MDA) tool³².

In wireline testing. Halliburton's Reservoir Description Tool (RDT), Schlumberger's Modular Formation Tester (MDT) comprises the current, commercial modular tools with versatile configuration.

Halliburton has introduced of late the Down hole Video services³³ which provides inspection of down hole mechanical equipment and characterization of well bore fluids, especially fluid entry points. This will find wide application in cased hole services. It has also limited scope for use in openhole applications in case drilling mud can be replaced with clear fluids.

In measurement while Drilling (MWD), more improved additional tools i.e. acoustic, density and neutron porosity tools are providing more accurate versions of existing sensors like resistivity and gamma ray tools. This will enhance efficiency in drilling and formation evaluation in problematic areas.

Schlumberger's MDT with optical Fluid Analyser uniquely predicts formation hydrocarbon properties while testing in boreholes drilled with synthetic oil-based muds. Halliburton's Reservoir Description Tool (RDT) became commercially available during 1999³⁴.

Schlumberger's Geo chemical logging tool (GLT) introduced in mid 90's for geochemical chemical logging will find useful application in coal bed methane (CBM) exploration in the present decade.

Application of well logs in other domains in the country:

Besides its application in hydrocarbon prospecting, well logging has been widely used in coal, ground water and mineral prospecting in the country. One of its earliest application was made by the Geological Survey of India (GSI.) GSI carried out ground water work with Indo-US team as early as 1956 with WIDCO Logger. The first electrical log was taken in Punjab by noted geophysicist. Mr. Amalendu Roy in 1953³⁵ In seventies it introduced along with the WIDCO LOGGER, the log Master. The surveys provided were single electrode resistivity. Temperature and gamma ray logs. By August 1972 Ground water Board was formed and the ground water logging was detached from G.S.I. In 1973 onwards GSI undertook well-logging in coal - bearing areas of Bengal, Bihar and Orissa extensively for detailed study of Coal Particularly in evaluation of coal quality³⁶. The Widco and Log master were replaced by new logging units pyo logger from Japan along with UPTRON made logging units Under Govt. of India. These units had multiple logging tools. In mid 90's Robertson Logger from U.K. had been introduced. These provide excellent digital logging services and have single electrode resistivity, multiple electrode resistivity (normal, Lateral), sonic, density, gamma, neutron, temperature, caliper and susceptibility meter etc. In addition to coal prospecting, GSI also undertake mineral exploration work through well-logging³⁶. Along with coal and mineral survey, ground water survey was still continued by GSI.³⁷ Among others in the forefront are Coal India Limited (CIL) doing extensive logging work for coal exploration. Mineral Exploration Corporation Limited (MECL) is doing logging for coal, ground water, other minerals and CBM exploration. Besides, any state governments are also engaged in well-logging work for ground water survey etc.

Conclusion

Well-logging, though started with a rudimentary services in India, particularly in ONGC in fifties, has developed into well advanced sophisticated services in the years to come and presently it provides latest technology in the field of data acquisition and data interpretation for hydrocarbon exploration and exploitation. In the coming decade, it opens enormous scope for utilization of new tools and services which will enhance hydrocarbon production in the country. Other than oil exploration, the services have been updated for coal and mineral exploration by GSI and other various organizations in the country with latest technology.

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References

- Schlumberger, C and M, and Leonardon, E.G. (3 papers all in Trans. AIME, Vol. 110, 1934). "Some observation concerning electrical measurements in Anisotropic Media, and their interpretation" pg. 159. "Electrical Coring; a method of Determining Bottom Hole Data by Electrical Measurements" pg. 237. "A new contribution to subsurface studies by Means of Electrical Measurements in Drill Holes" pg. 273.
- Schlumberger Ltd. (1972). Log Interpretation, Volume I principles.
- Jagannathan, C.R. (1983) : Schlumberger, The First Fifty Years.
- Sinha, S.C. (1958) : Lithological description from Electrical logs in Jwalamukhi well No. 1, unpublished Report of ONGC.
- Mironuvov (1958) Unpublished Report of ONGC.
- Savostyanov, N.A. (1959) Unpublished Reports of ONGC.
- Singh, Inderjit (1960): Correlation of Cambay wells No. 1,2,3,4, unpublished Report of ONGC.
- Garg R.C. (1961) Unpublished Reports of ONGC.
- Paul, A.C. Phukan, G.C. Roy, US (1968): Formation Evaluation of Rudrasagar Field, Assam, Unpublished Report of ONGC.
- Gupta, D.K., Sharma, S.K. Et al (1981) Koithara, Josesh. Hashny, K.H. (1968): Unpublished Report of ONGC.
- Paul, A.C. (1990): Some Memories on Three Decades of Wett Logging Services in ONGC-India, published in 'Memoir in three decades of Well-Logging in India'.
- Schlumberger Ltd. (1974) : log interpretation, Volume II Application.
- Serra, (1986) : Sedimentary Environments From wire line logs, Schlumberger publication.
- Schlumberger Ltd. (1990): The Maxis System: Oil Field Review Brochure: SMP 6018-1
- Halliburton Ltd. (1992) : Excell 1000, Visual Logging System Borhcure: EL-1011, 4/92.
- Serra, (1984) : Fundamentals of well-log interpretation. vol. 1 Schlumberger publication.
- Sen Gupta, A Dhanraj. D. Chakraborty, R.N. (1974) : SPILD - A well log interpretation software, unpublished Report of ONGC.
- Roy, P.K. (1980) : Updation of SPILD Software. Unpublished Report of ONGC.
- Gupta, A.K. Garg, R.C. (1980) : LACOR -well-logging software. Unpublished Report of ONGC.
- Serra, (1986) : Advanced Interpretation of Wireline Logs Schlumberger Publication.
- Alberty, Mark and Hashmy.Khalad H.(1984): "Application of Ultra log Analysis" 25th SPWLA Annual Logging Symposium.
- Basu, D (1989) Multi Mineral Model using optimizing Techniques, unpublished report of ONGC.
- Yadav, R. Bansal., C.R. (1989). An optimizing Technique for Multi Minerals, unpublished Report of ONGC.
- Vaish, J.P. (1995) : Geophysical Well-Logging published by Asian Books private limited. New Delhi.
- Rao, T.V.S. (1990) : Dipmeter Interpretation Technique and Facalog. Unpublished Report of ONGC
- Schlumberger publications (1993) : ARI Azamuthal Resistivity Imager
- Schlumberger publications (1997) : ARI Array Induction Imager
- Schlumberger publications (1994) : Array Sonic Tool
- Halliburton. Energy Services (1995) EXCELL 2000 Brochure (EL1094).
- Mckee O. etal (1999): "An improved NMR Tool Design for Faster Logging". SPWLA Annual logging symposium. Transactions. Oslo, Norway.
- Prammer, M.G. etal (1999): "Theory and operation of New, Multivolume NMR logging systems " SPWLA Annual Logging Symposium Transactions, OSLO, Norway.
- Tello, L. etal. (1999) "A Dipole Array Sonic Tool for Vertical and Deviated Wells". SPE Annual Technical conference and Exhibition, Transactions, Houston, Texas.
- Halliburton Ltd. (1996). "Downhole Video Services-Application' and well preparation" Brochure H00023.
- Halliburton Ltd. (1999). : "Reservoir Description Tool RDT" Brochure Ho 1961.
- Bose, R.N. Rtd. Sr. DDG. (GSI). Personal communication.
- Koyal, J.R.: Personal Communication.
- Koyal, J.R. (1992), Borehole Geophysics - Application to coal and Mineral Exploration, AE Int. Seminar Proceedings, 1991. Hyderabad (invited paper.).