A PERSPECTIVE ON THE FUTURE ROLE OF MWD SYSTEMS

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Abstract

Commercial Measurement While Drilling systems have now been available for over ten years. A broad range of capabilities have been developed, albeit at significant cost. Development has primarily been driven by technology availability. The market for MWD services has been primarily limited by capability, supply and cost. MWD technology has now matured to the point where it is possible to offer significantly more capability than may be required in a given situation.

Current MWD applications can be categorized as directional drilling, drilling efficiency, non-reservoir formation evaluation, and reservoir evaluation. The basic data requirements of these applications are sometimes complementary, however the cost of providing a system to cover all applications is prohibitive for the majority of wells.

MWD is a technological development impacting several other wellsite services. The most significant of these are Drilling Equipment, Mudlogging and Wireline Logging. MWD cannot fully supplant any of these services, and must coexist alongside them all. Thus, any projection of the future role of MWD must look at the current and future interaction between all these services.

Analyzing the inherent capabilities and limitations of each service provides an insight into their intrinsic benefits and value. Projecting likely future developments, it is concluded that MWD services will evolve to offer a broad range of applications solutions. These will focus on the inherent unique capability of MWD systems to provide downhole information as the well is being drilled. This should result in MWD services becoming an economically viable option for a wide range of wells.

Historical Perspective

The first downhole Measurement-While-Drilling (MWD) systems were developed over fifty years ago during the early 1930's. The intended application was as an alternative to wireline logging. However, two barriers proved insurmountable with the technology available at that time. The first problem was the lack of a practical way to transmit data to the surface while drilling. The attempted method being to hardwire the drill pipe. Providing electrical connections across every joint of pipe was not economically practical then, and still is not today. The second problem was developing measurement systems suitable for the drilling environment. The fragility of vacuum tubes being one example of the limitations of the technology then available.

Mud pulse telemetry, the first practical method of data transmission for MWD, was pioneered in the early 1950's. However it was the development of solid state electronics in the 1970's that finally allowed the development of a viable commercial MWD system.

The early non-commercial attempts at developing MWD systems had focussed on formation measurements as an alternative to wireline logging, which was itself still in its infancy. By the time technology allowed the development of commercial MWD systems, wireline logging was fully established. Because of this, commercial MWD development was directed towards meeting the recognized need for realtime control of directional drilling.

Rarely acknowledged as such, the first commercial MWD systems were the wireline steering tools used to control directional drilling assemblies during a kickoff. The big advantage of steering tools over whipstocks and single shot surveys, was the ability to provide realtime feedback on the progress of the kickoff. A steering tool proved a valid technical solution to the problem of dynamically controlling directional drilling. However,the need to run a wireline in addition to the drill string imposes operational and economic limitations.

The effective combination of rugged, accurate downhole directional sensors, a downhole power source, and mud pulse telemetry to the surface was achieved in the late seventies and signaled the start of commercial directional MWD services. In operation, these MWD systems were far more efficient than previous methods of directional control. However the savings in rig time were only justified for high cost operations: typically offshore.

Alongside the commercial deployment of directional MWD systems, significant efforts were expended in the development of other MWD sensors. To a large extent, these initial sensor developments were technology driven.

Basic sensors to monitor the formation, the mud and the drill string were devised. Specific economic applications were hard to quantify, and the tools were expensive. The prime use was thus on high cost offshore exploration wells, where the potential benefits of any additional information were greatest. A second application was on offshore development wells, where the use of directional MWD was already cost justified, and a case could be made for the potential benefit of the additional information offsetting the additional cost.

At this point, MWD systems had been shown to be capable of making accurate measurements of formation characteristics. However, due in part to the limited sensor suites available, the data was only used qualitatively for formation evaluation. Economic justification of MWD was based on the perceived value of the data as drilling information. In addition, some downhole drilling data measurements were available, but few commercially viable applications had been identified.

Current Status

We now have the situation where some basic MWD services are considered a normal requirement on a variety of wells. However, the range of available MWD sensors and services exceeds the requirements of almost all wells. The decision as to what, if any, MWD services are used on a well should be based on an analysis of the overall information requirements of the well, and the relative economics and benefits of obtaining the data by alternative methods.

A well is typically drilled to penetrate one or more geological targets. Information is gathered during the well for two prime purposes. Firstly to monitor and aid the progress and performance of drilling the well. And secondly to evaluate the actual geology encountered, including the objective(s).

Drilling Information

As the well is being drilled, the goal is to drill a well safely to the objectives at minimum cost. The driving force is thus drilling efficiency. The information needs as the well is being drilled can be broadly grouped into the following categories:

Geological: Formation properties are fundamental in determining how to drill a well. Rock and fluid properties can be controlling factors in bit, casing and mud programs. The value of monitoring these parameters while drilling will depend on how significantly variations in them will effect the drilling operation.

Correlating the formations encountered as the well is drilled with the prognosis may confirm the well plan, or provide data on which to base decisions modifying the plan. This might result in a redefinition of the objective for the well or its location.

This leads to the concept of "Geological Steering", whereby the well path is controlled dynamically by geological information, rather than the geometrical control normally applied. this concept is of particular significance for horizontal wells, where the objective might be to extend the wellbore for a significant distance within a particular geological horizon.

Directional: In order to drill a well to an objective, it is necessary to monitor and to control the well trajectory. This requires as a minimum, periodic determination of the bottom hole position. The complexity of the well plan, and allowable spatial tolerances will determine whether real time control is required.

Operational: Surface and, or downhole measurements can monitor the use and performance of all components of the drilling system, including the drill string, downhole drilling tools, and the mud system. Monitoring the rotational orientation of the drill string (toolface) in conjunction with a steerable drilling system allows the future path of the wellbore to be controlled.

Formation Evaluation Information

The goal of the geological evaluation of a well is to obtain the maximum useful information concerning the location, geological context, volume, type and producibility of potential hydrocarbon accumulations, at minimum cost. Thus the driving force is information value versus cost

Geological information is paramount. In addition to the drilling applications identified above, geological information acquired during drilling can be used to optimize subsequent evaluation.

Directional information is required, as the path of the wellbore provides a spatial framework for the data.

Operational information can be used to aid the interpretation of other data. Since the drilling systems interacts with the formation, this may provide additional geological information.

There are a wide variety of formation evaluation methods in use. Some of these, seismic for example, are of prime importance before a well is drilled. Others, such as reservoir modeling or core analysis are of use once the well has been drilled. Whilst the applications of MWD may well interact to some degree with these formation evaluation methods, by far the most significant interactions will occur with existing wellsite formation evaluation methods.

Wellsite Information Sources

Wireline logging as referenced here is defined as wireline conveyed downhole instrumentation. The capabilities of these services have now expanded to provide a very broad range of information regarding almost all aspects of the subsurface environment. There are significant constraints that are placed on the sensor designs in terms of pressure, temperature and form factor requirements. But these are far less than the constraints imposed on MWD sensors. MWD systems have to meet the shock, vibration, and abrasion demands of the drilling environment in addition to functioning as a mechanical member of the drillstring. The wireline offers effectively unlimited data rate capability, and the actual utilization time of the wireline tools is comparatively short compared to MWD: utilization of the latter being tied to the drilling time of the well, or hole section.

Thus on a direct comparison of measurement cost, the economics of wireline appear extremely favorable versus MWD. However, MWD offers two benefits that frequently are difficult to quantify. Firstly, the timeliness of the data, and secondly, the quality of the measurement environment.

Wireline offers a broad array of downhole information after drilling. Apart from the delay in acquiring the data, which is only significant if there is an earlier need for the data, the only other potential drawback is the degradation of the measurement environment caused by the presence of the wellbore.

Surface monitoring during drilling operations, generically described as "mudlogging", is relatively economical, and a broad range of data is available continuously. The description stems from the earliest data collection efforts which were concentrated on evaluating mud returns for information pertaining to downhole geology. The scope of mudlogging has expanded considerably during the past twenty years as the service companies have developed methods of monitoring all aspects of the drilling operation.

Unlike wireline logging whose development has centered on formation evaluation, wellsite surface monitoring has evolved into a variety of fields.

Depth registration of mud returns requires monitoring of the hole depth and penetration rate as well as the mud circulation time. Hydrocarbon gas liberated from the mud provides indications of potential hydrocarbon accumulations, and potentially provides early warning of high pressure zones. Thus the scope of mudlogging was expanded to include safety monitoring. Various other sensors were added to monitor for potential hazards, and mudloggers became the de facto experts in attempting to predict and identify the occurrence of high pressure zones while drilling.

Aided by a plethora of sensors and computer systems, the modern mudlogger can monitor almost all aspects of the drilling operation. Using this data, in conjunction with observation of the cuttings and fluids transported to the surface, he can determine many characteristics of the formations being drilled.

Since the data is collected as drilling progresses, it can be, and is, used for making drilling decisions. However there is a fundamental limitation of surface monitoring that remains, and this concerns the interpretation of the data. The correlation of phenomena observed at the surface with a unique set of downhole conditions is far from straightforward. Thus surface monitoring is used primarily qualitatively at present.

MWD is, at present, a relatively high cost method of obtaining a limited array of data. However, it has two significant advantages over current alternative wellsite information sources. The major one is the availability of quantitative downhole data in realtime while drilling. The second is the quality of the measurement environment. This leads to three areas of potential benefit:

- Realtime downhole data can directly reduce costs by providing the most efficient method of obtaining information. Examples of this include the use of MWD for directional control, and the use of MWD formation measurements to pick casing or coring points.

- The second potential benefit is to minimize trouble costs. In this application, MWD is used as an additional, often redundant information source. Here the use of MWD is justified, not by the direct cost savings, but by reducing the probability of additional expenditure. The most significant current use of this application is running MWD formation evaluation measurements, while still planning a full suite of wireline logs. In the event of hole problems, the MWD data can then be used in the decision as to whether to pursue obtaining the wireline data.

- The third potential benefit results from the measurement environment. In an ideal case, it would be possible to obtain in situ measurements of undisturbed formation. However, the presence of the borehole, ensures that the environment directly surrounding any wireline or MWD sensor is not undisturbed. MWD offers two potential advantages over wireline. Firstly, due to the comparatively short exposure time, the disturbed (invaded) zone is typically smaller for MWD measurements. This means that MWD sensors can be designed with shallower depths of investigation. This is an advantage since it inherently allows better vertical resolution to be obtained. In addition the logging speed while drilling is typically substantially slower than used for wireline logging. This is a direct benefit for statistical measurements such as gamma ray, neutron porosity, and density measurements.

This suggests that MWD sensors are only economically justified if:

1) They either provide information that can be used in realtime to improve the overall efficiency of either drilling the well, or evaluating the geological objectives.
   or
2) They can provide a measurement more economically than

alternative methods (typically wireline).
  or
3) The quality of the data is worth the cost.

Applying the above criteria to existing commercial MWD sensors we see that:

MWD Gamma ray measurements are commonly used with the primary application being correlation with several direct uses for aiding overall drilling efficiency. MWD gamma ray logs can provide better vertical resolution that comparable wireline logs, due to the smaller crystal permitted by the slower logging (drilling) speeds for MWD. However, the economic justification of using MWD gamma ray sensors based on data quality alone would be extremely tenuous.

MWD Resistivity measurements are used for correlation, to determine pore pressures, and identify potential hydrocarbon zones for both safety (shallow gas) and economic considerations. In addition, MWD resistivity measurements provide a once only opportunity to obtain true resistivity readings in thin beds. Whilst MWD Gamma/Resistivity can significantly enhance reservoir evaluation, the log suite is not complete and thus cannot fully replace wireline logging for basic reservoir evaluation.

MWD Porosity measurements are used primarily for reservoir evaluation in conjunction with gamma and resistivity measurements. In addition, applications have been identified using porosity information to improve realtime pore pressure estimates. Current MWD porosity measurement quality benefits from the generally better measurement environment provided by minimal hole degradation, however there are also significant limitations on the measurement capabilities. For example, all current commercially available MWD Formation density measurements require the drillstring to be rotating. This is not operationally compatible with current steerable drilling assembly use.

We can thus conclude that MWD resistivity and Gamma sensors have several potential applications in all sections of a well, whereas the currently identified applications for existing porosity sensors are limited to potential reservoir sections and some potential overpressured intervals. The technological and operational complexity of the porosity sensors is significantly greater than for gamma and resistivity. Coupled with the reduced range of applications, this implies that the incremental cost of adding porosity to an MWD service will be high.

However, because porosity completes the log suite for basic reservoir evaluation, the MWD "triple combo" does replace basic wireline logging. Thus, if MWD gamma/resistivity is justified for other reasons, the incremental cost of MWD porosity may be justified against the reduction in wireline costs. This may well be the case in horizontal and other high angle holes, where the overall costs of obtaining wireline logs can be high.

For drilling information, MWD has evolved from replacing steering tools and single shot survey instrumentation to enabling the development of steerable drilling assemblies. These can now combine the straight line drilling performance of normal rotary drilling assemblies with dynamic steering capability. Downhole drilling dynamics information, including drill string forces and vibrations is now being used to improve understanding of drilling mechanics and in some instances diagnose problems such as stabilizer hangups, and potential catastrophic bit failures.

Future Developments

Since surface measurement and monitoring systems are inherently less expensive than downhole monitoring, there are significant economic advantages to developing analysis and interpretation techniques that would allow surface monitoring to fulfill some or all realtime formation evaluation and drilling efficiency needs. MWD provides the downhole measurements that could be the key to such a development.

Wireline services include cased hole logging and other mechanical operations such as setting packers that are beyond the scope of this discussion. However, the existence of these additional services ensures that there is a significant future requirement for wireline services, regardless of the future of open hole wireline logging.

It is theoretically possible to incorporate almost any open hole wireline measurement into an MWD system. However, there are two significant practical considerations that will limit the adaptation of many of the current wireline measurements to MWD. The first is that the sheer cost of developing and deploying these sensors would result in systems that are uneconomic to run compared to wireline. Secondly, the data volume generated would swamp the realtime transmission capability of any MWD system, and severely test the capacity of any downhole memory system.

This strongly suggest that there is a practical limit for the range of sensors that can be economically incorporated into MWD systems, and that this limit is significantly less than current wireline capability. However, it is also apparent that MWD does have significant application in providing a base suite of Formation Evaluation information in many wells. In addition, under some circumstances, MWD may be the only, or preferred method of acquiring downhole geological and petrophysical data.

As a reservoir evaluation tool, realtime availability of the information is not paramount. The main potential benefit of MWD is the quality of the data. The driving force will be the relative cost of obtaining the data from MWD versus the cost of obtaining it by other means, or not having access to the data at all.

As a drilling aid, the requirement is for usable realtime information. The driving force is drilling efficiency, thus the decision to utilize MWD will be made on economic grounds. Technology developments will decrease the cost and operational complexity of basic MWD systems. This will open the way for MWD to improve efficiency by monitoring a limited range of key information, even on low cost wells. Another development envisaged is the incorporation of MWD into a drilling system. Monitoring, and even directly controlling the drilling assembly, significant improvements in drilling efficiency may be realized by enabling better utilization of drilling tools.

Conclusions

The future of MWD is inextricably linked with a variety of technologies and competing wellsite information services. MWD offers some unique advantages over other wellsite information systems. Offsetting these advantages is the fact that MWD is inherently more expensive than either surface measurements while drilling, or wireline logging. Thus whilst MWD usage will undoubtedly increase, applications will be restricted to those where the unique capabilities of MWD can be economically justified. Firstly by providing realtime downhole data, primarily of use for drilling efficiency decisions. Secondly providing information unobtainable by other means, such as time sensitive measurements, or due to practical constraints on alternative methods.

MWD has matured to the point where more capabilities are available than is required throughout most wells. Future applications of MWD will be constrained less by technological limits than by comparative economics. Whilst further capabilities will undoubtedly be developed, these will more likely be concerned with providing capabilities unique to MWD rather than attempting to directly replace existing methods.

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