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How Can We Best Manage Lost Circulation?

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Abstract

Worldwide oil and gas operators are expecting Service Companies to deliver integrated methods for preventing and minimizing drilling problems. At the same time, for the service industry there is no way to proactively respond to the rapid changes and expanded knowledge of the E&P companies.

The last five years has brought a dramatic shift in the business logic and management culture of the drilling industry, from "quick-fix management" to "project planning and learning organizations". A large majority of oil and gas operators have started an effort to build a more performance-oriented culture. Based on this dramatic change in the management culture of the E&P companies, a Client-Oriented Technology Improvement Process has proven very successful during the project-planning phase.

This concept is a process that involves exploring and assessing the project specific problems and then linking them to existing products and services. The process focuses on service offerings (i.e., drilling fluids, waste management, solids control, R&D capabilities) and uses existing resources to create project-oriented and problem-specific plans and solutions.

An application of this project planning process is the Lost Circulation Assessment and Planning process (LCAP), which involves exploring and assessing project-specific lost circulation problems and afterwards linking them to existing lost circulation products, systems and services. For maximum success, emphasis is placed on assessment and planning rather than individual products. This methodology prevents and minimizes lost circulation problems rather than depending on after-the-fact attempts at cure.

Introduction

The problem of lost circulation became apparent in the early history of the drilling industry and was magnified considerably when operators began drilling deeper wells and/or through depleted formations. The industry spends millions of dollars a year to combat lost circulation and the detrimental effects it propagates, such as lost of rig time, stuck pipe, side-tracks, blow-outs and, occasionally, the abandonment of expensive wells. It is estimated that lost circulation cost the industry around $800 million per year, while the lost circulation products could represent as much as $200 million. Moreover, lost circulation has even been blamed for minimized production in that losses have resulted in failure to secure production tests and samples, while the plugging of production zones has led to decreased productivity.

Deepwater drilling has brought lost circulation control to a more critical level as it involves narrow pore pressure/fracture gradient windows, cold drilling fluid temperatures, high equivalent circulating densities (ECD's), high cost-per-barrel of synthetic-based fluids (SBM) and a high cost for lost rig time/non-productive time (NPT).[1,2]

Drilling through salt formations presents a number of additional potential problems. Typically, the formations immediately below the salt are either mechanically weaker or fractured, introducing a greater risk for loss of returns. The lost time treating severe sub-salt losses can be up to several weeks, with obvious cost implications, especially for deepwater drilling operations.[3]

Often on exploration wells, little information regarding pore pressure and fracture gradient is available. Gulf of Mexico sub-salt wells often encounter higher pore pressures below the salt, creating well control issues. In this instance the higher mud weights required to balance the pore pressure place even greater stresses on the weakened sub-salt formations. As deeper wells are being drilled in old development areas there is an increased potential for lost circulation when drilling through depleted zones.[3]

Induced fractures represent an even more complicated problem, as the shape and structure of induced formation fractures are always subject to the nature of the formation, drilling and mechanical effects, as well as geological influences over time. One condition of paramount importance in sealing induced fractures is having the lost circulation material (LCM) reaching the tip of the fracture. Related to the "breathing" tendency of induced fractures (to change shape and size as per wellbore pressure changes), "pressure buffering" is another condition that has to be fulfilled for effective sealing. Ideally, to stop the breathing tendency in a robust manner, the pills should be able increase the fracture gradient at a level sufficiently high to avoid re-opening the fracture during the subsequent drilling phases.[4]

Traditionally the control of the lost circulation has been a reactionary process. The Lost Circulation Assessment and Planning (LCAP) process involves proactively exploring and assessing project-specific lost circulation problems and linking them to existing lost circulation products, systems and services.

The process focuses on available products (i.e. conventional LCM, specialized polymer cross linked pills, software tools) and uses existing resources (offset well analysis, logs, mineralogy/geology analysis) to create project-specific plans and solutions. For maximum success, emphasis is placed on assessment and planning rather than individual products. This methodology prevents and minimizes lost circulation problems rather than pursuing an after-the-fact cure. Careful preplanning simplifies the process of choosing from the 177 specialized lost circulation products offered by 46 different drilling fluid suppliers.

Lost Circulation Assessment and Planning – The Process

The Lost Circulation Assessment and Planning concept is a process that involves exploring and assessing project specific lost circulation problems and links them to existing lost circulation products, systems and services. The process focuses on using existing resources to create project-specific plans and solutions.

There are five key elements to this continuous improvement process (Fig. 1):

- Exploration
- Development
- Implementation
- Execution
- Evaluation

Exploration Phase: During this phase, a multidisciplinary exploration team (operator and service company technology center specialists, service company field specialists, rig supervisors, drilling engineers, geologists, logistics personnel, formation evaluation personnel) is formed to identify candidate wells for the LCAP process, assess the magnitude of the lost circulation potential, obtain offset well information, develop strategic plans, and define the roles and the responsibilities of the development team.

Development Phase: A technical development team (project engineers, drilling engineers, drilling supervisors) analyzes the offset wells data to identify the most probable thief zones, links existing LC products and technology with potential for solving the specific problem, uses existing engineering tools (software, best practices) to develop the Lost Circulation Assessment and Planning Program (LCAP Program) and develops the training curriculum for both operator and service companies in-process engineers (drilling engineers, field service engineers).

The Lost Circulation Planning and Assessment Program (report) represents by far the most important document that has to be completed during the *Development* phase. The program represents the final planning document to be delivered to the well team, for implementation and execution. The remaining part of this paper explains the stepwise process to develop the *Lost Circulation Assessment and Planning Program* and the information and engineering tools needed during this process.

There are <u>four key steps</u> to the Lost Circulation Assessment and Planning Program (Fig. 2):

- Gathering and processing all the available project-related and problem-specific data (i.e., well team input, offset well data including logs, recaps etc.)
- Identifying the most probable thief zone(s) and loss mechanics
- Developing project, and thief zone, specific lost circulation prevention and mitigation measures and guidelines
- Identifying the best conventional lost circulation treatments, and recommending the contingency specialized treatments (i.e., cross-linking pills, gunk squeezes) including detailed operational procedures.

Step 1: Gathering and processing all the available project-related and problem-specific data. This represents a key difference from the after-the-fact, reactive approach to lost circulation. The type of data available includes:

- Pattern of lost circulation as part of geology, lithology and stratigraphy analysis
- Pore pressure and fracture gradient
- Logging data (i.e., imaging, wireline, pressure-while-drilling, array resistivity logs)
- Drilling reports (indicating pre-loss and post-loss drilling conditions, drilling events etc.)
- Offset wells lost circulation analysis (treatments and results, lessons learned)
- Hydraulics analysis, pressure loss and ECD/ESD simulations
- Evaluation of historical cost associated with lost circulation

Step 2: Identifying the most probable thief zone (type and location). The type of thief zone refers to the nature of the loss zone (i.e., induced fractures, natural fractures, permeable formations) and the location refers to the relative position of the loss zone. The types of tools/methods available for thief zone identification are:

- Pressure Transducer Surveys, Open Hole Logs (e.g. UBI, CDR), Hot Wire Surveys, Radioactive Transducer Surveys, Temperature Surveys, and Spinner Surveys.

- Best practices and the pre-loss events analysis
- Real-time geomechanical analysis methods
- If available, use lost circulation expert software tools. The use of the expert software requires a good understanding and knowledge of pre-loss conditions.

Step 3: Developing project and thief zone specific lost circulation prevention measures and guidelines. The lost circulation prevention measures should be tailored for each specific thief zone that is likely to be encountered (e.g. permeable formations, natural fractures, induced fractures) and should be integrated in the overall well drilling best practices. However, there are lost circulation preventive measures that can be applied regardless of the type of the thief zone, as follows:

- Keeping ECD to a minimum
- Minimizing surge and swab pressures
- Running LCM in the drilling fluid
- Minimize annular Loading
- Maintaining good drilling fluid properties
- Chose the appropriate surface and compatible downhole equipment
- Experienced and trained personnel
- Quick response

Step 4: Identifying the best conventional lost circulation treatments, and recommending subsequent contingency specialized treatments (i.e., cross-linking pills, gunk squeezes) including detailed operational procedures. The types of tools/methods available for identifying the best project-specific conventional LCM pills and specialized LC treatments are:

- Use existing lost circulation expert software tools
- Utilize proven lost circulation decision trees/flow charts
- Use the well- and project-specific drilling best practices

At the end of this step a formal project-specific Lost Circulation Assessment and Planning Program should be developed and provided to well execution team. The recommended LC treatments should always include both conventional LCM pills and treatments (e.g. blended pills of granular, flaky and fibrous materials etc.) and specialized LC treatments (e.g. cross-linking technology, oil gellant pills etc.). Always include pre-treatment procedures (i.e., LCM mixed in the whole drilling fluid system). Check with the drilling/directional engineer and the MWD/LWD operator for the smallest passage in the downhole tools (i.e., smallest clearance in the MWD tool) and verify that the D_{90} particle size distribution of the chosen LCM passes through the tool openings. Include detailed mixing and spotting procedures for all the pills that will be mixed as a stand-alone spotting pill treatment. Make sure that considerations are given to the rig specific mixing equipment and mixing tanks. Identify the pill specific mixing tanks/pits and determine the dead volume. Always consider the dead volume in the mixing procedures (i.e., add the extra volume). For all cross-linking pills, best practices include the use of cementing units for pumping and squeezing.[5]

Implementation Phase: Technical and operational implementation team (service company field specialists, rig supervisors, drilling engineers, geologists, logistics personnel, formation evaluation) delivers the lost circulation plan to the execution team by:

- Distributing the LCAP program document to all team members
- Conducting training at the project engineering and field service engineering level.

Execution Phase: The execution team (project engineers, drilling engineers, drilling supervisors, rig crews):

- Applies the process and methods as per the LCAP program.
- Creates contingency stocks on location of all the conventional LCM and specialized pills before the job starts.
- Supervises the day-to-day operations and monitors the execution of the LCAP process.
- Documents in-process successes & failures.

Evaluation Phase: A multidisciplinary evaluation team (operator and service company technology center specialist, service company field specialists, rig supervisors, drilling engineers, geologists, logistics personnel, formation evaluation):

- Evaluates the extent of plan's success/failure
- Measures the overall process impact, including time and cost savings
- Collects and documents all the lessons learned
- Estimates the value added to the drilling project
- Redevelops plans for the future wells and communicate them to the well execution team.

Lost Circulation Assessment and Planning – Case Study – Induced Fractures in Deepwater

Planning for a deepwater, sub-salt Gulf of Mexico well included the LCAP process because of expected lost circulation problems, as experienced during the offset wells.

Three intervals were analyzed: 14 ½-in, 12 ¼-in and 9 $^{7}/_{8}$-in. Miocene type lithology (shale and sandstone) typified the first two intervals; the bottom section was a transition Miocene – Oligocene with the possibility of limestone stringers. The thief zone immediately below the salt formation (the first interval) was expected to be a typical rubble zone of highly fractured shale.

The fracture gradient in the rubble zone was less relevant, but could present important variations (much lower values) from the estimated range (14.5 – 15.0 lb/gal mud weight equivalent).

A development team was assembled, all the necessary data was gathered and a LCAP process document was generated. The highest potential loss zone to be encountered, other than the rubble zone, was determined to be induced fractures shale, followed very closely by porous sandstone, induced fractures sandstone and natural fractures sandstone.

Wells of this nature are typically drilled with synthetic-based mud (SBM). Some types of material, such as synthetic graphite, have a neutral surface and can work in both types of fluid (WBM and SBM). Accordingly, a typical formulation for curing seepage losses may contain a blend of granular calcium carbonate and synthetic graphite. Optional treatments, ranging from conventional to specialized, follows:

- Pre-treating the whole mud system with $CaCO_3$ (8 - 10 lb/bbl) and synthetic graphite (8 - 10 lb/bbl)
- Mixing fiber based particulate LCM (20 to 25 lb/bbl) in the system as passing through the seepage loss zone
- Pumping 15 to 20 lb/bbl synthetic graphite sweeps (25 to 50 bbl volume) at a frequency of one sweep every third stand, and if needed as often as one every stand
- Spotting a sequence of blended LCM pills as needed starting with 35 lb/bbl, then 65 lb/bbl and 95 lb/bbl respectively, followed if needed by a soft set pill (i.e., PCP) or a reverse gunk squeeze.

A series of lost circulation decision trees were developed to address lost circulation problems for this deepwater prospect (Fig. 3).[6]

Lost Circulation Assessment and Planning – Case Study – Naturally Fractured Carbonate

Lost circulation is a significant drilling problem in this Central Asia fractured carbonate field. Whole mud losses in some of these wells has reached 10,000 to 80,000 bbls including productive horizons. The analysis of the severity and pattern of the lost circulation included lithology data, logs, pore pressure and fracture pressure analysis, casing programs, daily drilling reports and end-of-well recaps.

The lost circulation has been attributed to severely fractured and/or highly porous reservoir, 1-meter to 7-meters cavities and excessive mud weights due to insufficient initial geological and pore pressure data.

Typical mixed LCM pills, gunk squeezes and cement were not effective. From the analysis of the offset wells, it 200-lb/bbl pill was designed specifically for these formations. This pill is formulated with grit, very coarse, coarse and medium calcium carbonate. The proposed specialized treatment included a soft-set, crosslinked polymer pill.[7] Well- interval-specific flow charts are presented in Fig. 4. Even though these pills worked over moderate intervals, the lost circulation zone was so long that eventually the well was only being completed using mud cap drilling.

Lost Circulation Assessment and Planning – Process Overview and Benefits

For many years now there has been no room for “Ready, Aim, Fire” in the lost circulation business. It has been nothing but “Ready, Fire, Re-fire”! This is maybe the reason why today we are using almost the same reactive approach as our predecessors fifty years ago. We are forgetting to aim and keep missing the target. The key word here is *aim* and should be translated as *planning for the lost circulation event, defining the target and have everything handy when the lost circulation occurs*.

Being a project specific methodology, the LCAP process involves exploring and assessing well- and interval-specific lost circulation problems and links them to existing lost circulation products, systems and services in order to create project-specific plans and solutions.

The dynamics of the LCAP process are exploring specific project needs, using existing resources (personnel, knowledge, software) and creating ad-hoc teams to develop the LCAP program followed by implementing and executing the process.

The proper execution of the *implementation* phase is going to be the most critical step. It involves not just deploying the LCAP program but conducting project-specific training at well team project engineering and field service engineering level.

If the LCAP program has been implemented correctly, the *execution* would become a natural step by applying the process and methods and documenting in-process successes & failures.

The LCAP program overall benefits are as follows:

- Gets problems solved, or at least makes progress as part of a continuous improvement process.
- Extensive pre-planning allows for in-depth data gathering and a greater chance for success.
- The well-execution team receives a documented process/plan - Lost Circulation Assessment and Planning Program - to follow and to measure performance with regard to technology, cost, training etc.
- Provides fit-for-purpose solutions.
- The project- and well-execution team gets an opportunity to input project specific problem needs into the Lost Circulation Assessment and Planning process.

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SI Metric Conversion Factors

bbl	X 1.5897	E-01	= m^3
°F	X (°F-32) X 5/9 = °C		
ft	X 3.048	E-01	= meters
gal	X 3.785	E-03	= m^3
in	X 2.540	E-02	= meters
lb	X 4.536	E-01	= kg
ppb	X 2.853	E+00	= kg/m^3
ppg	X 1.198	E+02	= kg/m^3
ppg	X 1.198	E-01	= Specific Gravity (SG)

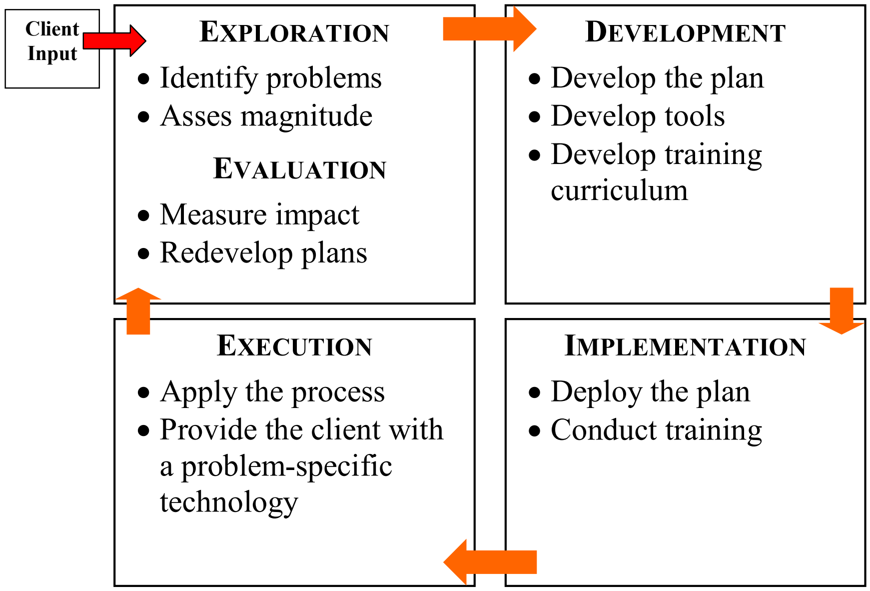

Fig. 1: The Lost Circulation Assessment and Planning concept is a process that involves exploring and assessing project specific lost circulation problems and links them to existing lost circulation products, systems and services. The process focuses on using existing resources to create project-specific plans and solutions.

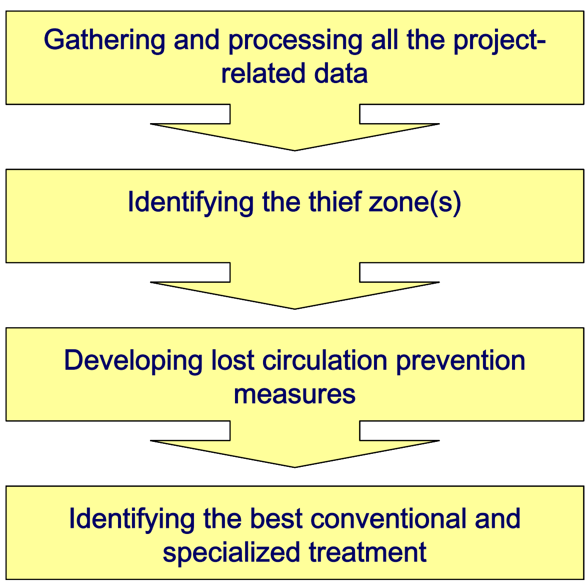

Fig. 2: The four key steps to the Lost Circulation Assessment and Planning Program

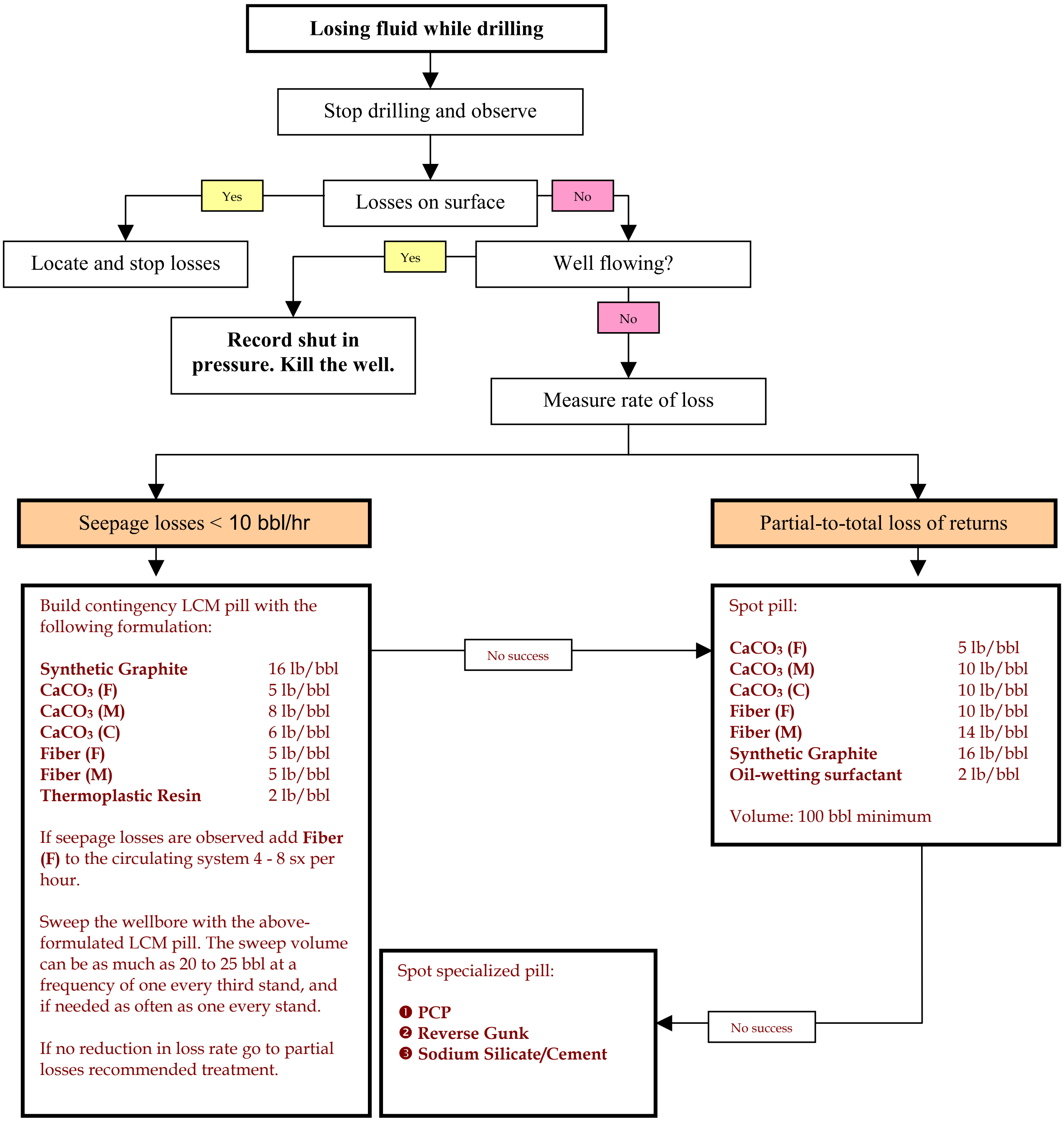

Fig. 3: The Lost Circulation Assessment and Planning decision tree covering conventional, specialized and contingency lost circulation treatments for a deepwater, sub-salt Gulf of Mexico well.

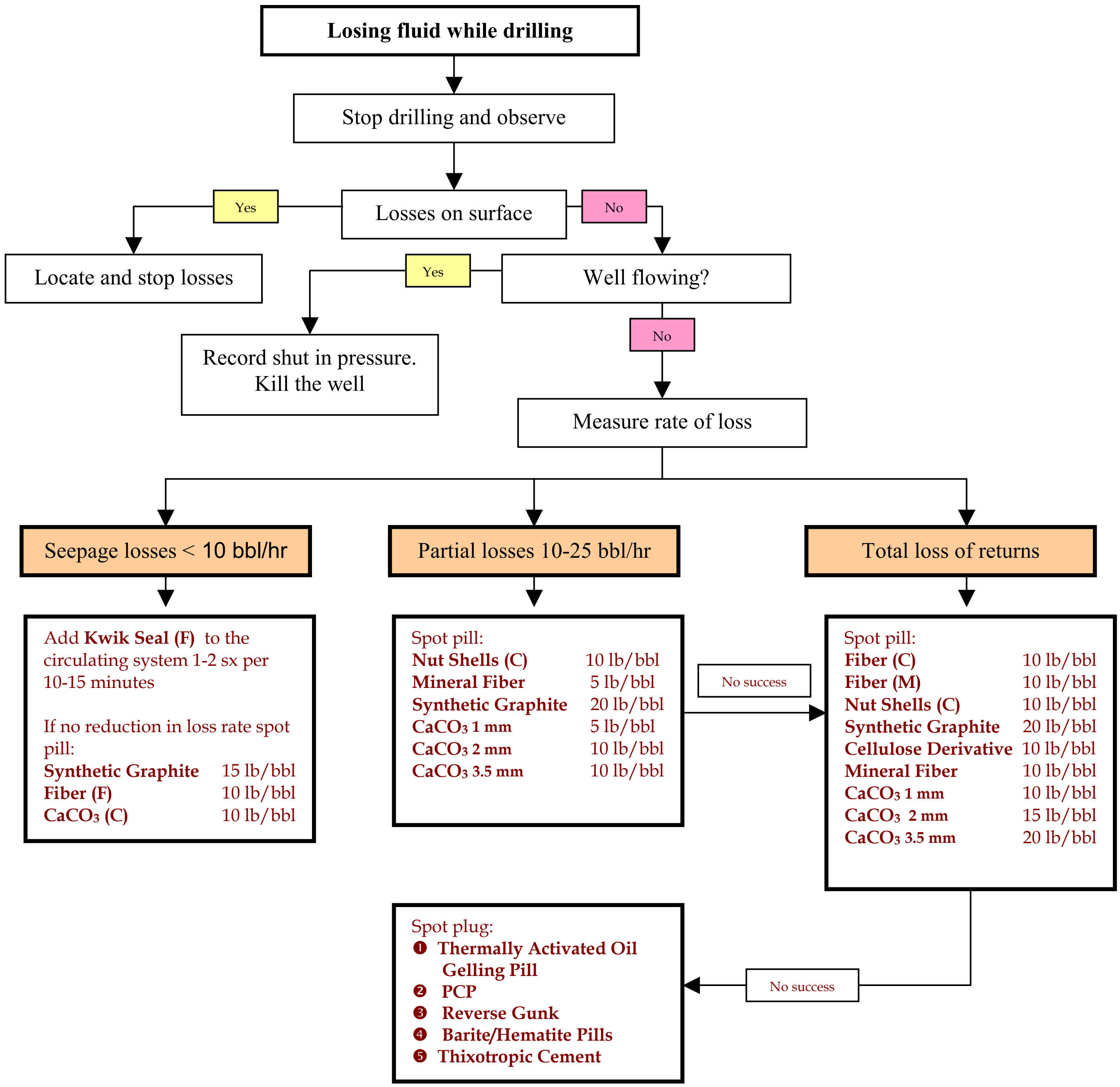

Fig. 4: The Lost Circulation Assessment and Planning decision tree covering conventional, specialized and contingency lost circulation treatments for a naturally fractured carbonate well in Central Asia.