



Unique Engineering Software Developed for Lost Circulation Planning and Assessment

Catalin Ivan and James Bruton, M-I SWACO and Jean-Philippe Bedel, Schlumberger

This paper was prepared for presentation at the AADE 2004 Drilling Fluids Conference, held at the Radisson Astrodomo in Houston, Texas, April 6-7, 2004. This conference was sponsored by the Houston Chapter of the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individuals listed as author/s of this work.

Abstract

An innovative software program has been developed to explore and assess operator and well-specific lost-circulation problems and link them to available solutions. The software tool is an integral part of an underlined process that focuses on existing resources, such as lost-circulation products, procedures, geo-mechanical models, logs and mineralogy/geology analysis to create project-specific plans and solutions.

The software contains four key modules designed to (a) consider well-specific data, (b) determine the most likely thief zones, (c) locate the position of potential thief zones relative to key depths of interest, such as the casing/liner shoe, and (d) identify the most appropriate preventative and treatment measures. Case histories will be included to demonstrate its use and outline lessons learned.

The goal of this software and the process to which it is associated to is to minimize and prevent lost-circulation problems rather than an after-the-fact cure. The integrative pre-planning process analyzes offset histories and formation data to identify risk zones, but also to gather information on the exact fracture and pore size as well as fracture density. Afterward, detailed interval-specific solutions are developed for stopping losses encountered while drilling or tripping in.

Introduction

The problem of lost circulation (LC) 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 costs the industry around \$800 million per year, while the LC 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 LC 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, 3, 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 crosslinked 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 LC problems rather than pursuing an after-the-fact cure. Careful preplanning simplifies the process of choosing from the 177 specialized LC 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 LC problems and links them to existing LC products, systems and services.

The process focuses on using existing resources to create project-specific plans and solutions.^{5,6,7} There are five key elements to this process (Fig. 1):

- Exploration
- Development
- Implementation
- Execution
- Evaluation

Exploration Phase: During this phase, candidate wells for LCAP process are identified, the magnitude of the lost-circulation potential is assessed, and strategic plans are developed.

Development Phase: A technical development team 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 to develop the Lost Circulation Assessment and Planning Program (LCAP Program).

The Lost Circulation Planning and Assessment Program software is used during the *Development* phase.

There are three key steps to the Lost Circulation Assessment and Planning Software:

- Gathering and processing all the available project-related and problem-specific data (*i.e.*, pore pressure and fracture gradients, geology/lithology etc.)
- Identifying the most probable thief zone(s), loss mechanics, and the relative position to bit
- Identifying the best conventional LC treatments, and recommending the contingency specialized treatments (*i.e.*, crosslinking 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 (Fig. 2):

- 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 (Fig. 3 and 4):

- Pressure Transducer Surveys, Openhole 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: Identifying the best conventional lost-circulation treatments, and recommending subsequent contingency specialized treatments (*i.e.*, crosslinking pills, gunk squeezes) including detailed operational procedures (Fig. 5 and 6).

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.* crosslinking 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 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

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: 14½-in., 12¼-in. and 9⅞-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

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 bbl 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, a 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.

LCAP – Process Overview and Benefits

Being a project specific methodology, the LCAP process involves exploring and assessing well- and interval-

specific lost-circulation problems and links them to existing LC 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 (software), developing the LCAP program followed by implementing and executing the process (Fig. 7 and 8)

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.

Acknowledgements

We thank the management of both M-I SWACO and Schlumberger for support and permission to publish this paper. Special thanks go to Mary Dimataris and Jim Redden from M-I SWACO for professionally revising this paper.

References

1. Sweatman, R. Faul, R., Ballew, C.: "New Solutions for Subsalt-Well Lost Circulation and Optimized Primary Cementing," SPE 56499, SPE Annual Technical Conference and Exhibition, Houston, October 3-6, 1999.
2. Brady, S., *et al.*: "Evolving Solutions for Improving the Drilling Efficiency of Deepwater Extended Reach Wells: A Model for Implementation of New Technology," AADE-02-DFWM-HO-05, AADE Technology Conference "Drilling & Completion Fluids and Waste Management", Houston, April 2 - 3, 2002.
3. Ferras, M., *et al.*: "Lost Circulation Solutions for Severe Sub-Salt Thief Zones," AADE-02-DFWM-HO-30, AADE Technology Conference "Drilling & Completion Fluids and Waste Management", Houston, April 2 - 3, 2002.
4. Ivan, C. D., *et al.*: "Making a Case for Rethinking Lost Circulation Treatments in Induced Fractures," SPE 77353, SPE Annual Technical Conference and Exhibition, San Antonio, September 29 – October 2, 2002.
5. Caughron, D., Ivan, C., Bruton, J. R., Bratton, T.,: "Unique Cross-linking Pill in Tandem with Fracture

Prediction Model Cures Circulation Losses in Deepwater Gulf of Mexico,” SPE/IADC 74518, SPE/IADC Drilling Conference, Dallas, February 26-28, 2002.

6. Sanders, W. W., *et al.*: “Lost Circulation Assessment and Planning Program: Evolving Strategy to Control Severe Losses in Deepwater Projects,” SPE 79836, SPE Drilling Conference, Amsterdam, February 19 – 21, 2003.
7. Bruton, J. R., *et al.*: “Lost Circulation Control: Evolving Techniques and Strategies to Reduce Downhole Mud Losses,” SPE 67735, SPE/IADC Drilling Conference, Amsterdam, February 27 - March 1, 2001.

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	= m
gal	x 3.785 E-03	= m ³
in.	x 2.540 E-02	= m
lb	x 4.536 E-01	= kg
lb/bbl	x 2.853 E+00	= kg/m ³
lb/gal	x 1.198 E+02	= kg/m ³
lb/gal	x 1.198 E-01	= specific gravity (SG)

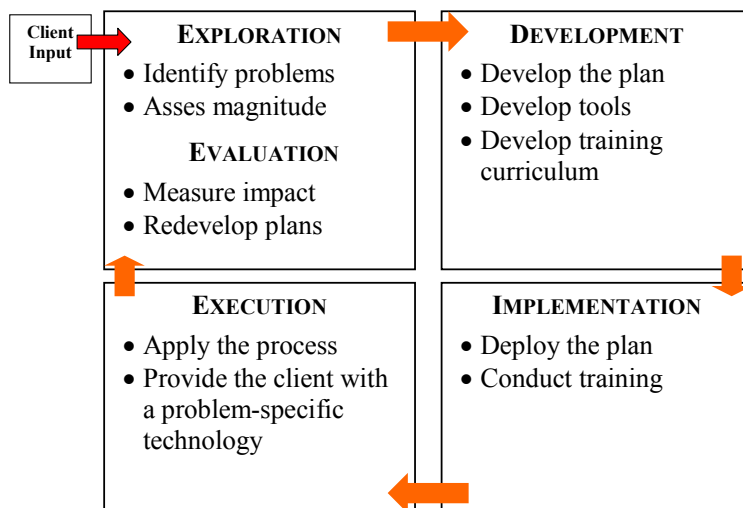


Fig. 1: The Lost Circulation Assessment and Planning concept is a process that involves exploring and assessing project specific lost circulation problems and links them to existing lost circulation products, systems and services. The process focuses on using existing resources to create project-specific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

Admin	Well Data	LCM Pill ID	Q Formation ID	Formation ID	Q Spec LC Treat ID	Specialized LC Treat ID	Report	Disclai
<input type="radio"/> Metric unit <input checked="" type="radio"/> Oilfield unit								
Fluid Density		13		ppg				
OH Diameter		8.25		in				
BHST		180		deg F				
CSG/Liner Shoe		@ 10000		ft (TD)				
		10000		ft (TVD)				
Present TD		@ 15000		ft (TD)				
		15000		ft (TVD)				
Has a LCM pill been pumped to solve this particular problem? <input checked="" type="radio"/> Yes <input type="radio"/> No								
Are you cementing? <input type="radio"/> Yes <input checked="" type="radio"/> No								
LC Rate		90		bbl/h				
Pump Rate		10		bbl/min				
Fluid Level		0		ft				
Pore Pressure		9360		psi				
Pore Press Gradient		0.62		psi/ft				
Equiv. Fluid Density		12		ppg				
Frac Pressure		10920		psi				
Frac Gradient		0.72		psi/ft				
Equiv. Fluid Density		14		ppg				
OH Stratigraphy Losses								
Sandstone		yes		don't know				
Limestone		no						
Dolomite		don't know		don't know				
Evaporite		no						
Shale		yes		don't know				
Back		CALCULATE				Print Page		

Fig. 2: Gathering and processing all the available project-related and problem-specific data.

For help contact administrator		Menu			Calculate	Help
Well 1						
QUESTIONS (click on the question for help)	Yes	NA	No			
Was action "RIH Pipe" when losses started?			X	Lost Circulation Formation Identification 		
Are losses flow rate sensitive?	X					
Was action "breaking circulation" when losses started?			X			
Are losses partially recovered after pumping stopped (ballooning)?	X					
Did pump pressure decrease when losses started ?			X			
Did pump pressure increase prior to losing returns ?			X			
Were any heavy pills pumped (i.e., slug pills) prior to losing returns?			X			
Was any overpull experienced prior to losing returns (i.e., during the last tripping out or during making connections while drilling)?			X			
Have any of the offset wells been hydraulically fractured?			X			
Did offset wells encounter natural fractures?	X					
Did the ROP decrease prior to losing returns?			X			
Did the ROP increase prior to losing returns?			X			
Do geology data indicate fault zones or other tectonic activity?			X			
Have any hydrocarbons (i.e., gas, liquid) and/or connate water been observed at the surface prior to losing returns?			X			
Are the sand formations drilled in gauge in this field?		X				
Were losses encountered before in this interval?	X					
Did the bit drop prior to losing returns?			X			
Is the well deviated in this interval (30° to 60°)?			X			
Has the drilling fluid density been increased throughout this interval?			X			
				SS - SANDSTONE	LS - LIMESTONE	Back Next Step
				SH - SHALE	DO - DOLOMITE	

Fig. 3: Identifying the most probable thief zone(s), loss mechanics, and the relative position to bit.

Admin	Well Data	LCM Pill ID	Q Formation ID	Formation ID	Q Spec LC Treat ID	Specialized LC Treat ID	Report	Display
<div> <div> LC Formation Identification Ranking 1. IND FRAC SH 2. IND FRAC SS 3. NAT FRAC SS 4. NAT FRAC SH </div> <div> Estimated Position of the LC Formation Close to TD 1. CS [] TD 2. CS [] TD 3. CS [] TD 4. CS [] TD </div> </div> <div> CS: Casing Shoe TD: Total Depth </div> <p>By clicking the "Next" button, the above LC formations and locations are validated. If the identified formation does not correspond to the actual formations in the wellbore please go back to the Well Data and the Formation Identification questions and re-answer them.</p> <div> Back Next </div>								

Fig. 4: Identifying the most probable thief zone(s), loss mechanics, and the relative position to bit.

For help contact administrator		Menu			Calculate	Help
	QUESTIONS (click on the question for help)	Yes	NA	No		
1	Is the thief zone in the productive formation (pay zone)?			X		
2	Have you already squeezed a cement plug in the loss-zone ?			X		
3	Is the drilling string open-ended?			X		
4	Is the drilling fluid a Water Based System?			X		
5	Is wellbore sidetracking considered a risk?			X		
6	Does the mud weight need to be significantly increased after curing the LC problem ?			X		
7	Is there any sour gas (H2S) concern ?			X		
8	Is there any CO2 concern ?			X		
9	Has any pressured formation been drilled below the loss zone ?			X		
10	Is there any Cr-based products disposal limitation?			X		
11	Are there any disposal problems related to oil-base products or cuttings?			X		
12	Has any cross-flow been identified?			X		
13	Expected Fractures or Voids size (in)					

Specialized Lost Circulation Treatment Identification

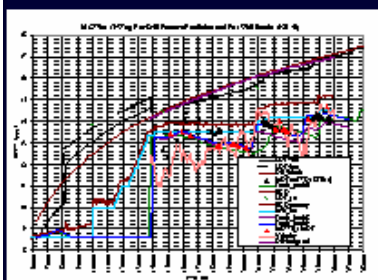
Back Next Step

Fig. 5: Identifying the best conventional lost circulation treatments, and recommending subsequent contingency specialized treatments (i.e., cross-linking pills, gunk squeezes).

Admin	Well Data	LCM Pill ID	Q Formation ID	Formation ID	Q Spec LC Treat ID	Specialized LC Treat ID	Report	Disal
<p>Recommended Treatment:</p> <p>Ranking</p> <ol style="list-style-type: none"> Form-A-Set AK VersaPac InstantSeal InstantSeal Cement Reverse Gunk High-Fluid-Loss Squeeze Protectozone Form-A-Plug II Zonelock SC LiteCRETE Cement 								
Back		Go to report						

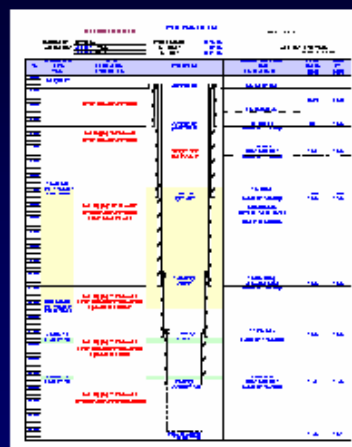
Fig. 6: Identifying the best conventional lost circulation treatments, and recommending subsequent contingency specialized treatments (i.e., cross-linking pills, gunk squeezes).

Lost Circulation Advisor – The Process



Geo-mechanical Model

LC Advisor – Well Data



Drilling Fluids Program

LC Formation Identification



Estimated Thief Zone Position

Fig. 7: 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 (software), developing the LCAP program followed by implementing and executing the process.

