STUCK PIPE FREEING PROBABILITY OF SUCCESS IN GEOTHERMAL DRILLING OPERATION: A CASE STUDY IN JAVA

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ABSTRACT

Stuck pipe is a common problem in geothermal drilling operations. Stuck pipe can lead to extra cost due to lost-in-hole tools, sidetrack, fishing operation, and cost due to prolonged total drilling operation/campaign. The commonly faced dilemma in mitigating stuck pipe is to decide whether to continue with the attempts to free the pipe or cut the pipe or sidetrack the well. One of the consideration factors for the issue is to calculate the probability of freeing the pipe.

The purpose of this study is to investigate the connection between the probabilities of success with stuck pipe freeing attempts. Using statistical analysis, the study analysed the events of stuck pipe from a drilling campaign in Java in the 1990s. This study finds out that the answer to previously unknown effective time of work pipe operations. Further studies are needed to establish the relationships of drilling parameters to the probability of success and develop a cost-effective preventive/corrective measure to stuck pipe problem.

1. BACKGROUND

The drilling of deep holes (typically 1.5 to 3 kilometers in depth in Indonesia) depends upon favorable results from the earlier stages – which includes well cost. Cost per meter is expected to range from $1,000/m to $5,000/m (with $3,960/m baseline) (Purwanto et. al., 2018), inclusive of the cost of the drilling is rig movement between well pads, but exclusive of initial mobilisation charges. Those numbers comprise some 46–58 percent of the total capital costs of a geothermal project in Indonesia (ARUP, 2017). Most of which will be incurred in determining the size, location, and power capacity of the geothermal resource.

The 80/20 rule states that: for many events, roughly 80% of the effects come from 20% of the causes. Stuck pipe events can come in serial order with loss of circulation, fishing and sidetrack (20% of the causes) – it makes up roughly 80% of non–productive time (NPT). A record of geothermal drilling performance during 15 years of operation in the Philippines has reported 15–25 percent of NPT (Sarmiento, 2007). In most recent cases in Indonesia, stuck pipe incidents accounted for 10–30 percent of total NPT – which implies, up to hundred thousand dollars undesired cost for prolonged total drilling time, replacement cost of equipment lost, and curative action to resume the operation (Arif, 2020). Hence, investigation on decision whether to continue with the attempts to free the pipe or cut the pipe to proceed or sidetrack the well all resulting in significant loss of money.

2. FREEING TECHNIQUE

Stuck pipe events are described as 'the Swiss cheese effect' with systematic failure of four levels: design or planning, equipment factors, hole-related cause and human error (Arif, 2020). Techniques and procedures for freeing a stuck pipe is dependent on the reasons that give rise to the event. Prior to taking the action to free the pipe, the cause of the problem must be determined.

In geothermal drilling, the most common cause is that water (the drilling fluid) do not properly transport cuttings when a loss zone is encountered (Figure 1). The cuttings in the wellbore pack off around drill string causing the string to get stuck (stuck pipe). If an adequate water supply is available, it is practical to drill without returns (total loss circulation).

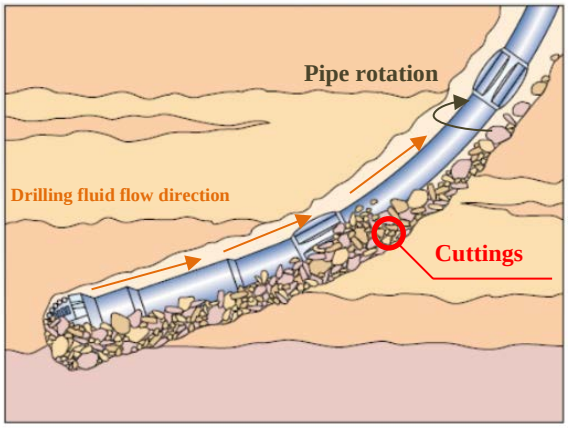

Figure 1 Hole cleaning issue in geothermal drilling (Modified from Halliburton, 2019).

The highest risk is when only partial returns are obtained, as the low annular velocities above the loss zones may not be adequate to clean the hole. High viscosity sweeps (mud-sweeps) are usually used to reduce this risk. Pumping water at high rates down the annulus as well as down the drill pipe will flush the cuttings away from the wellbore and provide positive wellbore pressure to hold up weak formations.

Sometimes, stuck pipe incidents are inevitable. The following is an over simplified-generic freeing procedure caused by poor hole cleaning while drilling:

- At the first signs of the drill string torqueing up, reverse movement of string against torqueing up direction is applied. If torque is escalating while drilling down, pull the string out of hole slowly;

- Continue cycling the torque with work the pipe up and down and maintain flow of water at high rate – as maximum as the down hole equipment and/or the formation can handle;

- Pump down hi-vis sweep or continue with aerated drilling. If the pipe is not free once full circulation is established, commence to work the pipe: try to rotate, jar up, and later begin to slowly ream to look for 'free movement'.

Unfortunately, freeing attempt may remain unsuccessful. It shall come to an end at a certain time. Otherwise, it can lead to extra cost due prolonged total drilling operation/campaign. Decision has to be taken on whether to continue with the attempt to free the pipe or cut the pipe.

3. METHODOLOGY

Statistical approach to freeing probability of success can help making more deliberate and thoughtful decisions on time limit to work the pipe. Records of freeing time (in hour) of 50 stuck pipe events from a drilling campaign in Java in 1990s (refer to Appendix A.1) were presented using Weibull plot with 50% error approximation. All in-data drilling parameters and techniques applied for freeing the pipe have presumably been set at optimum. Equation 1 gives the calculation of the cumulative probability of success:

$$P_s(t) = 1 - \exp(-\lambda t)^m \quad (1)$$

where probability of successful pipe freeing attempt P_s is a function of time t with Weibull scale factor λ and Weibull shape factor m.

The rate of change of pipe freeing probability of success was plotted against attempt time – with 2% rate of change picked as stagnation criterion for time limit to work pipe decision. The 90% percentile or P90 was also assessed to give consideration to 'finale say' by comparing with 2% stagnation criterion using Equation (2):

$$\$_{exp} = P_s(t) \times \$_r \times t + (1 - P_s(t))(\$_f + \$_{st}) \quad (2)$$

Where the expected undesired cost $\$_{exp}$ varies according to operation rate (freeing attempt rate) $\$_r$, fishing cost $\$_f$, cost of sidetracking $\$_{st}$ and of course the probability of successful pipe freeing attempts P_s as function of time t. The stagnation criterion and P90 should give different numbers of successful freeing probability. Therefore, the result with least undesired cost is preferred for decision on time to work pipe.

4. RESULTS & ANALYSIS

4.1 Probability Analysis

Weibull plot (Figure 2) with coefficient of determination R^2 of 0.83 gives a result that λ=16 and m=0.95.

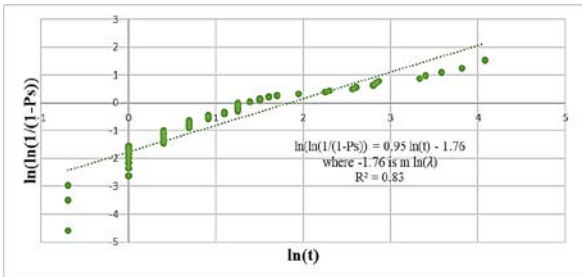

Figure 2: Weibull plot of 50 samples of stuck pipe events from a drilling campaign in Java in 1990s.

Hence, these parameters can be applied to equation (1) to get:

$$P_s(t) = 1 - \exp(-0.16t)^{0.95} \quad (3)$$

This probability of freeing the pipe P_s before time t is plotted together with its derivative in Figure 3. The derivative plot (rate of change) gives a sense of probability change over the time. In this case, P90 possess the higher probability of success freeing the pipe in comparison to the stagnation criterion's successful chance. The longer the time for the attempts, the more it is possible to get the pipe freed.

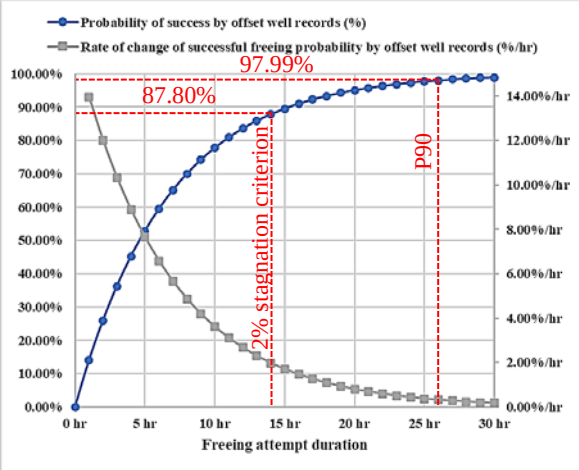

Figure 3: Plot of probability of success freeing the pipe and its derivative over the time.

The slope of the rate of probability change shall also be considered. It is peaking and declining by nearly 2%/hr at the beginning. It explains that the success probability diminished rapidly with time. The earlier the pipe freeing starts, the higher is the probability of getting it freed. Also, the longer the attempt takes, the lesser probability change it makes – which means the less effective it is to prolong the attempt.

4.2 Freeing Economy Analysis

Determination of decision parameters, whether to go with 2% stagnation or P90 criterion, is critical. Using Equation (2), the economy of a stuck pipe event from the 1990s' campaign in Java is shown in Table 1.

Table 1: Stuck pipe freeing economy comparing 2% stagnation and P90 criteria.

2% stagnation	Variable	P90
87.80%	P_s	97.99%
14 hr	t	26 hr
$1,000	$\$_r$	$1,000
$52,800	$\$_f$	$52,800
$240,000	$\$_{st}$	$240,000
$48,013.60	$\$_{exp}$	$31,362.68

It tells how P90 criterion (highlighted in green) is preferred by the least expected undesired cost, rather than 2% stagnation (highlighted in red) – all with the same rate and input except for probability and time (highlighted in yellow). Interestingly, at different rate arrangement, 2% stagnation might come out as preferred criterion with lower expected undesired cost. Therefore, at any arrangement of rates, these criteria should always be checked and recalculated.

5. CONCLUSION & PATH FORWARD

Statistical approach to freeing probability of success can help making decisions on freeing attempt time. This study has conveyed the method for assessment to previously unknown effective time of work pipe operations. The following lessons learnt have been concluded:

- Statistical based analysis requires competent data sets. Ensuring the quality of daily drilling report is crucial for delivering right decision.
- It is important to set clear time limit and make a re-evaluation to expected undesired cost. One criterion of freeing economy is not always resulting in lower costs.

This study does not consider drilling parameters in stuck events and freeing attempts. Therefore, further studies are needed to establish the relationships of drilling parameters to the probability of success and develop a cost-effective preventive/corrective measure to stuck pipe problem more accurately.

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APPENDIX

Appendix A: Figure A.1

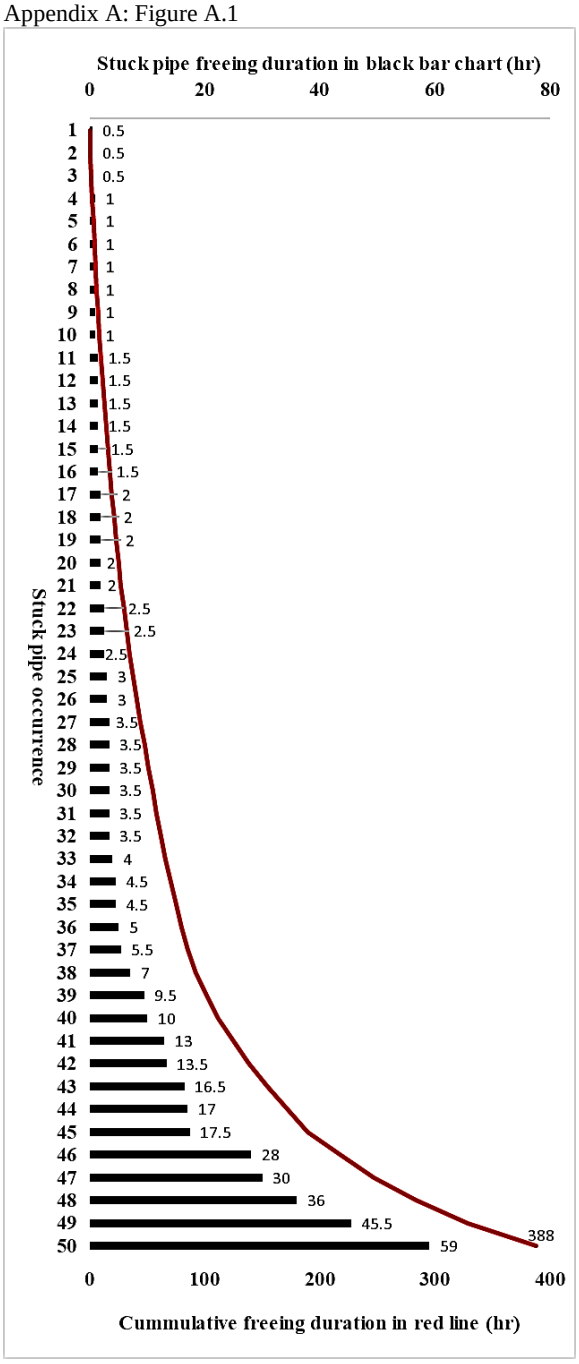

Figure A.1: Record of freeing time of 50 stuck pipe events from a drilling campaign in Java in 1990s.