PREDICTING SUCCESS OF WELL DISCHARGE AND AIR COMPRESSION OF TIWI WELLS USING THE RATIO OF AREAS OF FLASHING TO CONDENSATION (Af/Ac) METHOD

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ABSTRACT

The Tiwi Geothermal Field has a number of production wells that have difficulty in being re-discharged when they cease flow, resulting in loss of production. The wells are usually allowed to build up pressure and are then discharged to the sump to stimulate production but this may take quite a long time and is not always successful. An air compressor has therefore been mobilized to Tiwi to stimulate wells that are no longer able to self-discharge.

The downhole temperature and pressure data from the wells have been used along with the Af/Ac (Area of flashing to Area of condensation) ratio method (Sta. Ana, 1985) to help predict the likely success of self-discharge and air compression. In one of the test wells, the correlation predicted success for self-discharge, as Af/Ac was >0.85 based on the pressure and temperature survey and shut in wellhead pressure, but when the well was opened, it was unable to flow. The compressor was then used to stimulate the well to a higher wellhead pressure, which then resulted in a successful flow. The flow test results provided additional data and suggesting modifications to the Af/Ac ratio method to be able to account for: (1) surface discharge pressure effects as the well was flowed to a surface piping system which had higher back pressure than either flowing the well vertically or horizontally to an atmospheric test rig, (2) how the "Area of flashing" is defined below a wellbore obstruction or the total depth to consider for wells with shallow obstruction, and (3) the correct wellbore temperature survey to use for well leaking to the surface. After applying these corrections to the candidate well, the results then agreed with the threshold ratio of 0.85 described in the correlation.

In other test cases, recently reworked wells were successfully flowed to the system sooner than planned. The Af/Ac ratio method was used in evaluating if air compression was likely to be successful in stimulating the wells, which led to calculating a target pressure to achieve the 0.85 threshold ratio.

1. INTRODUCTION

The Tiwi geothermal field is located in the Bicol Peninsula region of Luzon Island Philippines and is operated by the Philippine Geothermal Production Company, Inc (PGPC). It started commercial operation in 1979 and was the first geothermal field developed in the Philippines. The field has experienced several changes in reservoir processes in response to more than 40 years of exploitation. As a result, the production behavior of wells have changed over the years, especially in the areas affected by pressure drawdown and meteoric recharge influx. In some cases, wells have become less productive and more sensitive to surface pressure changes. Some of these wells cease flowing if throttled or during power plant upsets that cause a sudden increase in pressure. Aside from the decrease in productivity, the production of the wells also become more difficult to recover. Kap-11, for example, was historically a productive well that has been able to self-discharge if flowed to the sump. However, in recent years it has taken more time building up pressure and its recent flow tests were unsuccessful.

The ceasing of flow of these pressure sensitive wells has resulted in a loss of production opportunities. To aid in stimulating these wells, an air compressor was mobilized to Tiwi with Kap-11 being the test case. The Af/Ac ratio method, which was developed by Sta Ana (1985) to predict the success of well discharge, was used in the analysis of its shut-in wellbore survey. This indicated that air compression should have an excellent chance of success in recovering the production of the well.

The flow tests of two recently reworked wells, Bar-11 and Bar-08RD, were also initially unsuccessful because the wells had not yet fully heated up. The feasibility of air compression in stimulating discharge of these wells was evaluated with the aim of flowing the wells sooner than their normal heat-up requirement. The Af/Ac ratio method was used to determine the air compression pressure that would result in a successful discharge at the current wellbore conditions. In both wells, the discharge tests were successful after compression to the calculated threshold pressure.

The Af/Ac ratio technique is one of the most commonly used methods for predicting the flow of wells because of its simplicity and ease of use, as it only requires an equilibrated wellbore pressure and temperature survey (Mubarok and Zarrouk, 2017). However, in some of the analyses, the method incorrectly predicted the successful discharge of wells and corrections to the method were implemented in the analyses of other wells. This study examines these corrections which improved the success of predictions made with the Af/Ac ratio method.

2. WELL DISCHARGE PREDICTION

The Af/Ac ratio method suggests that the "Area of flashing" (Af) is proportional to the excess energy of the fluid once the well is opened to flow. In contrast, the "Area of condensation" (Ac) is proportional to the energy taken from the fluid to heat the casing and nearby rock formation. The estimation of these areas is demonstrated in Figure 1 where Af is defined as the area bound by the water level after compression, the measured wellbore temperature, and a modified boiling point for depth curve drawn from the water level at the compressed state. On the other hand, Ac is defined as the area bound by the wellbore temperature and the saturation temperature for the pressure at which the fluid will be flowed, which is 100 ^{0}C for atmospheric conditions. The areas were estimated by binning pressure and temperature data The method proposes that the likelihood that the well will flow is dependent on the ratio of the excess energy to the deficit (Af/Ac). The ratios prescribed by Sta Ana in using the method are shown in Table 1. The succeeding subsections will discuss how the method was used in the analyses of discharge and air compression in particular wells.

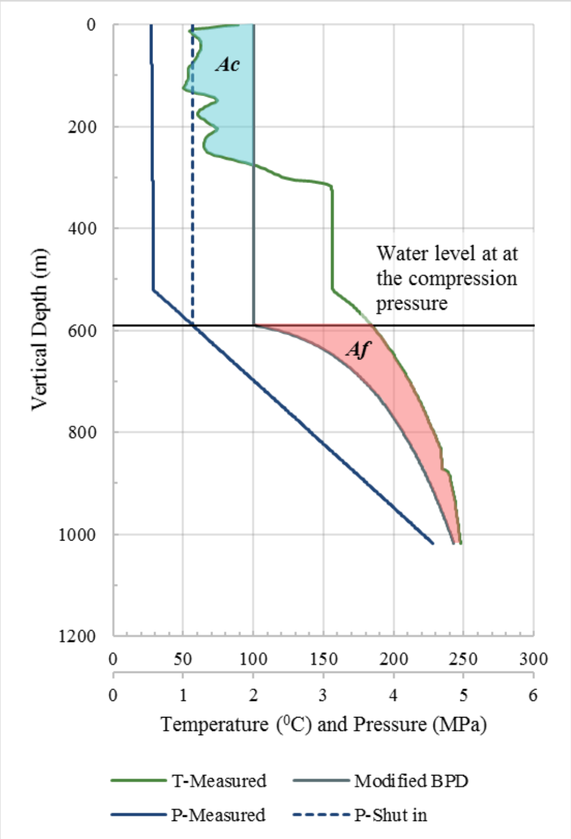

Figure 1: Estimating Areas of Flashing and Condensation

Table 1. Af/Ac Ratio Criteria

Af/Ac Ratio	Discharge prediction
<0.70	Failure
0.70-0.85	Uncertain
>0.85	Successful

2.1 Kap-11

Kap-11 is a liquid-dominated well, which has been a stable producer since it was drilled. In recent years, the well became sensitive to pressure changes. If subjected to significant pressure changes, such as during throttling or power plant upsets, the well ceased to flow. Kap-11 is among a group of production wells in Tiwi with similar behavior. If the wells cease flowing, they are shut in for pressure recovery and typically, they are able to recover production after flow tests to a diffuser or atmospheric flash tank.

Historically, Kap-11 was able to self-discharge and regain its production. However, its flow tests have been unsuccessful during its most recent ceasing of flow episodes in 2018. This is demonstrated in Figure 2 where the flowing wellhead pressure (WHP) of Kap-11 is compared to its separator pressure. A higher WHP indicates that the flow is from the well to the separator (Figure 2) from April to June, 2018. The well ceased flowing on June 28, 2018 and from July to September, 2018, the well was not able to recover production during the three flow tests, even when the shut-in wellhead pressures had recovered to 1.10, 1.03, and 1.17 MPa.

Analysis of the Af/Ac ratio of Kap-11 at the shut-in WHP actually indicated a good chance of success of self-discharge. As shown in Figure 3, the Af/Ac ratio at 1.17 MPa was 1.08, which is above the threshold ratio of 0.85. However, upon discharge, the well failed to flow and the Af/Ac method failed to predict this result. The well was then compressed to achieve a higher Af/Ac ratio and at a compressed pressure of 2.30 MPa, the Af/Ac ratio was 1.50. The flow test was then successful and the well recovered its production. The well was compressed to this pressure in succeeding air compression activities.

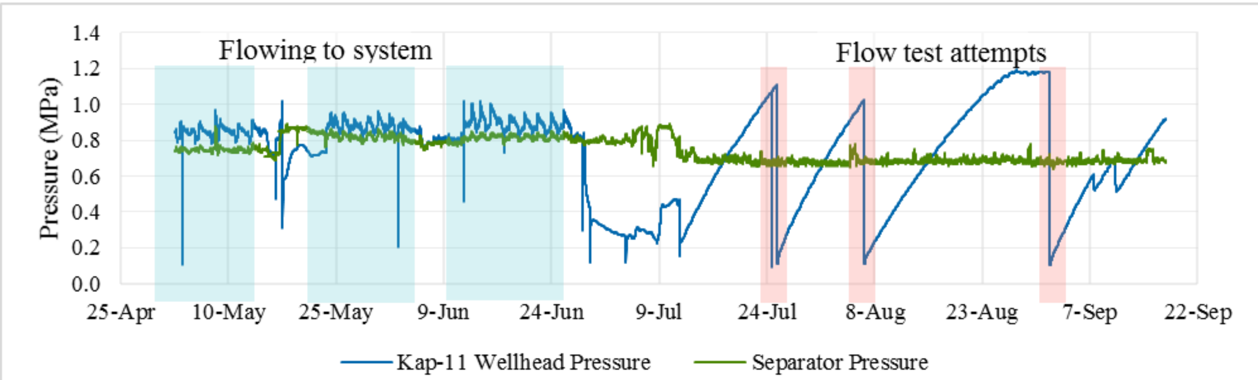

Figure 2: Kap-11 Flowing Wellhead Pressure

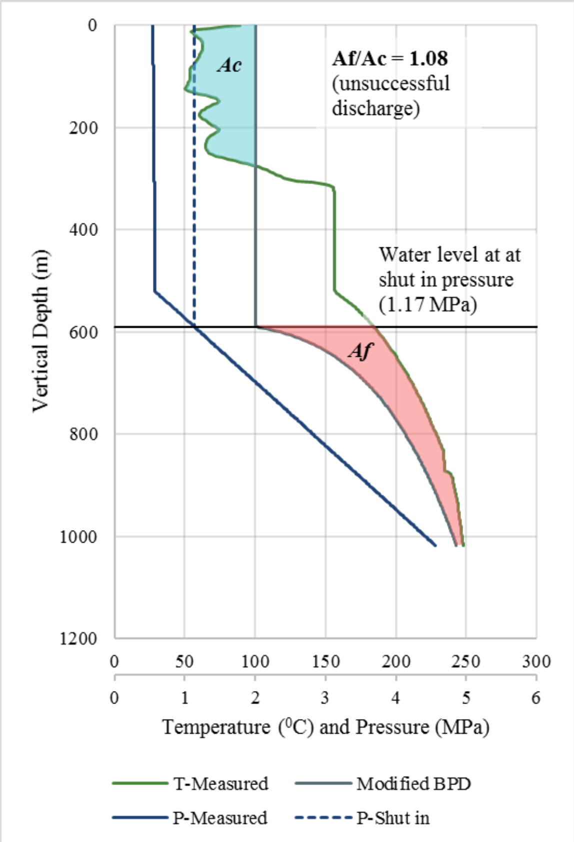

Figure 3: Af/Ac Ratio Analysis of Kap-11 for Self-discharge at 1.17 MPa

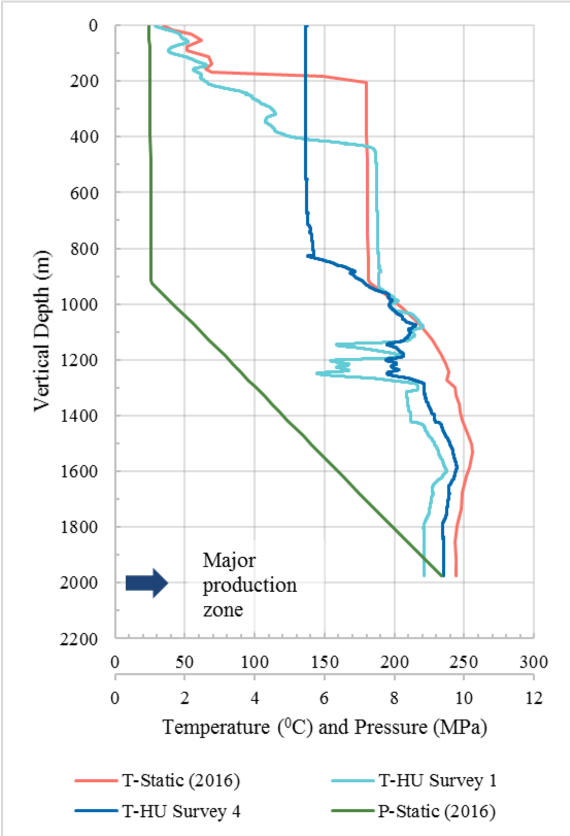

Figure 4: Bar-11 Heat-Up Surveys

2.2 Bar-11 and Bar-08RD

Bar-11 and Bar-08RD are liquid-dominated wells with deep production zones. Potential shallower feed zones were cased off to prevent entry of acidic fluids in this section of the wellbore. The wells are also drilled from the same production pad and are relatively close to each other in their cased sections.

The wells were recently reworked to drill out scale inside their wellbore that was causing production issues, and to reline Bar-11 as a hole was detected in the casing, which was allowing acidic fluids to enter the well. During the workover of Bar-11, water pumped inside the well was leaving the well through the hole in the casing and also deeper in the well, which caused significant cooling of the near-wellbore formation. This is evident in the pressure and temperature surveys from Bar-11 collected after the workover (Figure 4) where the post-workover temperatures were much lower than the static temperature profile measured in 2016, particularly from 1100 to 1300 m. These heat-up surveys were obtained to characterize the heating of the wells and determine if the well was ready for flow testing.

In the case of Bar-11, the well had not yet reached reservoir temperatures after 53 days of heat-up. It was discharged to the sump in an attempt to flow it but this was unsuccessful as the WHP was only 0.25 MPa. The operations team then decided to conduct stimulation by air compression to advance the flow of the well. The Af/Ac ratio method was applied to determine a compression pressure that would result to a good chance of successful flow and if this is within the capacity of the available compressor. The method showed that if Bar-11 is compressed to 3.30 MPa, the corresponding Af/Ac ratio is 0.85, indicating a good chance of success. Bar-11 was compressed to this pressure and was able to successfully flow initially to the atmospheric flash vessel and later to the system.

For Bar-08RD, it was also apparent that the well was heating up more slowly than expected and 34 days after the workover, the well was discharged to the sump with a WHP of only 0.14 MPa and as expected, it was not able to flow. Similar to Bar-11, the Af/Ac ratio method was used in evaluating minimum compression pressure. The calculated threshold pressure to achieve an Af/Ac ratio of 0.85 was 3.45 MPa. Bar-08RD was compressed to this pressure, resulting in a successful two-phase discharge to the sump.

3. POST-COMPRESSION ANALYSES

In the analysis of the flow and pressure data after the compression and discharge of the wells, some parameters were identified for improving the analyses using the Af/Ac ratio method.

3.1 Incorporating Discharge Line Conditions (Pressure, Length, Temperature)

After compressing to a pressure of 2.30 MPa, Kap-11 was allowed to stabilize overnight. Afterwards, the well was first discharged to the sump as part of the production test procedures of PGPC. Wellhead pressures during the production test were collected using an automatic data logger, and these are shown in Figure 5.

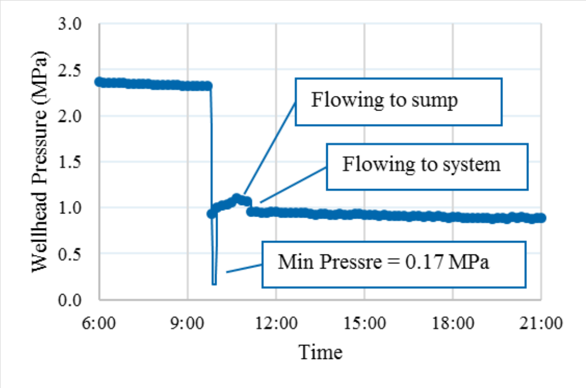

Figure 5: Kap-11 Wellhead Pressure During Flow Test

Upon discharge, the WHP immediately fell to 0.17 MPa as the production valve of Kap-11was opened. Shortly after, the WHP increased to 1.05 MPa as two-phase fluids started to flow to the sump. The well was allowed to discharge for 1.5 hours and fluid samples were taken. The samples indicated that the well was ready to be switched to the system. Upon switching, the flowing WHP decreased to 0.95 MPa. This is unusual because normally, flowing WHP would increase if a well is switched to the system due to the backpressure from the separator. It was concluded that scaling inside the discharge line was likely to be causing the additional backpressure during discharge to the atmospheric flash vessel, based on the WHP while discharging to the sump and upon switching to system.

In the Af/Ac ratio method, the areas of flashing and condensation are calculated using the atmospheric boiling temperature of 100^{0}C. This assumption is based on the instantaneous release of the gas column to atmospheric pressure. To avoid the possibility of environmental impact to surroundings, PGPC flows wells via surface piping to a sump where the flow is diffused and much of the steam is condensed. This may introduce significant pressure loss during flow. As observed in Kap-11, the lowest decompressed wellhead pressure was not atmospheric and was actually 0.15 MPa. This has a corresponding saturation temperature of 115^{0}C. The higher saturation temperature affects the calculation of the Af/Ac ratio. As demonstrated in Figure 6, increasing the saturation temperature to 115 ^{0}C consequently increases the Ac and slightly decreases the Af, resulting in a lower Af/Ac ratio.

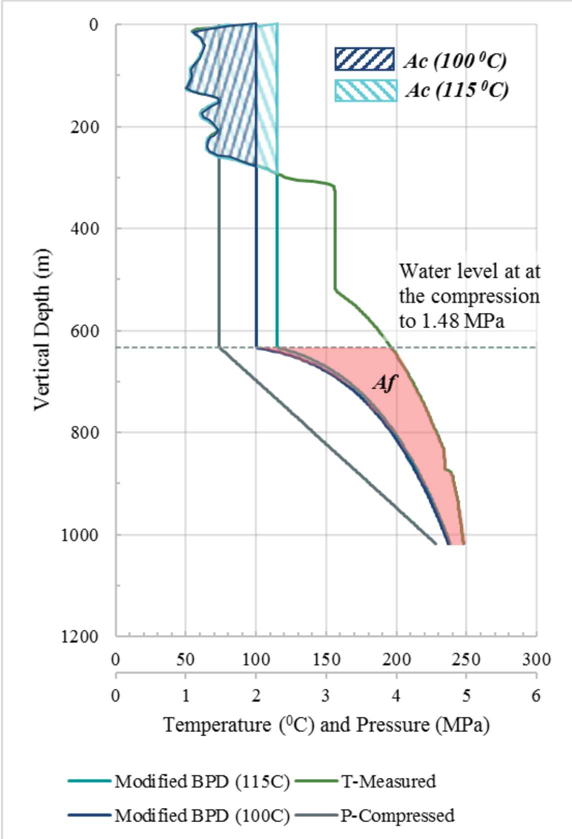

Figure 6: Af/Ac Ratio Decreasing with Higher Discharge Pressure

The Af/Ac ratios of flow tests conducted at lower shut-in WHP were re-analyzed using 115 ^{0}C saturation temperature and the results are summarized in Table 2. After correcting for the higher saturation temperature, the method correctly predicts that only compression to 2.30 MPa has a good chance of inducing successful flow.

Table 2: Comparing Af/Ac Ratios of Kap-11 at Different Tsat of Discharge Pressures

Pressure, MPa	Af/Ac (100C)	Af/Ac (115C)	Flow
1.17	1.08	0.70	Fail
1.48	1.30	0.80	Fail
2.30	1.50	0.98	Success

Wells may also experience additional backpressure if the production valves are opened slowly during flow tests. The initial release of compressed air will be throttled while the valve is being opened and as demonstrated, throttling reduces the chances of a well being able to successfully flow. Thus, during flow tests, it is important to open the valves as quickly as possible.

Surface pipeline effects also become significant for wells with very long discharge lines. Aside from backpressure losses, the surface piping will also tend to condense the fluid and in calculating Ac, any additional vertical length of the discharge line can be considered as an extension of the wellbore. However, pre-heating the discharge line will remove this additional Ac from the surface piping.

3.2 Corrections for well obstruction

In some wells, pressure and temperature data becomes limited due to wellbore obstructions. In the case of Kap-11, the total drilled vertical depth is 1115 m while its clear depth is only 1015 m. Analysis of Af should not be limited to the clear depth of the well. To demonstrate this, the Af/Ac ratio is calculated for the cases where Kap-11 compression pressure is increased from 2.30 to 2.86 and 3.55 MPa. The corresponding Af/Ac ratio decreased from 0.98 to 0.93 and 0.70, respectively as shown in Figure 7. In principle, the tendency of a well to discharge should be increasing with the compression pressure but because of the incomplete well data, the Af estimation is limited by the presence of the obstruction.

To incorporate the Af below the obstruction, the temperature profile was assumed to be isothermal from the last measurement until its intersection with the modified BPD. In most cases where wellbore temperatures are increasing with depth, this should be a conservative estimate in correcting the value of Af. However, this approach will overestimate the Af if there are temperature reversals. After including the Af below the obstruction, the ratio now increases with the compression pressure.

It is also demonstrated in Figure 7 that the Af analysis should also not be limited by the total vertical depth of the well. Theoretically, the fluids pushed out to the feed zones will exhibit the feed zone temperatures as they re-enter the wellbore during the discharge. Thus, the isothermal assumption also becomes useful in these cases in accounting for the area of flashing.

3.3 Using the correct wellbore temperature profile for wells on bleed

In the case of Bar-11, its production valve was not fully sealed prior to its flow test. This is evident in the later heat up surveys in Figure 4 where the well did not develop a gas column in HU survey 4, as indicated by a drop in temperature, and the wellbore temperature was saturated up to the surface. With a higher wellbore temperature than the saturation temperature at discharge pressure, the Ac was zero (Figure 8), which would make the Af/Ac ratio infinite. Despite having no Ac at the surface, Bar-11 was still not able to flow.

Because of the steam passing through the master valve, the temperature above the water level measured during the surveys was the saturation temperature of the shut in WHP. However, once air compression is started, the well will be subjected to a higher pressure and the wellbore fluids will stop flowing upwards. The near-surface section of the wellbore will once again be at formation temperatures. Therefore, the correct temperature profile to use in analyzing Ac should be that from a static survey. In the case of Bar-11, HU survey 1 was taken while no steam was flowing. Using this temperature profile for calculating Ac, the Af/Ac ratios for self-discharge and for compression at 3.30 MPa are 0.14 and 0.95, which now agrees with the results of the flow tests of Bar-11.

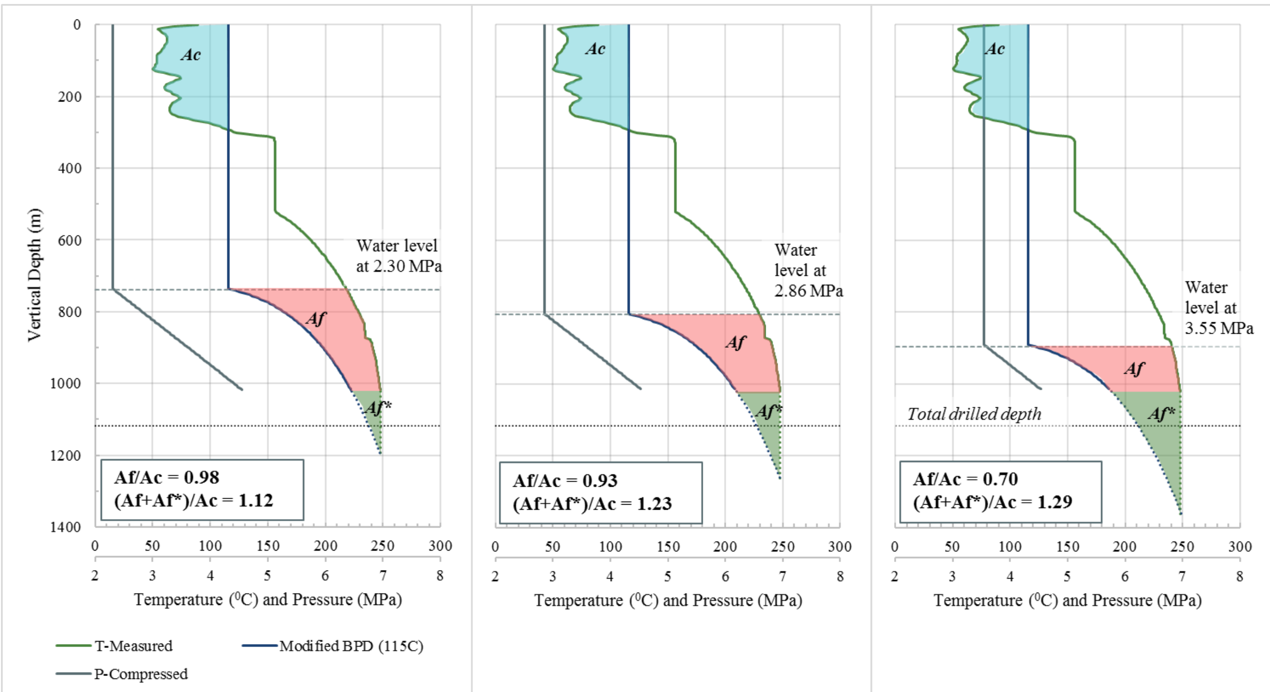

Figure 7: Evaluating Af/Ac Ratio of Kap-11 at Different Compression Pressures

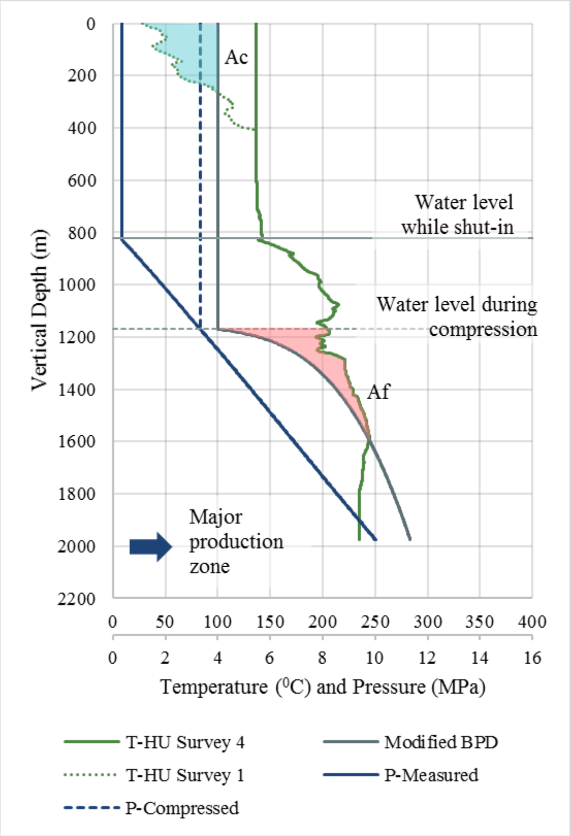

Figure 8: Evaluating Bar-11 Af/Ac Ratio

4. CONCLUSION

Case studies of Tiwi wells have shown that the Af/Ac ratio method is still an effective method in predicting the discharge of wells. As demonstrated, the method is simple and it only requires wellbore pressure and temperature data.

When the original Af/Ac success correlation was developed, it was based on data from wells that had been discharged vertically or through short discharge line flow setups. However, the case study of Kap-11 showed that analysis using the Af/Ac ratio method should incorporate discharge line effects where there is significant backpressure or vertical length, which affects the areas of condensation and flashing. The analyses also demonstrated the importance of the quick opening of production valves and pre-heating discharge lines prior to flow tests to improve the chance of flow.

The case studies also demonstrate how the Af/Ac ratio method can be used to prepare for well compression. In the case of Bar-11 and Bar-08RD, the method was used to determine a target compression pressure to obtain good chances of successful discharge.

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