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Data integration: feed zone, temperature and material corrosion rate in the planning of production casing and liner completion in geothermal wells

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Abstract. Planning of the completion program of production casing and liner in geothermal wells is one of the important stages of a drilling and production program, the purpose of which is to minimize drilling and production problems from aspects of rock formation penetrated by drilling. As a comparison, the planning of production casing and liner completion in Oil and gas wells usually only considers factors of casing load and formation pressure, especially for the geothermal wells where the factors high temperature, corrosion rate of material and corrosion characteristics of production fluid as well as the location of the feed zone must be integrated in detail and simultaneously with casing loads and formation pressure. The higher temperature of the well will increase the corrosion rate of production casing and liner materials because it is continuously in direct contact with the hot fluid so that the material life of the production casing and liner decreases. The prediction of the corrosion rate of production casing and liner materials must be done in detail, so that the life of production casing and liner can be estimated based on the strength of the production casing and liner materials on the corrosion properties of the hot production fluids. The purpose of this study is to optimize the completion of the production casing and liner installed in reference wells (D#3 and D#4) for the completion program of production casing and liner of the make-up wells (CCN # 4), so that its have a minimum age of 30 years production. The approach is to do data integration simultaneously, namely casing load, formation pressure, temperature, corrosion rate of material, corrosive properties of the production fluid and location of the feed zone. The results obtained are that the program of the optimum completion of the production casing and liner for make up well (CCN # 4), namely Conductor casing (0-30 mMD) grade X56-310ppf, Surface casing (0-340 mMD) grade K55-133ppf STC, production casing (0-1817 mMD) grade P110-72ppf STC, and perforated liner 10 ¾ "depth (1767-2355 mMD) grade N80- 40.5 ppf STC installed at 2 m from the bottom of the well.

Keywords: temperature, feed zone, material corrosion rate, corrosion characteristics of production fluid, minimum age of casing and liner

1. Introduction

High temperature in geothermal wells will accelerate the corrosion rate of the casing, this condition will directly affect the life of the casing during production. The higher temperature will faster the corrosion rate and the shorter life of the casing. The design of the casing must meet the minimum age criteria of the
casing based on the duration of geothermal field contract in Indonesia which is 30 years. The drilling of the well of CCN # 4 will be carried out for the purpose of a makeup well with a big hole well type. In reference wells (D # 3 and G # 4) grade casing that has been installed is grade X56 310 ppf for stove pipe casing, grade K55 133 ppf BTC for surface casing, grade L80 68 ppf BTC for production casing, grade K55 40 , 5 ppf BTC for liner 10 3/4, grade K55 24 ppf BTC for liner 8 5/8.

So far the casing design on the geothermal field is done by taking into account the quantitative loading factor and the qualitative corrosion factor based on grade casing. Casing design based on the load factor, the casing must meet the minimum safety factor requirement. S.S.Rahman (1995) explains that the casing's ability will change to temperature changes so that correction needs to be done in the casing design based on the loading factor. While from corrosion factor, API standard casing has been classified based on its application such as: H-40, J-55, and K-55 grade for general application, L-80, C-90, and T-95 for acidic environment, N-80 , P-110, and Q-125 for designs with high casing strength requirements.

Yoshiaki Kureta et.al. (1995) have published an equation for predicting corrosion resistance of casing material based on its constituent chemical components by converting to chrome equivalent (Cr.eq). Ekasari, Novianti and Marbun (2015) have published the development of the Equation Corrosion Rate Kureta et al by making various corrections with the aim to be applied in geothermal field in Indonesia.

The purpose of this paper is to plan the optimal casing design of well CCN # 4 in Indonesia's geothermal field based on integration of load, heat, corrosion and feed zone data. In order to obtain the optimum casing design of well CCN # 4, the load factor and corrosion factor are quantitatively calculated so that the casing life can be predicted by calculating the casing's ability to withstand the load received after corrosion under the condition of the production fluid temperature. The capability of the casing in bear loads based on API standards includes pipe body yield strength (Py), joint strength (Jy), Burts Rating (Pbr), Collapse Rating (Pcr).

1.1 Pipe body yield strength
Pipe body yield strength (Py) is the minimal force required to cause the plastic deformation (permanent deformation) of the casing, which is a function of the cross-sectional area and the minimum yield strength (Yp). It can be calculated by (1):

\[ P_y = 0.7854 \left( d_o^2 - d_i^2 \right) Y_p \]  

(1)

1.2 Joint Strength
Joint strength is the minimal tensile force required to cause damage to the joint casing.

1.3 Round thread
The amount of joint strength for the round thread can be calculated by (2) and (3):

\[ J_y = 0.95 A_{jp}L_{et} \left( \frac{0.74 d_o^{0.59} Y_{up}}{0.54 + 0.14 d_o} + \frac{Y_p}{L_{et} + 0.14 d_o} \right) \]  

(2)

\[ A_{jp} = 0.7854 \left[ (d_o - 0.1425)^2 - d_i^2 \right] \]  

(3)

1.4 Buttress thread coupling
Equations (4) and (5) are equations for calculating joint strength for buttress thread coupling (BTC):

\[ J_y = 0.95 A_{sp} Y_{up} \times \left[ 1.083 - 0.0396 \left( 1.083 + \frac{Y_p}{Y_{up}} \right) d_o \right] \]  

(4)

\[ A_{sp} = 0.7854 \left[ d_o^2 - d_i^2 \right] \]  

(5)

1.5 Extreme line thread coupling
For extreme line thread coupling (ETC), joint strength illustrates the smallest force required to cause damage to the casing, box or pin. The smallest value is determined by the smallest cross-sectional area of the casing, pin, or box. Equation (6) to calculate the joint strength for ETC in the casing :
Equation (7) to calculate the joint strength for ETC in the box:

$$J_y = 0.7854 Y_{up} (d_0^2 - d_i^2) \tag{6}$$

Equation (8) for calculating joint strength for ETC on pin:

$$J_y = 0.7854 Y_{up} (d_{pin}^2 - d_i^2) \tag{7}$$

1.6 Burst Rating
The burst rating (internal yield pressure) for the casing is calculated by equation (9) with 12.5% of the manufacturer tolerances permitted by the API set on the nominal wall thickness of the casing.

$$P_{Br} = 0.875 \frac{2Y_T}{d_0} \tag{9}$$

1.7 Collapse Rating
Collapse ratings based on API standards are calculated on transition conditions by equations,

$$P_{ter} = Y_p \left( \frac{E}{2\pi} - G \right) \tag{10}$$

$$A = 2.8762 + 0.10679 \times 10^{-5} Y_p + 0.21301 \times 10^{-10} Y_p^2 - 0.53132 \times 10^{-6} Y_p^3 \tag{11}$$

$$B = 0.026233 + 0.50609 \times 10^{-8} Y_p \tag{12}$$

$$F = \frac{46.95 \times 10^{ \frac{3B}{2+\alpha} } }{Y_p \frac{3B}{2+\alpha} \left( 1 - \frac{3B}{2+\alpha} \right)^2} \tag{13}$$

$$G = \frac{FB}{A} \tag{14}$$

2. Research Methods
2.1 Data Collection
The first step in the research is the collection of data from wells reference, such as lithology, pressure and temperature heating up test, drilling parameters, loss zone, feed zone, well profile and casing data, and exhaust temperature. The data of the well studied (CCN # 4) include drilling prognosis such as total depth, well profile, trajectory data, mud and cement programs.

2.2 Data Analysis
The data analysis is done by firstly making correlation of the studied well (CCN # 4) with reference wells, determining the depth casing setting per trajectory, choosing the bit size and casing per trajectory, making the casing design of well studied (CCN # 4), validating the casing design of the well studied with casing design of reference well, perform corrosion analysis to know prediction of casing life. Iteration of casing design is done until obtained age of casing ≥ 30 years and casing design of well CCN # 4 optimum if age of casing ≥ 30 years.

2.3 Setting Depth Casing
Setting depth casing aims to determine the optimum depth to occupy shoe casing in certain formation rocks. In the planning of setting depth casing, the most important thing is to determine the depth of the production casing. Wrong placement of the production casing can cause negative impact. If the depth setting passes through the productive zone, cementing the production casing will not be perfect because it tends to be channeling and if too far above the productive zone will cause the expected flow rate is not achieved, since long liner is required with a smaller capacity than the production casing. Determination of the casing depth setting on the geothermal well is divided into 2 stages, namely the determination of the production casing depth setting and the determination of the other depth casing setting (stove pipe and surface casing).
Setting Depth Casing Production

Approach for installation of production casing can be done in two ways, namely:

1. Analyze the temperature rise of the outgoing sludge to estimate the temperature at the bottom of the well. Generally, the outgoing sludge temperature greater than 150°F (65.6°C) has given the formation temperature three times the sludge temperature.

2. Cutting analysis is used to obtain the data of alteration intensity (hydrothermal alteration) and the type of rock and the presence or absence of mineral indicator. Hydrothermal alteration occurs due to the permeable zone and the hot fluid. The high intensity of alteration indicates the proximity to the permeable zone. The intensity of this alteration is determined by the percentage of secondary minerals in rock mass. The intensity of alteration is divided into 4, i.e., weak (0-10%), moderate (11-25%), strong (26-50%), and very strong (> 50%). The secondary mineral used as an indicator is the epidote mineral that is classified into the type of propylation alteration. The proployed alteration zone is a reservoir zone in the geothermal field.

Another Depth Casing setting

Determination of other depth casing setting uses correlation approach between lithology condition and field stratigraphy, the biggest pressure load on the casing. Lithology grouping is based on drilling operation constraints due to lithologic conditions and field geological structures. While setting depth casing based on the largest pressure load on the casing with overburden pressure limit and production fluid pressure. Another example of setting depth casing is shown in Figure 1.

2.4 Selection of Bit Diameter and Casing

The selection of bits and casing diameters in the geothermal field is generally influenced by 3 factors, namely: the production liner size, the number of casing required to reach the final depth, and the drilling conditions. The number of casing required to achieve the productive formation is influenced by the depth setting and geological conditions. In geothermal wells, the required casing minimum there are 4 types: conductor casing, surface casing, production casing, and perforated liner.

The drilling conditions affect the selection of casing sizes due to the size of bits used for subsequent route drilling, drill hole hydraulics, and the need for cementing casing. The inner diameter of the casing is used to select the bit diameter size used for subsequent route drilling. The bit diameter is used to determine the maximum outer diameter of the casing.

2.5 Selection of Nominal Weight, Grade and Case Connection

After the number of casing, setting depth, and outer diameter of the casing is determined, the next is the selection of nominal weight, grade, and casing connection. In practice, each casing is designed to
withstand the anticipated maximum load during running casing, drilling, and production. Concepts of loading experienced by the casing are: burst burden, collapse load, axial load (tension), biaxial load, triaxial load, and temperature influence.

2.5.1 Burst Load
Burst burden will be maximum if maximum internal pressure and minimum external pressure. Maximum internal pressure when steam with pressure gradient \( G_s \) exits from the bottom of the hole at depth (NHTD) with saturation pressure \( P_f \) @ NHTD. Minimum external pressure when magnitude equal to zero, so burst burden can be calculated by equation:

\[
P_b = P_t - P_e
\]

\[
P_t = P_f @ NHTD - G_s(NHTD - D_{TVD})
\]

\[
P_e = 0
\]

Safety factor (SF) minimum burst burden design is 1.1. Safety burst burden factor can be calculated by equation (18):

\[
SF = \frac{P_{Br}}{P_B}
\]

2.5.2 Collapse Load
The collapse load will be maximum if the maximum external pressure and minimum internal pressure. The maximum external pressure occurs when the external casing is filled with sludge so that the external force is equal to the amount of hydrostatic mud and the internal pressure is zero. The collapse load can be calculated by the equation:

\[
P_c = P_e - P_l
\]

\[
P_e = 0.052 \times \mu_m \times D_{TVD}
\]

\[
P_l = 0
\]

The maximum safety factor (SF) number for the collapse load is 1.1. Safety burst burden factor can be calculated by equation:

\[
SF = \frac{P_{Cr}}{P_C}
\]

2.5.3 Axial Load (Tension)
The tension load is the axial load \( (F_a) \) experienced by the casing due to the pull. When the casing is running into the hole, the tension load is the sum of the casing load in the mud \( (W @ mud) \), bending load \( (F_b) \), and shockload \( (F_s) \) which can be calculated by the formula:

\[
F_{aRH} = W_{@mud} + F_b + F_s
\]

\[
W_{@mud} = W_nB_f
\]

\[
BF = 1 - \frac{\mu_m}{65.4}
\]

\[
F_b = 63 d_P W_n \theta
\]

\[
F_s = \frac{2 W_n \mu_p \mu_l}{g}
\]

2.5.4 Biaxial Effects
Axial load tension will lead to an increase in the burst rating and decrease in collapse rating, whereas compression will cause a decrease in the burst rating and increase in collapse rating. Burst and collapse rating due to biaxial effects can be calculated by first determining the effective yield yield strength \( (Y_{pa}) \) with the equation:

\[
Y_{pa} = Y_p Y
\]

\[
Y = \pm \left( \sqrt{1 - 0.75(\pm X)^2} - 0.5(\pm X) \right)
\]

\[
X = \frac{\sigma_{axial}}{Y_p} = \frac{F_a}{0.7084 (d_e^2 - d_i^2) Y_p}
\]

The effective yield strength \( (Y_{pa}) \) was used to calculate the burst rating using equation (9), calculating the collapse rating factor using equations (11), (12), 13, 14, and calculating the collapse rating using equation (10). The decrease of burst and collapse rating \( (PB \ corr \ and \ PC \ corr) \) due to biaxial effect is
controlled using safety factor number (SF) which is the same magnitude as collapse load and burst load. Safety burst and collapse load factors due to biaxial effects can be calculated by the equation:

\[
SF = \frac{P_{B \text{corr}}}{P_B} \quad (31)
\]

\[
SF = \frac{P_{C \text{corr}}}{P_C} \quad (32)
\]

2.5.5 Triaxial Expenses

Triaxial loads occur due to radial stress (σr), tangential stress (σt), and axial stress (σa). The magnitude of the triaxial load can be calculated by the equation "Von Mises Equivalent Stress" (σVME),

\[
\sigma_{VME} = \sqrt{\frac{(\sigma_{\text{axial}}-\sigma_r)^2+(\sigma_r-\sigma_t)^2+(\sigma_t-\sigma_{\text{axial}})^2}{2}} \quad (33)
\]

\[
\sigma_r = \frac{-p_r r_f^2 (r_f^2 - r_r^2) - p_r r_f^2 (r_f^2 - r_t^2)}{r_f^2 (r_f^2 - r_r^2)} \quad (34)
\]

\[
\sigma_t = \frac{p_r r_f^2 (r_f^2 + r_r^2) - p_r r_f^2 (r_f^2 + r_t^2)}{r_f^2 (r_f^2 - r_r^2)} \quad (35)
\]

Maximum triaxial load occurs on the outer side of the casing (ro). The minimum safety factor for triaxial loads is 1.1 by comparing to yield strength (YP) such as equations,

\[
SF = \frac{Y_P}{\sigma_{VME}} \quad (36)
\]

2.5.6 Thermal Effect

An important factor in the design of geothermal well casing is the influence of high temperature and corrosive production fluids. With higher temperatures, the chassis will undergo Long and Yield Strength changes. The change in yield strength at a temperature variation is called hot yield strength (Ypt), as in Table 1.

The magnitude of the change in length is affected by the thermal expansion coefficient (β) of the casing and the temperature difference (ΔT) which can be calculated,

\[
\Delta l = l_f \beta \Delta T \quad (37)
\]

The amount of ΔT (o F) is the difference between the surface temperature and the temperature of the production fluid. For production casing, because the casing in the cemented state so that the cement bond with the casing will hold the casing for expansion, consequently the tendency of expansion of the casing turned into a compression stress called thermal stress (σthermal). The amount of thermal stress is influenced by the modulus of elasticity of the casing (E), the thermal expansion coefficient (β), and the temperature change (ΔT) which can be calculated by the equation:

\[
\sigma_{\text{thermal}} = \beta E \Delta T \quad (38)
\]

**Tabel 1. Yield Strength pada Beberapa Variasi Temperature**

| Steel grade | 60°F | 77°F | 90°F | 100°F | 120°F |
|-------------|------|------|------|-------|-------|
| H-40 ST (F)| 4000 | 4000 | 4000 | 52800 | 61000 |
| J-20 ST (F)| 5900 | 5900 | 5900 | 62000 | 61700 |
| C-30 ST (F)| 6300 | 6300 | 6300 | 62000 | 62000 |
| L-60 ST (F)| 7500 | 7500 | 7500 | 69400 | 69400 |
| N-80 ST (F)| 8000 | 8000 | 8000 | 69500 | 69500 |
| P-110 ST (F)| 9600 | 9600 | 9600 | 79000 | 79000 |
| P-100 (F)  | 10000| 10000| 10000| 10000| 10000 |
| P-100 (F)  | 11125| 11125| 11125| 11125| 11125 |

ST = standard, TR = thermal resistance
The amount of $\Delta T$ ($^\circ$F) in the thermal stress is the difference between the baseline temperature of the well and the temperature of the production fluid. The minimum safety factor for thermal stress is 1,

$$ SF = \frac{\sigma_{net}}{\sigma_{thermal}} $$ (39)

Thermal stress will cause a decrease in burst rating and increase collapse rating so that burst correction and collapse rating need to be done as in biaxial effect calculation, axial stress is replaced with thermal stress.

2.5.7 Influence of Corrosive Fluid

The magnitude of corrosive resistance is influenced by the material of the casing. Selection of grade casing in its resistance to corrosion can prevent the occurrence of casing failure so that the age of the casing can be longer. Yoshiaki Kureta et al (1995) in his paper has published an equation for predicting corrosion resistance of casing material based on its constituent chemical components by converting to chrome equivalent ($Cr_{eq}$) casing material. Chrome is the basic composition of corrosion resistant material. The magnitude of chrome equivalent can be calculated by equation (39). Chrome equivalent API casing values are presented in Table 2.

$$ Cr_{eq} = Cr - 13.73C + 1.598Si - 0.433Mn + 27.28P - 51.12S + 0.237Ni + 0.712Mo - 1.06Cu $$ (40)

| Grade casing (API 5CT) | Cr equivalent |
|------------------------|---------------|
| H40                    | -8.5 to -7.5  |
| J55                    | -6 to -5,4    |
| K55                    | -6 to -5      |
| N80-1                  | -2 to -1.5    |
| N80Q                   | -2 to -1.5    |
| M65                    | -5.5 to -4.3  |
| P110                   | -2.4 to 2     |
| L80-1                  | -2.4 to -1.8  |
| L80-9Cr                | 10 to 11.5    |
| L80-13Cr               | 11 to 12      |

Yoshiaki Kureta et al (1995) published his paper on equations for predicting the value of Corrosion Rate (CR) on the casing material, which is influenced by temperature, acidity (pH), and chrome equivaling. This CR equation is the result of his research on several geothermal fields in Japan. NoviantiEkasari and Marbun (2015) at Proceedings World Geothermal Congress have published the development of the Kureta et al K equation, by making various corrections in order to be applied in geothermal field in Indonesia. The CR equation (40):

$$ CR = 10^{2.981 - 2912Cr_{eq} - 4.532 pH - 25.052 (\frac{1}{T})} $$ (41)

The casing requires a certain thickness to keep the load, this thickness is called the minimum thickness ($t_{min}$). When a casing has a thickness ($t$), the permitted tor- tioned thickness ($t_{corrosion}$) can be calculated by equation (41), and the age (LT) of the casing can be determined by equation (42)

$$ t_{corrosion} = t - t_{min} $$ (42)

$$ L.T = \frac{25 \times A_{corrosion}}{C.R.} $$ (43)

The required casing thickness is different to hold a load with other load. To withstand burst burden ($P_B$) and load collapse ($P_C$) with safety factor (SF), the casing requires burst rating ($P_{Br}$) and collapse rating ($P_{Br}$) whose magnitude can be calculated by equations 43 and 44, 

$$ P_{Br} = SF P_B $$ (44)

$$ P_{Cr} = SF P_C $$ (45)

The thickness to hold burden burden can be checked by changing the equation (9) to:

$$ t = \frac{d_0 P_{Br}}{1.75 Y_p} $$ (46)

The thickness to hold the collapse load can be calculated by converting equation 10 to:
the burst load is calculated by substituting equation (43) into equation (46) and the load of collapse is calculated by substituting equation (44) to equation (47) to:

\[ t_{B_{\text{min}}} = d_o \frac{SFF_B}{Y_p} \]

(48)

\[ t_{C_{\text{min}}} = d_o \frac{SFF_C}{Y_p} + G \]

(49)

In the case of the casing receiving a biaxial effect, the \( t_{\text{min}} \) will be of greater value. To calculate the burst and collapse rating on the biaxial effect condition, effective yield strength parameters (Ypa) are used so that the equations (48) and (49) are:

\[ t_{B_{\text{min}}} = d_o \frac{SFF_B}{1.75 Y_p} \]

(50)

\[ t_{C_{\text{min}}} = d_o \frac{SFF_C}{Y_p} + G \]

(51)

If the hot yield strength (Ypt) is the minimum yield strength (Yp) in a particular tempetar (T), then under the conditions of the biaxial effect and the thermal effect of equation (26) becomes:

\[ Y_{pa} = Y_{pt} Y \]

(52)

The magnitude of \( t_{\text{min}} \) is calculated by substituting equation 52 into equations (50) and (51), being

\[ t_{B_{\text{min}}} = d_o \frac{SFF_B}{1.75 Y_{pa}} \]

(53)

\[ t_{C_{\text{min}}} = d_o \frac{SFF_C}{Y_{pa}} + G \]

(54)

To withstand the axial load of tension (Fa) and axial compression load (-Fa) with safety factor (SF), the casing requires a body yield strength (Py) whose magnitude can be calculated as follows:

\[ P_y = SF Fa \]

(55)

\[ P_y = SF (-Fa) \]

(56)

Substitute equations 55 and 56 into equation (1), being,

\[ SFF_a = 0.7854 (d_o^2 - d_i^2) Y_p \]

(57)

\[ SF (-Fa) = 0.7854 (d_o^2 - d_i^2) Y_p \]

(58)

If the outer diameter (do) is limited, then the maximum internal diameter (at max) to be able to withstand axial loads can be calculated by converting equations 57 and 58 into:

\[ d_{\text{imax tension}} = \sqrt{d_o^2 - \frac{SFF_a}{0.7854 Y_p}} \]

(59)

\[ d_{\text{imax compression}} = \sqrt{d_o^2 - \frac{SF (-Fa)}{0.7854 Y_p}} \]

(60)

If, the thickness is formulated as follows:

\[ t = d_o - d_i \]

(61)

then the minimum thickness (t\( \text{min} \)) to withstand axial load can be calculated by converting equations 59 and 60 into equations 62 and 63,

\[ t_{\text{min tension}} = 0.5 \left( d_o - \sqrt{d_o^2 - \frac{SFF_a}{0.7854 Y_p}} \right) \]

(62)

\[ t_{\text{min compression}} = 0.5 \times \left( d_o - \sqrt{d_o^2 - \frac{SF (-Fa)}{0.7854 Y_p}} \right) \]

(63)

3. Results and Discussion

A data correlation approach from reference wells is done to estimate the geological condition of well CCN # 4, especially productive zones. The D # 3 well and G # 4 are wells that are used as reference wells due to the same fault with the CCN# 4 well drilling target, as can be seen in Figure 2.

Rock lithology at the well is generally composed by altered breccia andesite have been changed, altered tufa breccia, altered basaltic andesite, and meta sediment. D #3 well's total loss zone at elevation (-905)mdpl with feed zone at (-850) to (-1080)mdpl interval, alteration zone propylatic at elevation (-
175)mdpl to total depth. Total loss zone of G # 4well at elevation (-1105)mdpl with feed zone at intervals (-900) to (-1275)mdpl, alteration zone propylatic at (-625)mdpl elevation to total depth. The mud and cement density to be used in drilling CCN # 4well is shown in Table 3.

![Figure 2. Location and Directions of CCN #4Well](image)

**Table 3. Mud and Cement Density of Well CCN#4**

| Trayek   | Densitas Lumpur (ppg) | Densitas Semen (ppg) |
|----------|------------------------|----------------------|
| 36       | 8.5                    | 15.8                 |
| 26       | 8.5-8.7                | 15.8                 |
| 17 1/2 (1)| 8.5-8.7               | 14                   |
| 17 1/2 (2)|                      | 16.2                 |
| 12 1/4   | 8.33-8.7               | 15                   |
| 9 7/8    | 8.33                   |                      |
| 7 7/8    | 8.33                   |                      |

The result of correlation of lithology, loss zone, feed zone, and outbound sludge temperature is shown in Figure 3 and the correlation result of CCN # 4 well temperature and pressure saturation is presented in Figure 4. Based on the correlation result, it is estimated that CCN # 4 well supply zone well is starting depth 1872-2220 mMD / 1771.5-2086.5 mTVD / (-862.5) - (-1177.5) mdpl and taking into account the deepest feed zone at the G # 4 reference well with elevation (-1275)mdpl and small slope temperature at a depth of 1800 mTVD, the drilling CCN # 4 well is suggested to a depth of 2355 mMD / 2209.25 mTVD / (-1300)mdpl.

The next step is determine the casing setting depth. Based on correlation of loss zone and feed zone, alteration zone and intensity of alteration and exhaust temperature, then setting depth casing of production at depth 1817 mMD / 1721.66 mTVD / (-812.37)mdpl with safety range 50 m from feed zone and setting depth surface casing at 340 mTVD, as shown in Figure 5. Stove pipe casing is installed at depth of 30 mTVD based on a reference well to prevent scattering. The resulting depth casing is shown in Table 4.

The selection of bits diameter and casing of well CCN # 4 is based on big hole well type with 13-3 / 8 inch production casing diameter, using reference of bits diameter and casing (Figure 6). The result of the selection of bits diameter and casing of well CCN # 4 is presented in Table 4.
Figure 3. Correlation of Lithology, Loss Zone, Feed Zone, Alteration Zone and Intensity Alteration of CCN # 4 Well from Reference Wells G # 4 and D # 3

Table 4. Setting Depth, Bit Size and Casing of CCN # 4 Well

| Jenis Casing       | Bit Size | do   | Interval Kedalaman | Ls       |
|--------------------|----------|------|--------------------|----------|
|                    | inch     | inch | mTVD               | mMD      | m     |
| Stove Pipe         | 36       | 30   | 0 – 30             | 0 – 30   | 30    |
| Surface Casing     | 26       | 20   | 0 – 340            | 0 – 340  | 340   |
| Production Casing  | 17 1/2   | 13 3/8 | 0 – 1722          | 0 – 1817 | 1850  |
| Perforated Liner   | 12 1/4   | 10 ¾  | 1676-2209          | 1767-2355| 555   |

Case design is only done on the surface casing, production casing and perforated liner. Calculation of the casing design on the stove pipe is not done because the casing setting depth shallow so that the casing does not receive a large load.
The result of surface casing design was obtained K55 grade 133 ppf joint STC, at temperature condition 269.43°C, safety factor small burden burden 2.78, load collapse 3.01, axial load casing 8.06, axial load joint STC 4.55, load burst at 2.82 biaxial effect, collapse load when biaxial effect 3.1, triaxial load at maximum burst load 3.18, and triaxial load at maximum collapse of 7.86. The surface casing design calculations are shown in Table 5. The result of the production casing design is obtained with P110 72 ppf joint STC grade, at temperature condition 274.69°C, minimum safety factor burst load 3.02, collapse load 1.1, axial load casing 3.06, axial load joint STC 1.88, burst load when biaxial effect 3.2, collapse load at biaxial effect 1.1, triaxial load at maximum burst load 3.22, triaxial load at maximum collapse 3.06, and thermal stress 1.16. Based on the calculation of thermal effect, production casing will experience the addition of length due to expansion of 6 meters. The result of production casing design is shown in Table 6. The result of perforated liner design obtained J55 40.5 ppf joint STC grade, at temperature condition 279.96°C, minimum safety factor axial load casing 5.91, and axial load of joint STC 3.38. Based on the calculation of thermal effects, perforated liner will experience the addition of length due to expansion of 1.7 meters. The results of the perforated liner design calculations are shown in Table 7. To examine whether the reference wells design can be applied to CCN # 4, a comparative study of subject casing design with reference wells casing design was conducted. The result is that the reference wells casing design is stronger than the CCN # 4 casing design except in the production casing.

After the casing design is obtained, a corrosion analysis is performed to determine the age of the production casing and the perforated liner which results are shown in Table 8. The corrosion analysis is carried out with the assumption that its fluid production has a pH of from 4 to 5. This is based on the presence of H2CO3 as a result of the reaction between CO2 and H2O and H2S are weakly alkaline (pH 4-6). Estimated age of production casing P110 72 ppf STC known to survive during production of 30 years while perforated liner less than 30 years.

Due to the age of perforated liner less than the minimum age (30 years) at pH 4 then iteration of casing design. This stage is done by first calculating the minimum chrome equivalent that must be owned by the casing whose magnitude is -5. Based on the calculation of Cr equivalent minimum and by using Table 2, grade casing which can be used for casing can survive during production of 30 years is grade L-80 and N80. Based on API Standard for 10 ⅜ inch casing with nominal weight of 40.5 ppf grade available only N80. Next is calculated casing design and corrosion analysis to load on perforated liner N80 40.5 ppf to prove strength and age of casing. Perforate liner design results (Table 9) obtained grade N80 40.5 ppf joint STC, at temperature conditions 279.96°C, the smallest safety factor axial load casing 6.63, and axial load joint STC 4.89. Added length by expansion of 1.7 meters. Perforated liner settlement by hanging liner on liner hanger on production casing. Because the perforated form of perforated liner will reduce liner strength, so the installation using a combination of blind liner on the top with a length of ± 50 meters and perforated liner at the bottom. Judging from the magnitude of the addition of length due to the thermal effect, then to prevent the occurrence of buckling, liner should be hung ± 2 meters from the bottom of the well.

4. Conclusion
1. Based on the correlation of data reference wells, it is estimated that the depth of feed zone of CCN # 4 well is of 1872-2220 mMD and by considering the deepest feed zone in reference wells G # 4 and temperature slope, the drilling of well CCN # 4 is targeted to a total depth of 2355 mMD.
2. Based on the result of corrosion simulation on the assumption of production fluid having a pH range between 4 to 6, it is predicted that production casing life able to survive for 30 years and perforated liner does not reach 30 years.
3. The optimum casing design of well CCN# 4 are stove pipe casing (0-30 mMD) grade X56 310 ppf, surface casing (0-340 mMD) grade K55 133 ppf STC, production casing (0-1817 mMD) grade P110 72 ppf STC, and perforated liner 10 ¾ ” depth (1767-2355 mMD) grade N80 40.5 ppf STC.
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Symbol List

| Symbol | Definition |
|--------|------------|
| Awp   | the width of the insulator on the last thread, inch |
| As    | area of casing, ft² |
| Asp   | area of cross section of casing, inch² |
| BF    | Bouyancy factor (fraction) |
| C     | percentage of carbon mass, % |
| Ceq   | Chrome equivalent, % mass |
| Cu    | percentage of mass of copper, % |
| dbox  | the diameter of the box on the last thread, inch |
| di    | inner diameter of the casing, inch |
| dji   | internal diameter joint, inch |
| djo   | outer diameter joint, inch |
| d1    | outer diameter of the casing, inch |
| dsec  | the outer diameter of the pin on the last thread, inch |
| DTVD  | vertical depth, ft |
| E     | modulus of elasticity (30x10⁶), psi |
| Fha   | axial load tension, lbf |
| Fb    | bending load, lbf |
| Fs    | shock load, lbf |
| g     | gravity speed, (32.174 ft / s²) |
| Ge    | pore formation pressure gradient, psi / ft |
| Gs    | steam pressure gradient at P and T, psi / ft |
| Jj    | joint strength, lbf |
| L     | length of casing, ft |
| L1    | length of casing, ft |
| L2    | length of casing, ft |
| Mn    | percentage of mass of manganese, % |
| Mo    | percentage of molydenum mass, % |
| Mr    | molecular weight of vapor, kg / kmol |
| NHTD  | next depth of trajectory, ft |
| Ni    | nickel mass percentage, % |
| P     | phosphorus mass percentage, % |
| Pa    | burst load, psi |
| Par   | Burst rating, psi |
| Pb    | burst rating due to biaxial effect, psi |
| Pcc   | burst rating due to biaxial effect, psi |
| Pcr   | collapse load, psi |
| Pcorr | burst rating due to biaxial effect, psi |
| Pe    | collapse rating, psi |
| Pe    | external pressure, psi |
| Pf    | fluid saturation pressure, psi |
| Ph    | hydrostatic pressure, psi |
| Pi    | internal pressure, psi |
| Pij   | pipe body yield strength, lbf |
| r     | radius observed, inch (ri or ro) |
| re    | radius drainage, m |
| ri    | radius internal of casing, inch |
| ro    | radius outer of casing, inch |
| rw    | radius of well, m |
| S     | Sulphur mass percentage, % |
| SF    | safety factor |
| Si    | silicon mass percentage, % |
| t     | wall thickness of casing, inch |
| tB    | burst load, lbf |
| tC    | collapse load, psi |
| tCorr | burst rating due to biaxial effect, psi |
| Pcc   | burst rating due to biaxial effect, psi |
| tcorros | the permissible thickness is corroded, inch |
| tmin  | minimum thickness of casing withstand load, inch |
| tcomp | minimum thickness withstand compression, inch |
| tmn   | minimum thickness withstand tension, inch |
| Wt/mud| the weight of the casing in the mud, lbf |
| Wn    | nominal weight of casing, pph |
| X     | factor due to internal pressure and axial load (tension (+) / collapse (-)) |
| Y     | factor of decrease or increase of burst (+) and |
Appendices

Table 5. Surface Casing Design Result of CCN #4 Well

| Grade | T | Wo | Pr | Pcr | Pbr | Ji | Py | t | di |
|-------|---|----|----|-----|-----|----|----|---|----|
|       | ft | lb/ft | psi | psi | psi | psi | psi | inch | inch |
| K-55  | 60 | 133 | 1500 | 3660 | 1253 | 455 | 2123 | 2125 | 0.635 | 18.73 |
| K-55  | 269.43 | 133 | 1546.93 | 3543.76 | 1391.5 | 1611.04 | 2377.7 | 2463.9 | 0.635 | 18.7 |

Beban Burst dan Collapse

| Depth | Burst | Collapse | SF |
|-------|-------|----------|----|
| mMD  | psi   | psi      |    |
| 0    | 1239.21 | 0.00 | 1239.21 |
| 340  | 1270.02 | 0.00 | 1270.02 |
| 0    | 128829.7 | 0.00 | 128829.7 |
| 340  | 128829.7 | 0.00 | 128829.7 |

Beban Axial

| Depth | BF/Pb | Ps | Fa | σ axial | σ aksial | σ plast | Pst | PCr |
|-------|-------|----|----|--------|----------|---------|----|-----|
| mMD  | psi   | psi | psi | psi    | psi      | psi     | psi | kgf |
| 0    | 17800 | 30983.7 | 8.96 | 3.97 | 4.55 | 5.37 |
| 340  | 498.71 | 498.71 | 2.79 | 2.79 | 3.10 |

Eksliplastisal

| Depth | Fa | σ axial | Yps | Ypa |
|-------|----|--------|-----|-----|
| mMD  | psi | psi    | psi | psi |
| 0    | 128829.7 | 3334.84 | 1.06 | 0.93 |
| 340  | 128829.7 | 1.00 | 1.00 | 64405 |

Beban Triaksial

| Depth | Yps | Ypa | Fa | σ axial | PBr | PCr | σ plast | Pst | PCr |
|-------|-----|-----|----|--------|-----|-----|---------|----|-----|
| mMD  | psi | psi | psi | psi    | psi | psi | psi     | psi | psi |
| 0    | 128829.7 | 3334.84 | 1.06 | 0.93 | 63768.5 | 59931.7 | 3743.2 | 3.004 | 0.056 | 1.96 | 0.04 | 1518.3 | 3.1 |
| 340  | 128829.7 | 1.00 | 1.00 | 63768.5 | 59931.7 | 3743.2 | 3.004 | 0.056 | 1.96 | 0.04 | 1518.3 | 3.1 |

Figure 5. Production Casing Setting Depth Based on Pressure Load on Casing and Feed Zone
### Table 6. Production Casing Design Result of CCN#4 Well

| Grade | T | Ws | Prf | Pfr | STC | LTC | RTC | Py | t | di |
|-------|---|----|-----|-----|-----|-----|-----|----|---|----|
|       | ft | lb/ft | psi | psi | Kbf | Kbf | Kbf | psi | inch | inch |
| P-110 | 60 | 2000 | 3010 | 1460 | 2284 | 0.53 | 12.3 |
| P-110 | 72 | 2730.8 | 3676.6 | 1130.6 | 1854.16 | 1907.4 | 0.51 | 12.3 |

### Table 7. Liner Design Result of CCN#4 Well

| Grade | T | Ws | Prf | Pfr | A | B | F | G | PCr | SF |
|-------|---|----|-----|-----|---|---|---|---|-----|----|
|       | ft | lb/ft | psi | psi | psi | psi | psi | psi | psi | psi |
| J-55  | 40.5 | 1580 | 3130 | 420 | 706 | 629 | 0.35 | 10.05 |
| N-80  | 40.5 | 1642.9 | 3594.3 | 412.4 | 737.4 | 721.4 | 0.35 | 10.05 |

### Table 8. Corrosion Analysis Result of CCN#4 Well

| Grade | T | Ws | Prf | Pfr | A | B | F | G | Py | t | di |
|-------|---|----|-----|-----|---|---|---|---|----|---|----|
|       | ft | lb/ft | psi | psi | psi | psi | psi | psi | psi | psi | psi |
| Liner (Cr eq min J55 = -d) |
| Depth | T | Ws | Prf | Pfr | STC | LTC | RTC | σ thermal | Ypt | Ypt | σ VME | σ VME | σ thermal | Ypt | Ypt | σ thermal | Ypt | Ypt | σ thermal | Ypt | Ypt |
|-------|---|----|-----|-----|-----|-----|-----|----------|-----|-----|--------|--------|----------|-----|-----|----------|-----|-----|----------|-----|-----|
|       | ft | lb/ft | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi |
| J-55  | 40.5 | 1580 | 3130 | 420 | 706 | 629 | 0.35 | 10.05 |
| N-80  | 40.5 | 1642.9 | 3594.3 | 412.4 | 737.4 | 721.4 | 0.35 | 10.05 |

### Table 9. Perforated Casing Design Result After Corrosion Analysis CCN#4 Well

| Grade | T | Ws | Prf | Pfr | STC | LTC | RTC | Py | t | di |
|-------|---|----|-----|-----|-----|-----|-----|----|---|----|
|       | ft | lb/ft | psi | psi | psi | psi | psi | psi | psi | psi |
| Liner (Cr eq min J55 = -d) |
| Depth | T | Ws | Prf | Pfr | STC | LTC | RTC | σ thermal | Ypt | Ypt | σ VME | σ VME | σ thermal | Ypt | Ypt | σ thermal | Ypt | Ypt | σ thermal | Ypt | Ypt |
|-------|---|----|-----|-----|-----|-----|-----|----------|-----|-----|--------|--------|----------|-----|-----|----------|-----|-----|----------|-----|-----|
|       | ft | lb/ft | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi | psi |
| J-55  | 40.5 | 1580 | 3130 | 420 | 706 | 629 | 0.35 | 10.05 |
| N-80  | 40.5 | 1642.9 | 3594.3 | 412.4 | 737.4 | 721.4 | 0.35 | 10.05 |

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**Table 6. Production Casing Design Result of CCN#4 Well**

- **Grade**: J-55, N-80
- **Depth**: P-110, P-110
- **Production Casing (Cr eq min J55 = -2.4)**
  - **Liner**: 60 ft, 2000 lb/ft, 3010 psi
  - **Production Casing**: 72 ft, 2730.8 lb/ft, 3676.6 psi

**Table 7. Liner Design Result of CCN#4 Well**

- **Grade**: J-55, N-80
- **Depth**: 40.5 ft, 1580 lb/ft, 3130 psi
- **Production Casing (Cr eq min J55 = -2.4)**
  - **Liner Design Result of CCN#4 Well**
  - **Production Casing**: 40.5 ft, 1642.9 lb/ft, 3594.3 psi

**Table 8. Corrosion Analysis Result of CCN#4 Well**

- **Grade**: J-55, N-80
- **Depth**: 40.5 ft, 1580 lb/ft, 3130 psi
- **Corrosion Analysis Result of CCN#4 Well**
  - **Liner Design Result of CCN#4 Well**
  - **Perforated Casing Design Result After Corrosion Analysis CCN#4 Well**
Efek Thermal

| Depth (ft) | T (°F) | Fy (ksi) | Fy (psig) | SF |
|-----------|--------|----------|-----------|----|
| 1767      | 305.2  | 68167.14 | 818748.54 | 12.01 |
| 2555      | 335.0  | 68167.14 | 818748.54 | 12.01 |

Pertambahan Panjang Liner

| Top (°C) | Bot (°C) | T Rata° (°C) | T Rata° (°F) | T s (°F) | AL (m) |
|----------|----------|--------------|--------------|----------|--------|
| 252.90   | 279.95   | 271.43       | 520.58       | 100.4    | 1.7074 |

Analisa Korosi

| Cr eq | t min | t corrosion | Laju Korosi (mmpy) | Usia Casing (tahun) |
|-------|-------|-------------|---------------------|---------------------|
|       | inch  | inch        | pH 4                | pH 5                | pH 6                |
|       |       |             | pH 4               | pH 5               | pH 6               |
| -2    | 0.091644 | 0.258356 | 3.32E-10           | 1.12E-14          | 3.29E-19            | ≥30         | ≥30         | ≥30         |
| 0     | 0.35  | 3.87E-10    | 1.14E-14           | 3.34E-19          | ≥30         | ≥30         | ≥30         |

Figure 6. Reference of Bit Diameter and Casing Size Selection