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Tubing Strength Evaluation and Failure Assessment for Reactivation of Well PDD-2 as Steam Injector Well

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ABSTRACT - Many old oil wells still exist in Indonesia, some of those wells has been shut in due to several reasons, two of those reasons are: the oil production that declines significantly and weak well integrity so that the well cannot withstand obstructions that occur during production. To maintain and boost Indonesia's oil production, Enhanced Oil Recovery (EOR) methods can be applied in mature fields. One of EOR methods that has the most extensive application is steam flooding, in which the fluid is injected continuously to drive the oil from injector to producer. This EOR method is a successful method to increase heavy-oil production.The application of steam flooding, most notably in older wells presents itself with possible well integrity problem. Steam flooding well has a very high risk of casing and tubing failure that caused by the loads from burst, collapse, tension, and thermal effect due to the high temperature steam that can decrease the rating of casing or tubing. Hence, this study focuses on evaluating tubing's strength on the existing well whether the tubing is applicable for steam flooding or must be replaced. In this study, a tubing strength evaluation of well PDD-2 for steam flooding method will be discussed. Tubing strength evaluation consists of two stage. The first stage is evaluation due to burst, collapse, and tension loads and the other stage is evaluation due to thermal effects of injected steam. Well PDD-2 has K-55 tubing with 3.5 inch OD, burst rating of 7,947.5 psi, collapse rating of 7,052.9 psi, and tension rating of 160,262 lbf. Based on the evaluation result, this existing K-55 tubing still be able to withstand the loads from burst, collapse, tension, and thermal effects. Hence, the reactivation of Well PDD-2 as steam injector well can be done without replacing or upgrading the tubing.

Keywords: thermal effect, steam flooding, EOR, tubing strength, tubing failure.

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INTRODUCTION

A. Background

Oil and gas sector has given a significant contribution to Indonesia's economy since the first oil was discovered in Pangkalan Brandan, Sumatra in 1885. As SKK Migas reported in 2019, Indonesia's oil production reached 745.1 MBOPD. On the other hand, Indonesia is facing problem of oil production that has been declining consistently since 1995. In 2009, Indonesia's oil production was 949 MBOPD (SKK Migas, 2019). Furthermore, the national oil reserve has also been depleting since 2000, from 5.2 MMMbbl to 2.44 MMMbbl of proven reserves in 2021. This depletion challenges Indonesia's government and oil company to arrange new strategies and innovations to achieve one million barrels of oil per day (1 MMBOPD) of oil production by 2030.

As there is no major reserve addition, it is crucial for Indonesia to boost the oil production by optimizing its mature fields through performing EOR methods. In Indonesia, implementing full-scale EOR is still difficult to be applied due to high cost, the availability of injectant (surfactant, gas, steam, etc), and the infrastructure (Abdurrahman & Permadi, 2017). However, the most extensive application of EOR methods is steam flooding that has been applied in Duri Field, popularly known as Duri Steam Flood (DSF). The contribution of DSF to the total national production is about 20% (SKK Migas, 2011).

Steam flooding is a successful operation to increase heavy-oil production, yet there is a risk of casing or tubing failure rates in steam flooding wells that are very high (Wu, et al., 2005). The casing or tubing failures can be caused by burst, collapse, and tension loads that exceed the casing's rating and thermal effects from injected steam that can decrease the casing or tubing rating.

In this study, tubing strength evaluation of PDD-2 in PDD field will be conducted to aim of ascertaining whether the PDD-2 well tubing is technically feasible for reactivation for steam flooding. The evaluation considers the loads of burst, collapse, and tension during steam injection period and thermal effect due to injected steam. Burst and collapse calculation using safety factor 1.2 and tension calculation using safety factor 1.6 (Bourgoyne Jr., et al., 1991).

B. Objectives

The objective of this study is to evaluate tubing integrity of PDD-2 in PDD Field for reactivation for steam flooding. The evaluation considers:

- Burst, Collapse, and tension loads during steam flooding,
- Thermal effects due to injected steam.

C. Basic Theory

1. Steam Flooding

Continuous steam injection is also called steam flooding or stream drive. Steam flooding is one of EOR methods which the steam is injected continuously to drive the oil from injector to producer. Steam flooding process is a more complicated process from the design and engineering point of view, when compared to huff & puff steam injection (Alikhalov & Dindoruk, 2011).

The mechanism of steam flooding is as follows: injected steam heats the formation around the wellbore and forms a steam zone that grows with continuous steam injection. Injected steam decreases the oil viscosity in the steam zone to a significantly lower value, pushing the mobile oil out of the steam zone (Alikhalov & Dindoruk, 2011). As the steam zone grows, more oil is moved from the steam to the unheated zones (Alikhalov & Dindoruk, 2011) . There the oil accumulates to form an oil bank.

Not all oil field can experience steam flooding. The steam flooding screening criteria can be summarized as follows: oil SG <34 ^{o}API; oil viscosity <5x10^6 cp; temperature <180 ^{o}F; porosity >7.5%; permeability >1.0 mD; formation-type sandstone, unconsolidated sand and carbonate (Wei, et al., 2014). Steam flooding has succeeded in increasing oil recovery for Cruse 'E' Field, Trinidad. Injection rate averaged 1,800 bbl of steam per day (BSPD) during 1986–1990, and oil production peaked at 300 BOPD in 1987 (Journal Petroleum Technology, 2005). One of the biggest steam flood application in the world is currently being implemented in Duri Steam Flood (DSF) Project in Indonesia, where it was implemented on almost 4000 wells with the peak production rate of 200,000 BOPD (Winderasta, et al., 2018). Several notable challenges during the implementation of steam flood are significant thermal effects on the tubular goods, steam condensation in producer wells, as well as calcium carbonate scale and gravel pack damage (Pearce & Megginson, 1991).

2. Burst, Collapse, Tension

For a given tubular specification, it is important to measure the axial tension, burst pressure, and collapse pressure to know the tubular's performance and prevent failures, especially for wells that are exposed to steam flooding, where the steam injected through tubing will affect tubing strength that contributes as internal pressure of tubing.

Axial tension load is primarily caused by the weight of the casing string and the buoyant forces acting on the casing (Bourgoyne Jr, et al., 1991). Pipe-body yield strength must be considered because it is the tensional force that will cause the pipe body to surpass its elastic limit. Joint strength, similar to pipe-body yield strength, is the minimum tensional force needed that can lead into connection failure. The illustration of axial loads can be seen in Figure 1. The pipe-body tensile strength can be defined as (Bourgoyne Jr, et al., 1991).

$$F_{ten} = \frac{\pi}{4}\sigma_{yield}(d_n^2 - d^2) \tag{1}$$

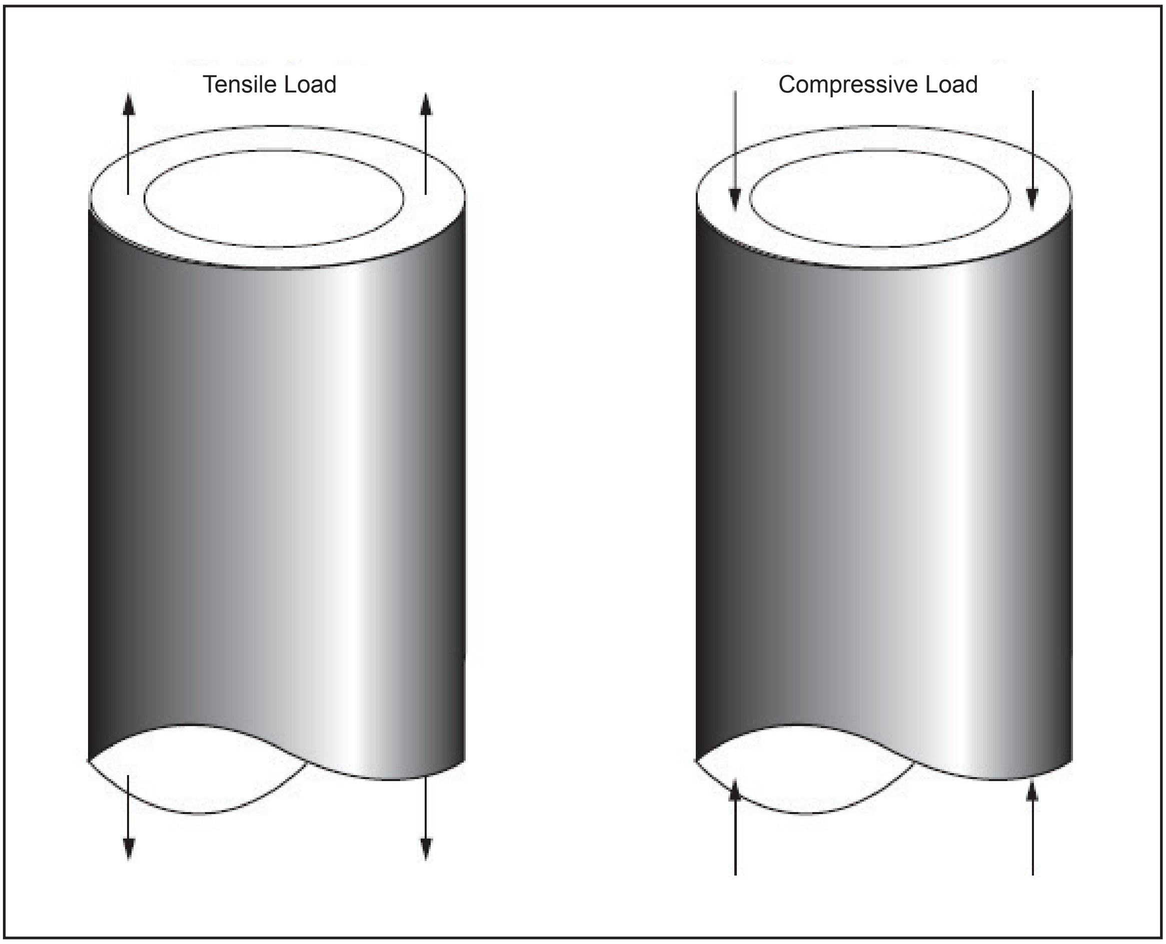

Figure 1
Axial loads on casing/tubing (Heriott-Watt University, 2005).

Burst pressure rating is the minimum internal pressure that will lead the maximum stress in the pipe to reach the minimum yield strength without external pressure and axial loading as illustrated in Figure 2. Burst load normally calculated by internal pipe load subtracted by any external pressure. If the burst pressure rating is exceeded, the pipe will start to burst. Therefore, changing the grade of pipe which has greater burst rating is needed to avoid the burst. The API burst-pressure rating is based on Barlow's equation as shown below (Bourgoyne Jr, et al., 1991).

$$p_{br} = 0.875\frac{2\sigma_{yield}t}{d_n} \tag{2}$$

For example, by using Eq.(2), a 13 3/8-in., 72-lbm/ft N-80 intermediate casing has burst rating 5,380 psia. The formation, in which the tubular is located, yields the pressure of 6,000 psia, formation depth at 12,000 ft, and gas gradient equal to 0.1 psi/ft. Therefore, in this example, the casing will experience load around 4,800 psia in terms of burst pressure. It shows that the casing is strong enough to resist this burst pressure.

Collapse pressure rating is the minimum external pressure that will lead the pipe walls to collapse without any internal pressure and axial loading as illustrated in Figure 3. Mud and possibly the cement are the types of fluid that primarily supply the collapse loads. Collapse resistance equations vary as a function of D/t ratio (Adams, 1985). Therefore, evaluating D/t range and selecting the proper equation must be a concern. Formula based factors must be used in collapse calculation.

Yield strength collapse pressure, the external pressure (P_{yp}) that generates minimum yield stress (Y_p) on the inside wall of a tube:

$$P_{yp} = 2\,Y_p\left[\frac{(D/t)-1}{(D/t)^2}\right] \tag{3}$$

The applicable D/t ratios for yield strength collapse are shown in Table 1.

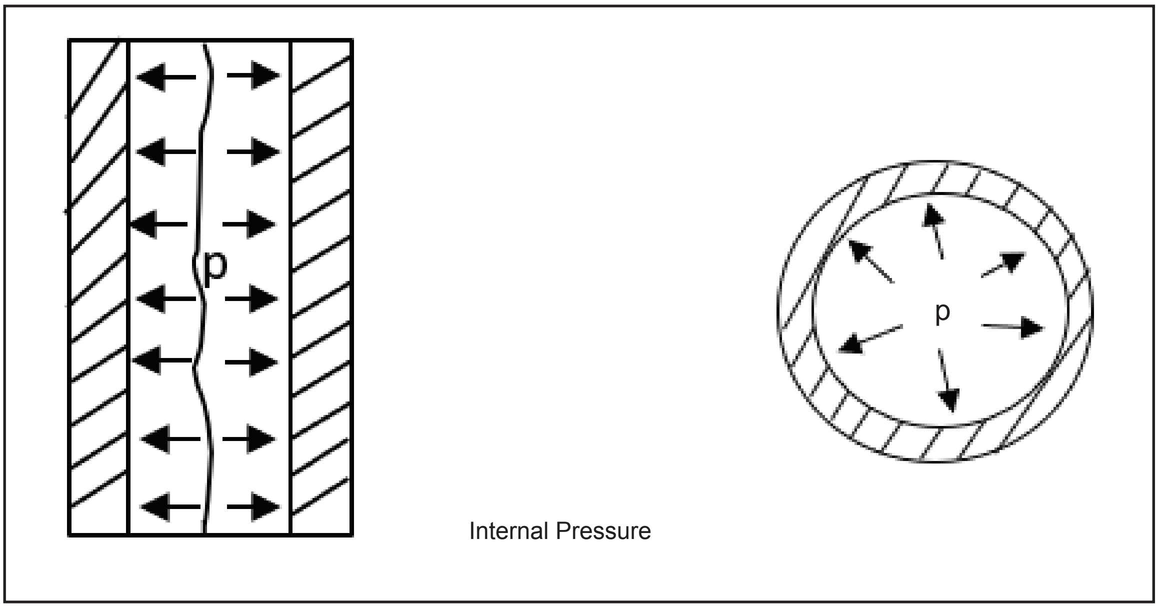

Figure 2
Burst loads from internal pressure (Bourgoyne Jr., et al., 1991).

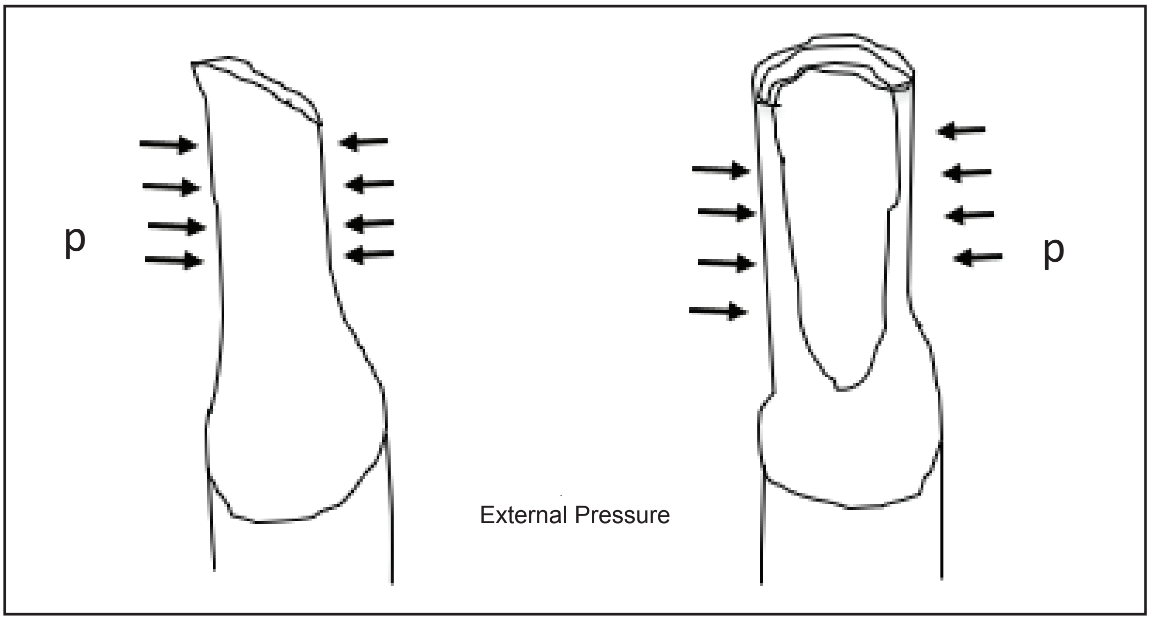

Figure 3
Collapse loads from external pressure (Bourgoyne Jr., et al., 1991).

The minimum collapse pressure for the plastic range of collapse (P_p) can be expressed as:

$$P_p = Y_p\left(\frac{A}{D/t} - B\right) - C \tag{4}$$

The factors and applicable D/t range for the plastic collapse formula are shown in Table 2.

The minimum collapse pressure for the plastic to elastic transition zone (P_t) can be expressed as:

$$P_t = Y_p\left(\frac{F}{D/t} - G\right) \tag{5}$$

Factors and applicable D/t range for transition collapse pressure formula are shown in Table 3. For example, a 7-in., 23=lbm/ft P-110 liner was predicted to experience a transition collapse, with the values for F = 2.066 and G = 0.0532. By applying Eq.5, the transition collapse rating pressure is 4,440 psi. Therefore, to prevent collapse, the collapse loads pressure of casing must smaller than the collapse rating.

The minimum collapse pressure for the elastic range of collapse (P_e) can be expressed as:

$$P_e = \frac{46.95\ x\ 10^6}{(D/t)[(D/t)-1]^2} \tag{6}$$

The applicable D/t range for elastic collapse is shown in Table 4.

3. Thermal Effects

Temperature changes encountered during the life of the well usually are small and can be ignored, most notably in shallow wells or wells without any significant thermal stimulation (Bourgoyne Jr, et al., 1991). However, in some cases, temperature changes are not negligible. Therefore, the resulting additional axial stress must be considered in the casing or tubing design.

During steam injection, casing axial compressive stress increases and it will cause the casing or tubing becomes hot-yielded at curtain temperature (Wu, et al., 2005). The high temperature steam will heat up the casing or tubing, causing it to expand. Since the hole geometry and friction restrict any form of expansion, the casing or tubing will experience high compressive thermal stress and may easily surpass the low-strength casing material yield strength and it will lead to a casing failure (Wu, et al., 2005).

The change in axial stress due to thermal expansion are defined as:

$$\Delta\sigma = -\alpha E \Delta T \tag{7}$$

$$F = -E\alpha\Delta T A_s \tag{8}$$

The change in tubing length because of thermal effect is calculated as follows:

$$\Delta L = L\alpha\Delta T \tag{9}$$

DATA AND METHODS

Several steps were performed to complete this study that illustrated in Figure 4. The methodology used to complete this study is as follows:

- Literature Study

Literature study was done by reading books and papers with the aim to gain theories and calculation about burst, collapse, tension, and thermal effects in tubing strengths. In this step, assumptions used to complete this study is collected.

- Data Preparation

In data preparation section, data that needed to complete this study was collected. The data used in this study includes well data, injection data, and injected fluid data.

- Tubing's Loads Evaluation

In this step, the strength of X-well's tubing is evaluated by calculating the loads incurred due to steam flooding. The loads consist of burst, collapse, and tension loads that calculated using Microsoft Excel. The steps of tubing's loads evaluation are as follows:

a. Collect well data and tubing catalogue;
b. Calculate the rating of production tubing;

Table 1
Applicable D/t ratios
for yield strength collapse (Bourgoyne Jr, et al., 1991)

Grade*	D/t Range
H-40	16.44 and less
H-55	15.24 and less
J-K-55 & D	14.81 and less
-60	14.44 and less
-70	13.85 and less
C-75 & E	13.60 and less
L-80 & N-80	13.38 and less
-90	13.01 and less
C-95	12.85 and less
-100	12.70 and less
P-105	12.57 and less
P-110	12.44 and less
-120	12.21 and less
-125	12.11 and less
-130	12.02 and less
-135	11.92 and less
-140	11.84 and less
-150	11.67 and less
-155	11.59 and less
-160	11.52 and less
-170	11.37 and less
-180	11.23 and less

Table 2
Factors and applicable D/t range for plastic collapse (Bourgoyne Jr., et al., 1991)

Grade*	Formula Factor			D/t Range
	A	B	C	
H-40	2.95	0.0465	754	16.44 to 27.01
H-55	2.976	0.0515	1056	15.24 to 25.63
J-K-55 & D	2.991	0.541	1206	14.81 to 25.01
-60	3.005	0.0566	1356	14.44 to 24.42
-70	3.037	0.0617	1656	13.85 to 23.38
C-75 & E	3.054	0.0642	1806	13.60 to 22.91
L-80 & N-80	3.071	0.0667	1955	13.38 to 22.47
-90	3.106	0.0718	2254	13.01 to 21.69
C-95	3.124	0.0743	2404	12.85 to 21.33
-100	3.143	0.0768	2553	12.70 to 21.00
P-105	3.162	0.0794	2702	12.57 to 20.70
P-110	3.181	0.0819	2852	12.44 to 20.41
-120	3.219	0.087	3151	12.21 to 19.88
-125	3.239	0.0895	3301	12.11 to 19.63
-130	3.258	0.092	3451	12.02 to 19.40
-135	3.278	0.0946	3601	11.92 to 19.18
-140	3.297	0.0971	3751	11.84 to 18.97
-150	3.336	0.1021	4053	11.67 to 18.57
-155	3.356	0.1047	4204	11.59 to 18.37
-160	3.375	0.1072	4356	11.52 to 18.19
-170	3.412	0.1123	4660	11.37 to 17.82
-180	3.449	0.1173	4966	11.23 to 17.47

c. Calculate steam flooding burst pressure;
d. Calculate steam flooding collapse pressure;
e. Calculate steam flooding tension load;

- Rating and Tubing’s Failure Analysis

After the tubing loads has been evaluated, the result of the evaluation must be compared to tubing rating. Authors give recommendation whether the tubing’s grade must be upgraded or not due to burst, collapse, and tension’s loads.

- Thermal Effects Evaluation

At this section, the tubing is re-evaluate by considering the temperature of injected steam. The evaluation has several steps below.

a. Collect well data and tubing’s material properties;
b. Collect injected steam data;
c. Calculate the change in axial stress due to thermal expansion;

d. Calculate the change in tubing length because of thermal effect.

A. Case Study

Field PDD is one of mature fields that is located in East Indonesia. In this field, many production wells had been producing oil since more than 25 years ago and some of the wells has been shut in. Oil production in Field PDD has declining consistently since 1970s. Therefore, to optimize oil production in Field PDD, steam flooding will be applied as secondary recovery as it has been producing heavy oil with relatively high viscosity of 10 cp and the field's proximity to industrial steam producer.

PDD-2 is a shut-in well that will be reactivated as steam flooding well, without any data on the latest CBL logging to assess the well's condition after shut in. This existing well has a K-55 grade tubing with OD size of 3-1/2 inch and 9.3 ppf weight installed

Table 3
Factors and applicable D/t range
for transition collapse pressure (Bourgoyne Jr., et al., 1991)

Grade*	Formula Factors		D/t Range
	F	G	
H-40	2.063	0.0325	27.01 to 42.64
H-55	2.003	0.0347	25.63 to 38.83
J-K-55 & D	1.989	0.036	25.01 to 37.21
-60	1.983	0.0373	24.42 to 35.73
-70	1.984	0.0403	23.38 to 33.17
C-75 & E	1.99	0.0418	22.91 to 32.05
L-80 & N-80	1.998	0.0434	22.47 to 31.02
-90	2.017	0.0466	21.69 to 29.18
C-95	2.029	0.0482	21.33 to 28.36
-100	2.04	0.0499	21.00 to 27.60
P-105	2.053	0.0515	20.70 to 26.89
P-110	2.066	0.0532	20.41 to 26.22
-120	2.092	0.0565	19.88 to 25.01
-125	2.106	0.0582	19.63 to 24.46
-130	2.119	0.0599	19.40 to 23.94
-135	2.133	0.0615	19.18 to 23.44
-140	2.146	0.0632	18.97 to 22.98
-150	2.174	0.0666	18.57 to 22.11
-155	2.188	0.06825	18.37 to 21.70
-160	2.202	0.07	18.19 to 21.32
-170	2.231	0.0734	17.82 to 20.60
-180	2.261	0.0769	17.47 to 19.93

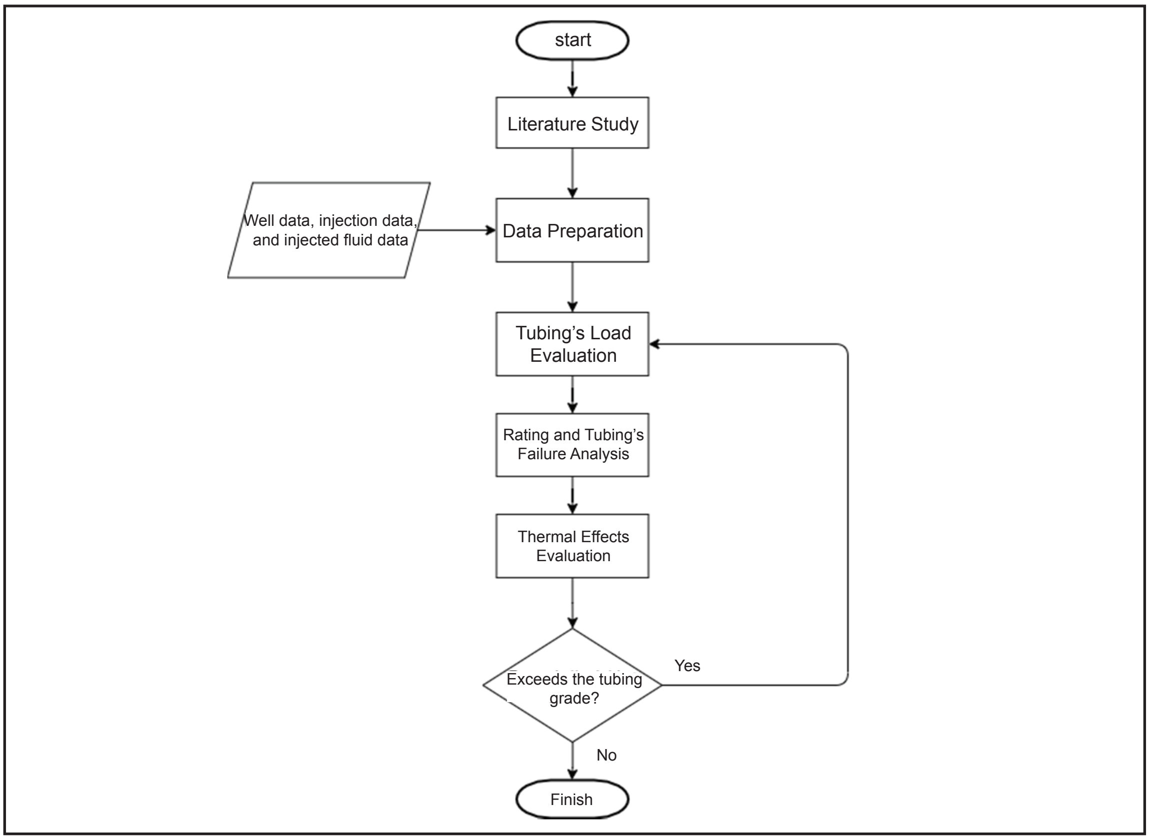

Figure 4
Flowchart of methodology.

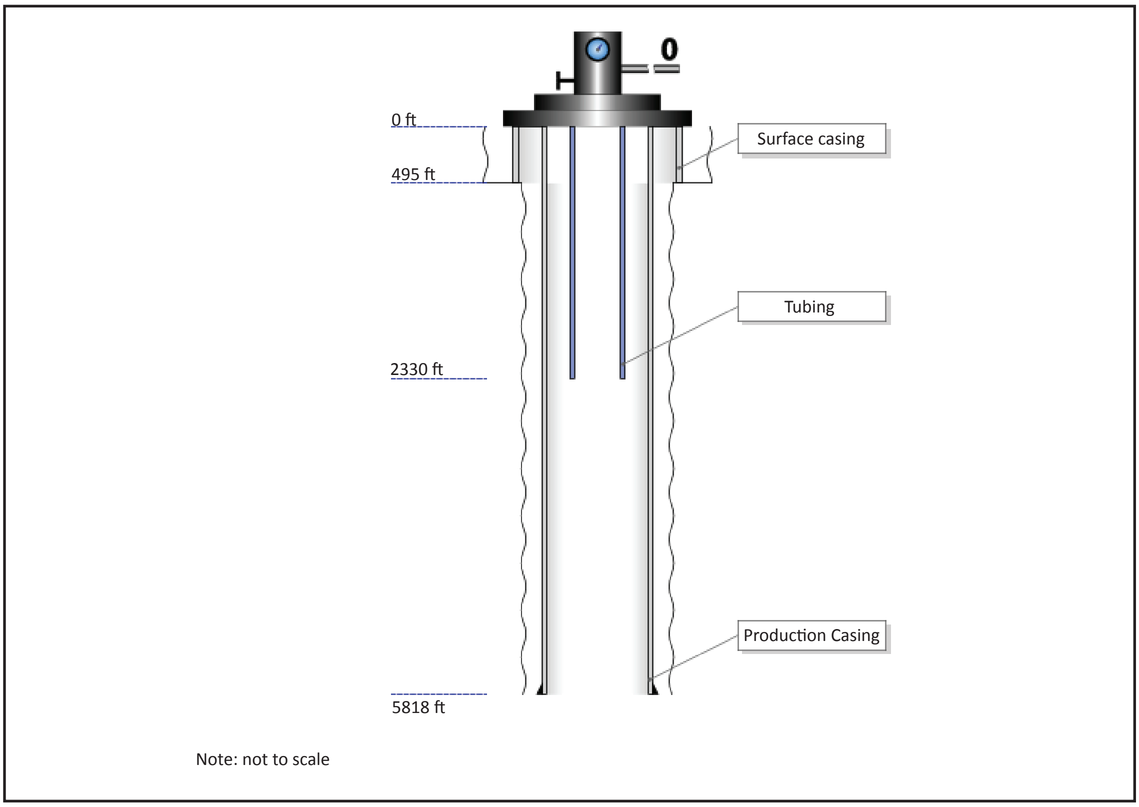

Figure 5
Well PDD-2 schematic.

at 2,330 ft depth. The detailed information about PDD-2 is shown in Table 5 and well schematic of PDD-2 is illustrated in Figure 5.

Steam injection will be applied in this well to boost oil production of Field PDD. Therefore, injection scenario is prepared to obtain an excellent steam flooding performance. Steam will be injected continuously with 80 GPM injection rate and 2,000 psi injection pressure. The steam quality is 80% with temperature of 250°F. The detailed information about injection scenario is shown by Table 6.

Tubing evaluation will be performed to see the feasibility of the tubing during steam injection. Several steps are executed to complete tubing evaluation:

a. Calculate burst rating, collapse rating, and tension rating for tubing;
b. Calculate burst, collapse, and tension loads. Since PDD-2 will performed steam flooding, the loads will be calculated during steam injection;
c. Calculate thermal effects that occur due to the injected steam during steam flooding;
d. Evaluate the result of burst, collapse, tension, and thermal effect that have been calculated by comparing with tubing's rating. Once the evaluation result is not exceed the rating of tubing, then the existing tubing can be used as steam injector. If the evaluation result exceeds the rating of tubing, the tubing's grade must be upgraded.

RESULTS AND DISCUSSION

A. Burst, Collapse, and Tension

Burst calculation is done by using safety factor 1.2 (Bourgoyne Jr, et al., 1991). The internal pressure comes from injection pressure and considering the column of injected steam inside tubing. While the external pressure comes from pore pressure that assumed as 0.465 psi/ft. The results of burst calculation is burst pressure of 2,000 psia at surface and 917.76 psi at 2,330 ft depth. This result is not exceed the burst rating which is 7,947.5 psi. The detailed result of burst calculation is shown in Table 7 and illustrated in Figure 6. Burst failure graph can be seen in Figure 7.

Safety factor of 1.2 is used to calculate collapse pressure (Bourgoyne Jr, et al., 1991). Calculation of collapse using the worst scenario when the tubing experience high external pressure and the internal pressure is zero. External pressure comes from pore pressure 0.465 psi/ft. The result of collapse pressure

Table 4
Applicable D/t range for
elastic collapse (Bourgoyne Jr, et al., 1991)

Grade*	D/t Range
H-40	42.64 and greater
H-55	38.83 and greater
J-K-55 & D	37.21 and greater
-60	35.73 and greater
-70	33.17 and greater
C-75 & E	32.05 and greater
L-80 & N-80	31.02 and greater
-90	29.18 and greater
C-95	28.36 and greater
-100	27.60 and greater
P-105	26.89 and greater
P-110	26.22 and greater
-120	25.01 and greater
-125	24.46 and greater
-130	23.93 and greater
-135	23.44 and greater
-140	22.98 and greater
-150	22.11 and greater
-155	21.70 and greater
-160	21.32 and greater
-170	20.60 and greater
-180	19.93 and greater

Table 5
Well PDD-2 data

Parameter	Value
Number of casing	2
Tubing Grade	K-55
Tubing OD, inch	3.5
Tubing ID, inch	2.922
Depth of Tubing, ft	2,330
Weight of Tubing, ppf	9.3
Pore Pressure, psi/ft	0.465

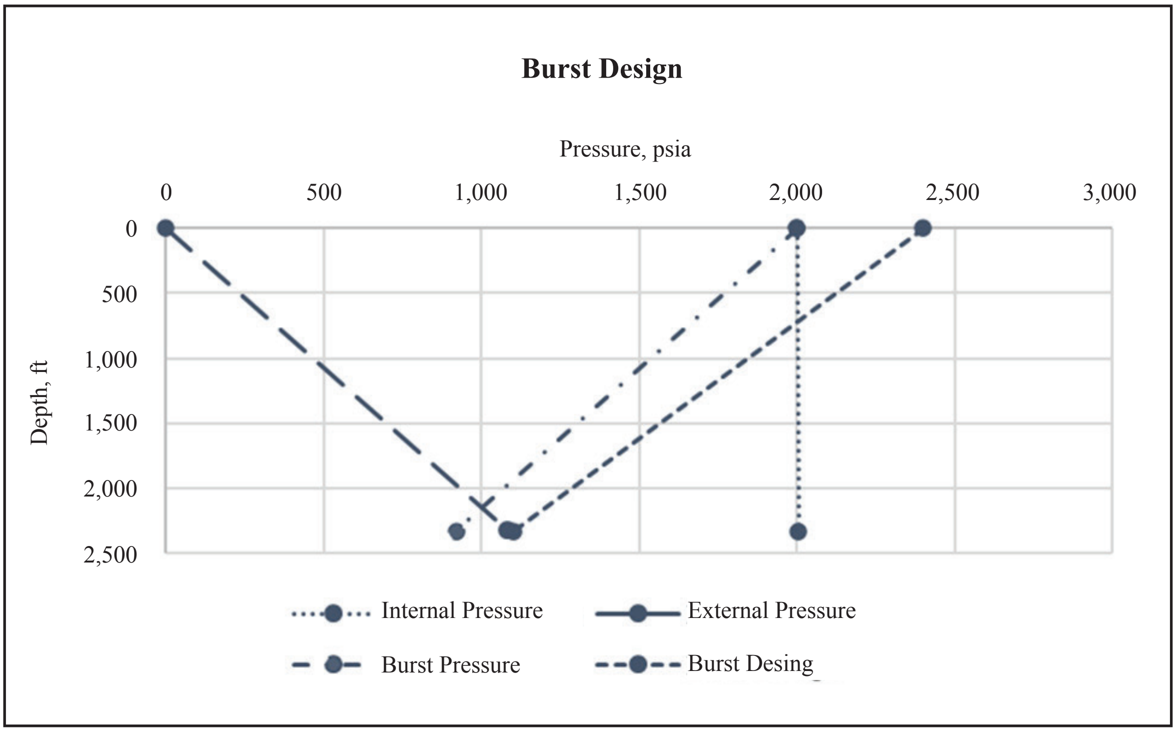

Figure 6
Burst pressure design.

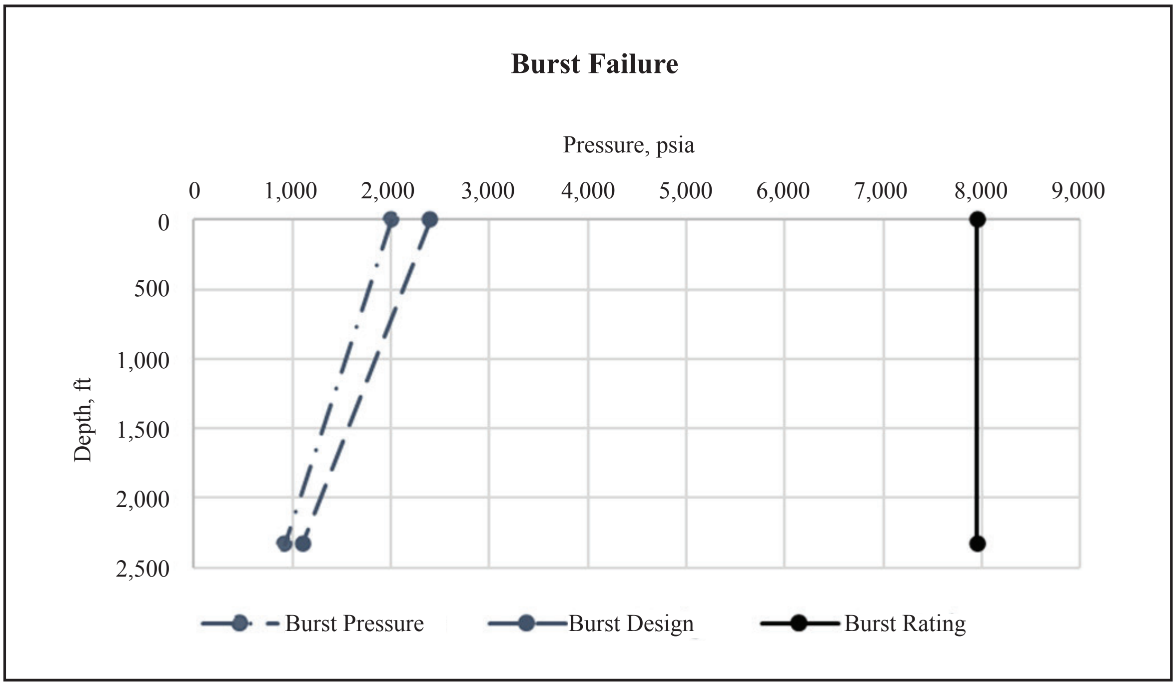

Figure 7
Burst failure analysis.

calculation is 1,300.14 psi at 2,330 ft depth which is the bottom of tubing. This collapse pressure meets the collapse rating requirement 7,052.9 psi. The detailed result of collapse calculation is shown in Table 8 and illustrated in Figure 8. Collapse failure graph can be seen in Figure 9.

Tension load calculation considers the weight of tubing per feet, 9.3 ppf, and the depth of tubing, 2,330 ft. This calculation using safety factor of 1.6 (Bourgoyne Jr, et al., 1991). Buoyancy effect is neglected in this calculation because the tubing has been cemented and it will not significantly affect the

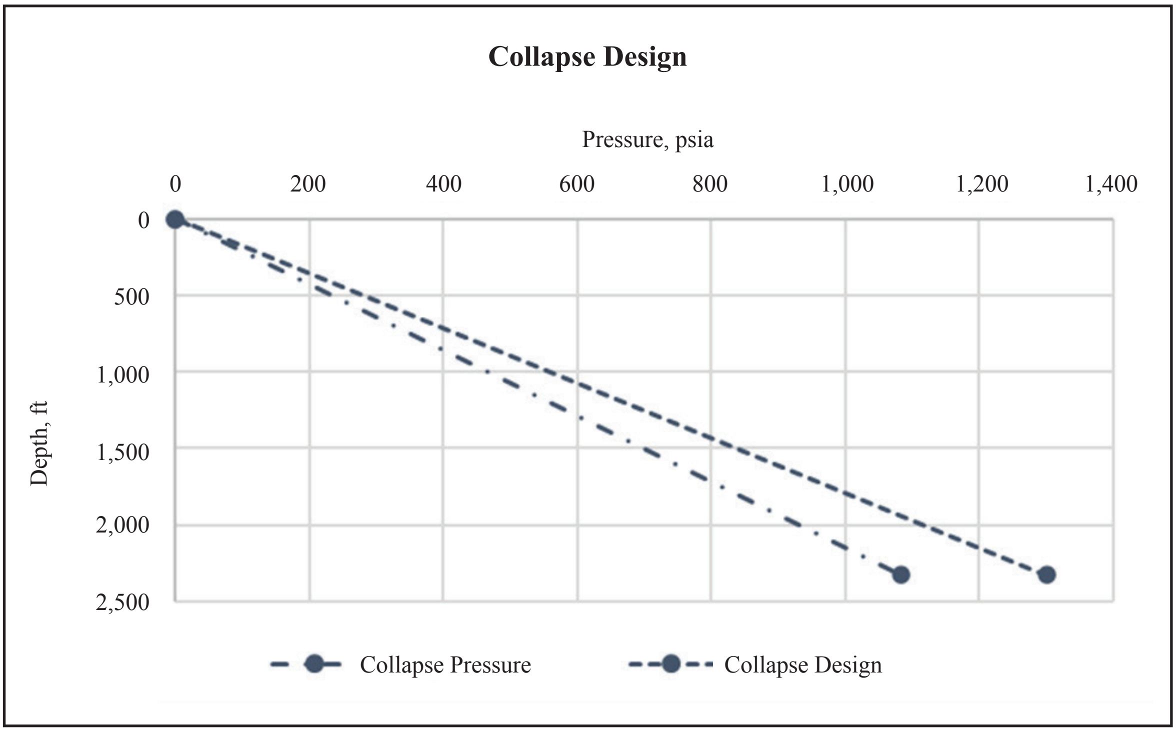

Figure 8
Collapse pressure design.

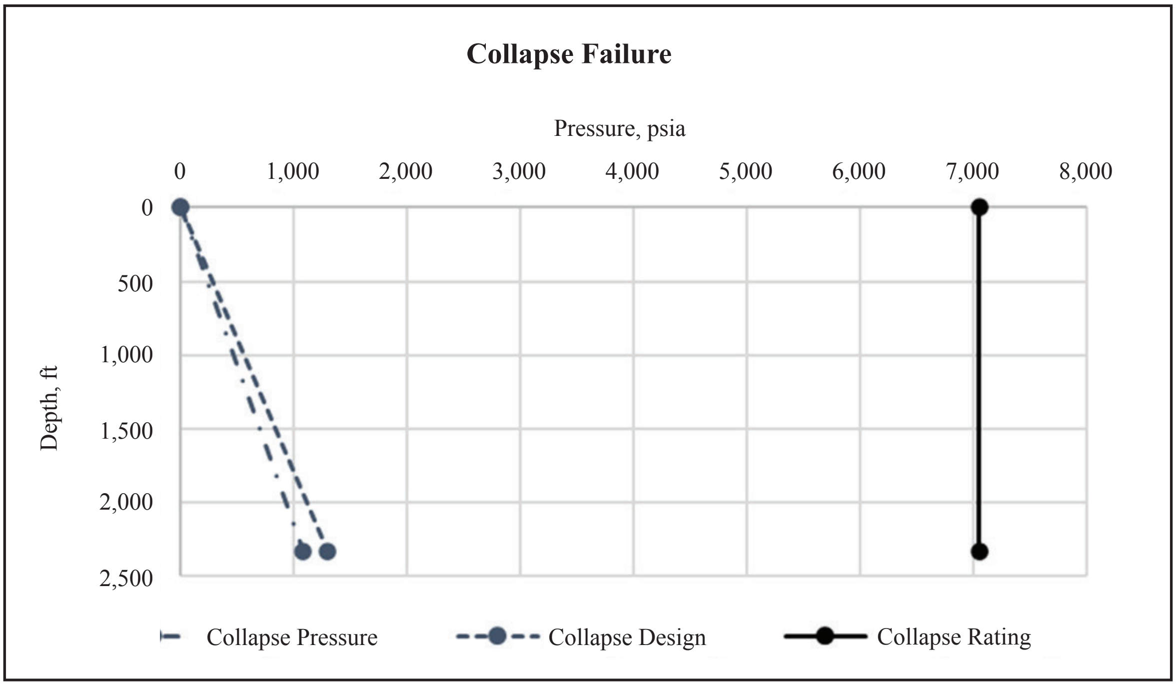

Figure 9
Collapse failure analysis.

calculation. The result of tension load is 34,670.4 lbf which is not exceeds tension rating 160,262 lbf. The detailed result of tension load calculation is shown in Table 9 and illustrated in Figure 10. Tension failure graph can be seen in Figure 11.

B. Thermal Effects

During steam injection, an additional tension load due to thermal effects of injected steam must be considered. In this calculation, some assumptions are applied: the heat transfer to other systems is close to zero due to excellent cementation and there is no leakage. When the steam of 250°F is injected, the tubing will be subjected to an increase in temperature and will start to expand of 3.89 ft length.

However, when the casing is restricted from expanding because it is already cemented and landed in sufficient tension, high compressive thermal stress will be developed. In this case, the change in temperature due to 250°F injected steam will result to 50,025 psi of axial stress and 145,765.55 lbf axial load. Then, the calculated tension load due to thermal effect must be compared to the tension rating of K-55 tubing grade. The result is that tension load due to thermal effect is not exceeds the tension rating of 160,262 lbf as illustrated in Figure 12.

The result of thermal loads is slightly under the tension rating. Since PDD-2 is an old well, concerns must be taken on how was the actual condition of tubing when the well was closed. The actual condition of tubing can be changed during the production time due to the burst, collapse, tension loads and corrosion that caused by water or gas production. Consequently, tubing's rating can be degraded. However, assumption that the tubing's rating is not degraded during production life is applied in this study.

CONCLUSIONS

Based on result and discussion that has been discussed in the previous section, can be concluded as shown below:

By the value burst pressure of 2,000 psia, collapse pressure of 1,300.14 psia, and tension load of 34,670.4 lbf, the K-55 tubing has less possibility to failure during steam flooding.

Thermal axial stress that caused by a 250°F steam is 50,025 psi and result to 145,765.55 lbf of axial load. This result meets the requirement of K-55 tubing which has tension rating 160,262 lbf.

Table 6
Injection data

Parameter	Value
Injection Pressure, psia	2,000
Injection Rate, GPM	80
Steam Quality, %	80
Steam Temperature, F	250

Table 7
Burst pressure calculation

Depth (ft)	Internal Pressure (psi)	External pressure (psi)	Burst Pressure (psi)	Burst Design (psi)
0	2,000	0	2,000	2,400
2,330	2,001.21	1,083.45	917.76	1,101.31

Table 8
Collapse pressure calculation

Depth (ft)	Internal Pressure (psi)	External pressure (psi)	Collapse Pressure (psi)	Collapse Design (psi)
0	0	0	0	0
2,330	0	1,083.45	1,083.45	1,300.14

Table 9
Tension load calculation

Depth (ft)	Pounder (ppf)	Tension (lbf)	Tension Design (lbf)
0	9.3	21,669	34,670.40
2,330	9.3	0	0

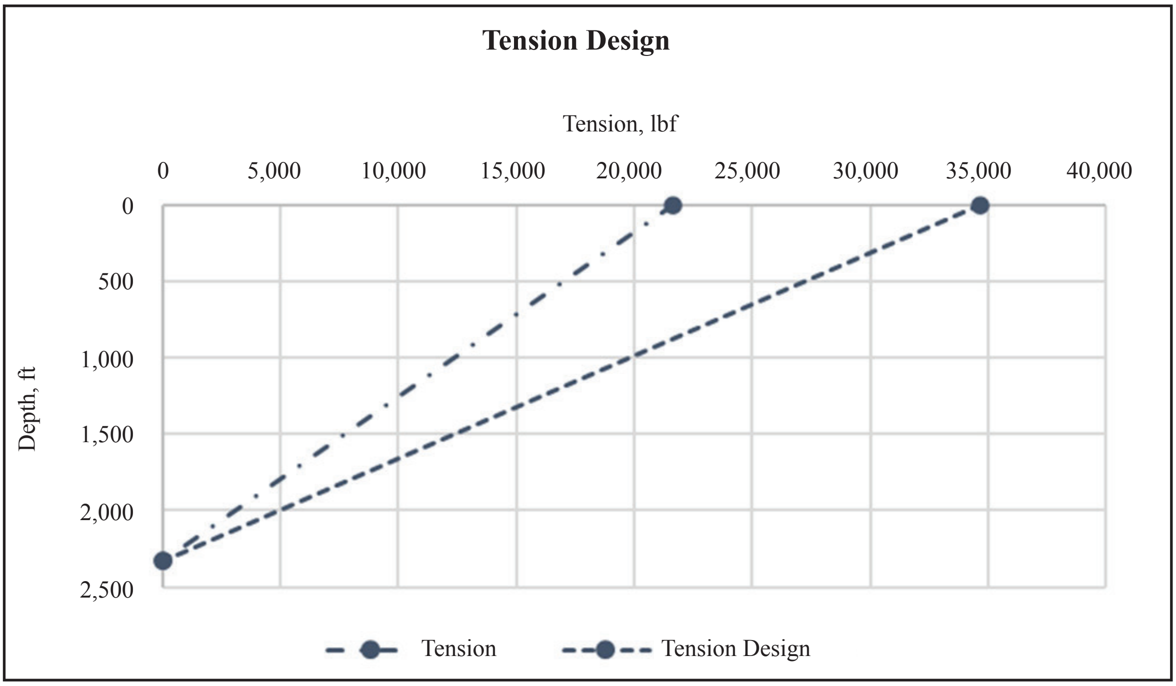

Figure 10
Tension load design.

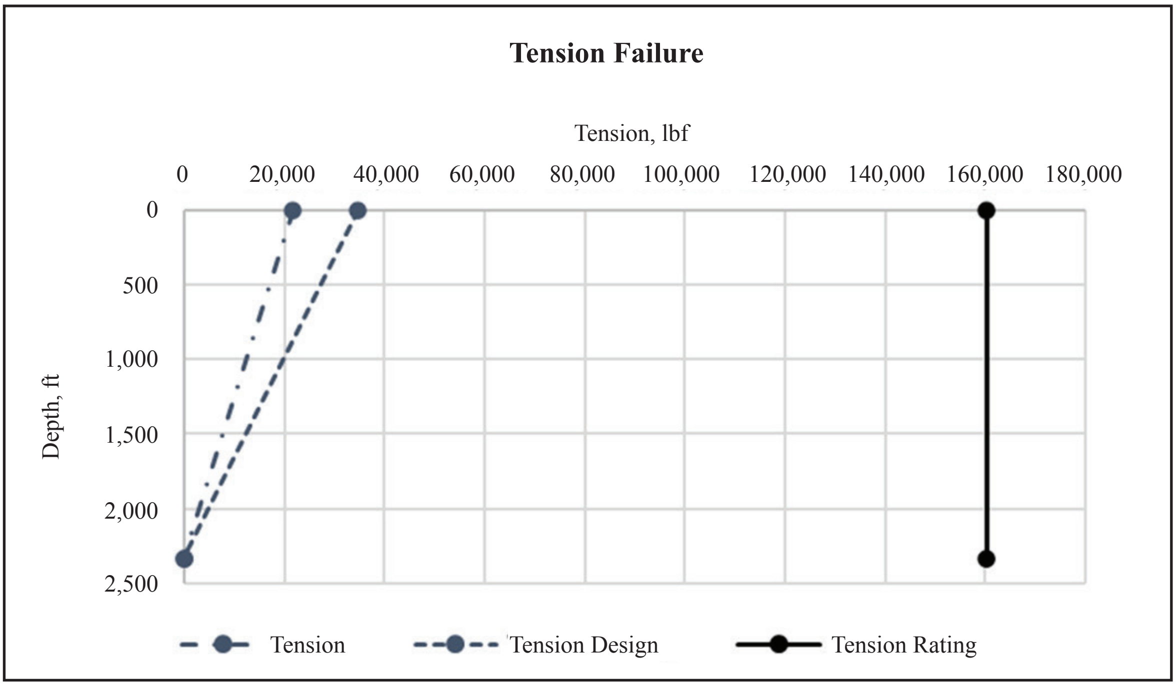

Figure 11
Tension failure analysis.

Burst, collapse, tension, and thermal effects evaluation show that the existing K-55 tubing still compatible to be used for steam flooding. Hence, there is no need to upgrade or replace the tubing.

Several recommendations are given by the author:

To prevent tubing failure due to thermal effects, usage of high strength tubing (P-110 and Q-125) can be considered. This type of tubing has a higher material yield strength that can reduce tubing hot-yielding. Economic analysis for the use of high strength tubing must be conducted since this type of tubing has a higher cost.

Tension load due to thermal effects can be reduced by decreasing the temperature of injected steam. To keep the performance of steam flooding

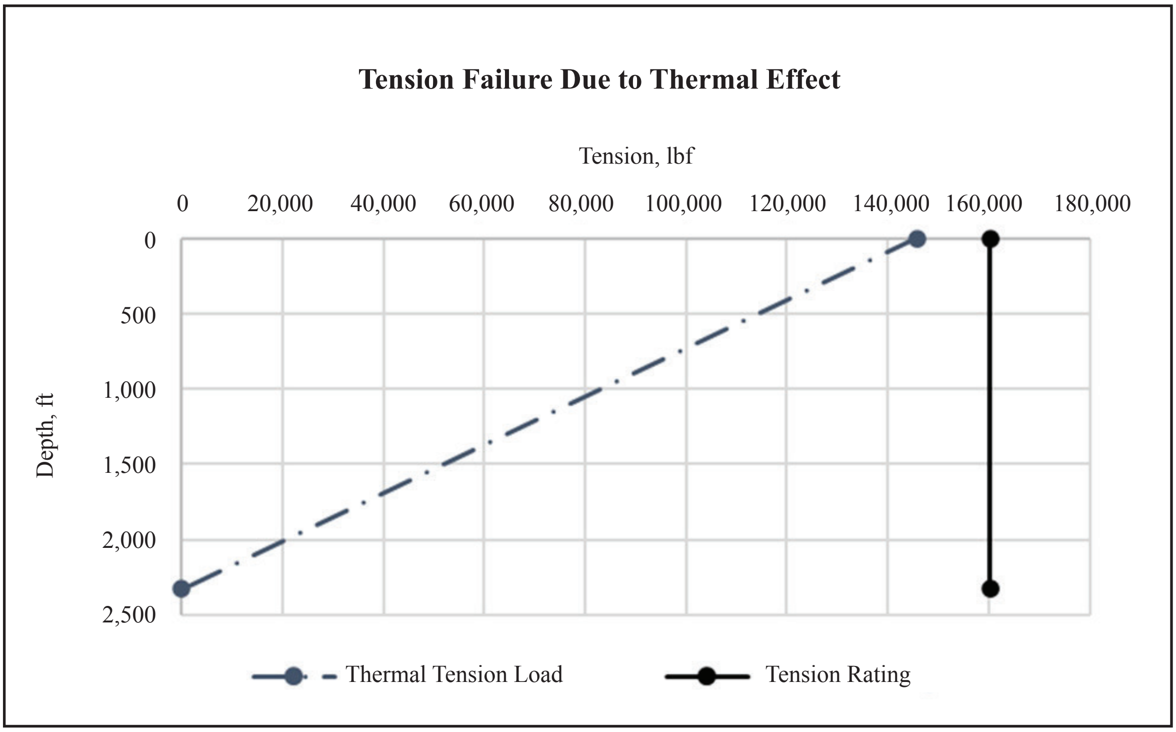

Figure 12
Tension rating analysis due to thermal effect list of tables.

by using lower steam temperature, heat loss must be reduced by insulating the wellbore in one of several ways, such as: insulating cement and insulating tubing.

Thermal wellhead can be used in steam flooding well. This kind of wellhead will allow the production tubing to expand when it is heated up by the injected steam. Economic factor must be considered because thermal wellhead has a higher cost than conventional wellhead.

For the improvement of further study, some assumptions that applied in this study, for example: buoyancy effect can be considered in the calculation for tubing loads, the degradation of tubing's grade can be considered by gaining more information and data about production.

Economic analysis can be considered in further study to give some options of tubing and injection scenario that will provide the highest profit.

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GLOSSARY OF TERMS

Symbol	Definition	Unit
API	American Petroleum Institute	
A	Tubular first formula factor	
A_s	Cross sectional area (in^2)	
B	Tubular second formula factor	
BOPD	Barrel Oil per Day	
Cp	Centipoise	
$\Delta\sigma$	change in axial stress	psi
D	diameter	inch
d	Inner diameter	inch
d	Inner diameter	inch
d_n	Outer diameter	inch
EOR	Enhanced oil recovery	
E	Young modulus of elasticity	psi
F	force	lbf
F_{ten}	Tensional force	lbf

Symbol	Definition	Unit
SKK Migas	Satuan Kerja Khusus Pelaksana Kegiatan Hulu Minyak dan Migas	
OD	Outer diameter	
P_{br}	Burst pressure	psi
P_{yp}	Yield strength collapse pressure	psi
P_p	Plastic collapse pressure	psi
P_t	Transitional collapse pressure	psi
P_e	Elastic collapse pressure	psi
Ppf	pound per foot	
t	Wall thickness	inch
α	average thermal coefficient expansion	$1/^{o}F$
σ_{yield}	Minimum yield strength	psi
ΔT	Temperature change	^{o}F
Yp	Yield stress	psi

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