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Casing Elongation Study in Geothermal Wells with Two-Stage Cementing and Tie-Back Cementing Methods

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ABSTRACT

Many wellheads had risen due to the increase in the length of casing in the working area of Pertamina Geothermal Energy (PGE) Kamojang and Lahendong. They caused problems related to safety and the decrease of steam production as a source of energy for PLTP Kamojang and Lahendong. Several factors were suspected to affect the extension of the casing namely the fluid temperature, the type of casing / sheath, and poor cement bonding. This research was conducted to find out the effect of fluid temperature on casing related to the rise of wellhead and also to find out whether the tie-back cementing method was effective in minimizing the lengthening of the casing. Besides that, the casing grade related to the length of the casing (congruence elongation) as well as the value of thermal expansion length increase to the casing used was investigated. There were several analyses done in this research that were casing elongation analysis (thermal effect on casing), cement design method analysis and also casing grade result analysis. The data used in this research were well data profile, casing configuration data, cement lab data, cementing SOP used, thermal expansion coefficient and temperature data. The results obtained from the research were the casing length increase of 10-15 cm for two-stage cementing method, while the method of tie-back cementing had not caused the rise of wellheads. Critical temperature (T_c) of casing with an L80 grade ranges from 369 to 375ºF, while that of casing with the C95 grade ranges from 420 to 423.5ºF. Critical depth of L3, L4, L5, and L6 wells range from 545 to 806 m with a critical temperature range from 369 to 372.5 ºF. If surface steam temperature is higher than the critical temperature then plastic deformation occurs along the production casing.

1. INTRODUCTION

Casing cementing in geothermal wells should be done throughout the casing is installed. This is performed to reduce the increase of casing length and also prevent the casing from buckling when hot steam is produced. A good cementing result is required on the production casing where the master valve is installed. If the cementing results are not good, it can lead to an increase in the length of the production casing which has an effect on the well head rise, and also results in vibration when the well is producing. The worse condition due to bad cementing is casing disjointing and steam blowout (Shryock, 1984].

The good quality of cement in the production casing is very necessary. If the quality of the cement applied is not good, there will be a trapped fluid that can come from drilling fluid, preflush fluid or mud spacer. This trapped fluid will warm up and increase in temperature under static conditions and when the well is produced. The temperature increase of the trapped fluid may result in the pressure increase of 45 – 50 psi/ºF. It may trigger the collapse of casing when the pressure outside the casing is high (Edwards et al., 1982).

This research was conducted on twelve geothermal wells in the working area of Pertamina Geothermal Energy (PGE) Kamojang and Lahendong and aimed to find out the effect of fluid temperature on casing related to wellhead rise and also to find out whether the tie-back cementing method is effective in minimizing the lengthening of the casing in the working area of PGE Kamojang and Lahendong. Kamojang Field is located in West Java, while Lahendong Field is located in North Sulawesi (Indonesia) [3,4].

2. LITERATURE REVIEW

2.1 Two-Stage Cementing

Cementing with the two-stage cementing method is generally carried out because of the large hydrostatic pressure of the cement which is feared to cause loss or casing to collapse (Evans Kiprotich Bett, 2010). This is related to the length of the cement column which will be filled by cement. As the name implies cementing with the two-stage cementing method is done with two cementing stages (Bett., 2010). In the first stage, cement slurry is pumped into the wellbore through the casing , then drop the flexible plug followed by drilling fluid pumping until the flexible plug sits on top of the float collar followed by an increase in pressure. In the second stage, the opening plug (bomb) is dropped until the bomb sits on the stage collar . Then a pressure of 800-2000 psi is applied to break the shear pin, so that a hole for the cement path is opened. After the cement path is opened, it is then followed by pumping the spacer. After that, Shut off Plug was dropped and followed by drilling fluid pumping until bump pressure is obtained. Eventually, the operation is completed by bleed off pressure. Two-stage cementing process cementing along with the application are presented in Figures 1 and 2.

2.2 Tie-Back Cementing

Cementing using the tie-back cementing method is basically the same as cementing with the two-stage cementing method, which consists of two stages of cementing. However, there are significant differences in the cementing accessories used and also from the cementing work procedure. In cementing with the tie-back cementing method, the casing is installed in two stages and gradually cemented, while in two-stage cementing, the casing is set to the setting depth then it is cemented. The application of the tie-back cementing method can be seen in Figure 3 (Pertamina Geothermal Energy Team, 2016).

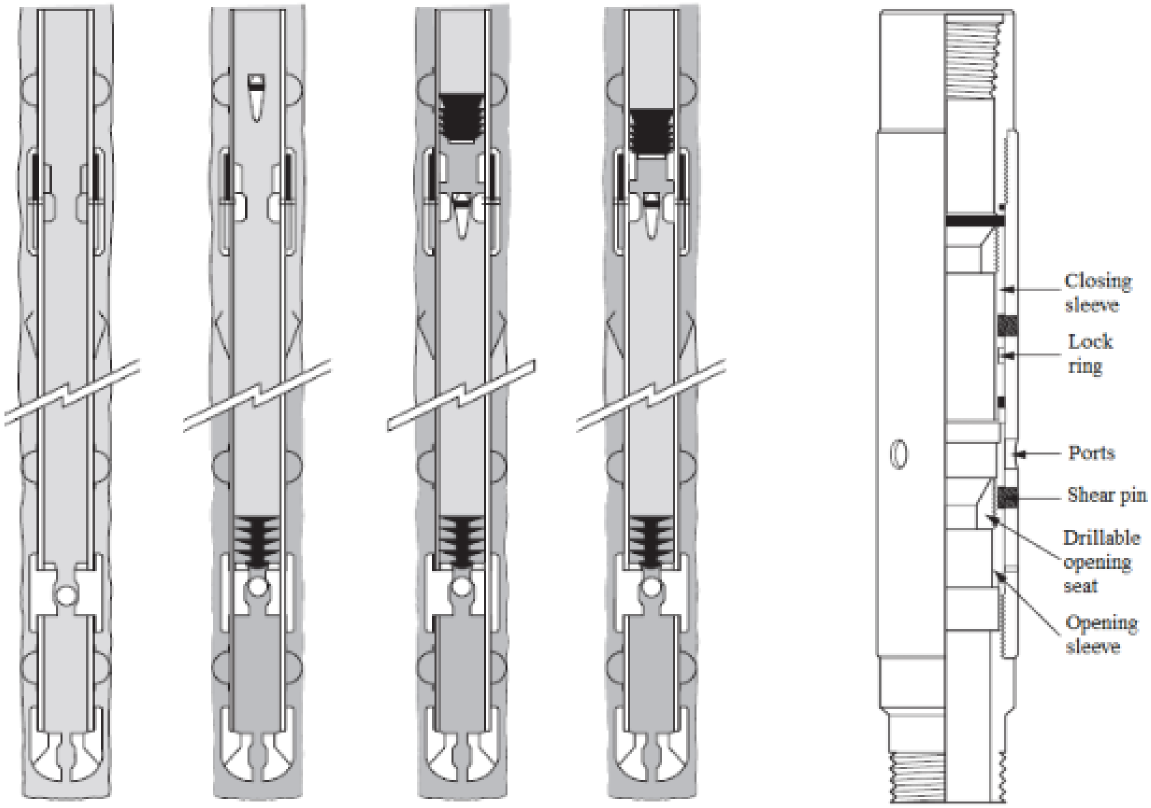

Figure 1: Two-stage cementing (Nelson, 1990).

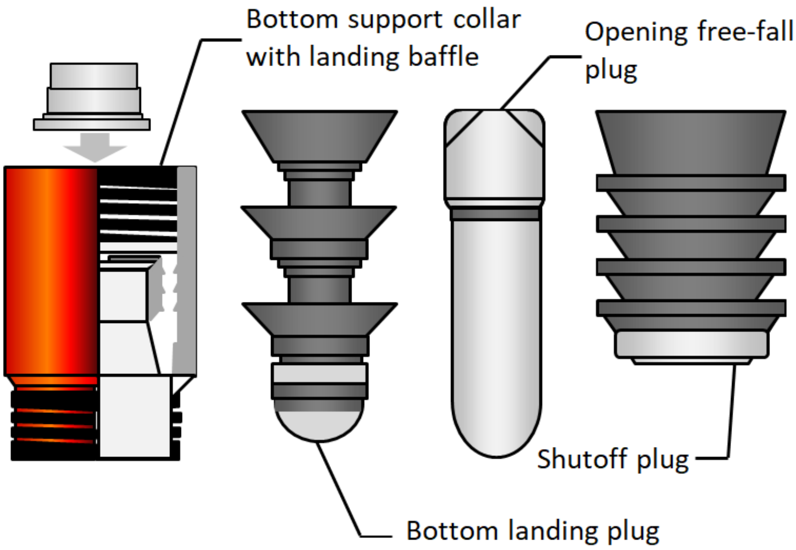

Figure 2: Two-stage cementing accessories (Crook, 2006).

2.3 Thermal Stress and Plastic Deformation

Thermal stress is the stress that occurs in the casing due to changes in temperature. Thermal stress will make casing expand and shrink and also will get failure at a certain temperature condition. One of the problems of the geothermal wells is high temperature. High temperatures will affect casing material and cause a plastic deformation effect. Dexter Pazziuagan (2000) provided input data for the coefficients of thermal expansion and Young's modulus at 100ºF and 650ºF. They are assumed to be equal for all types of casing material (Table 1).

Table 1: Value of thermal expansion and Young's modulus (Pazziuagan, 2000.).

	100°F	650°F
Thermal Expansion	6.67×10^{-6}/°F	9.00×10^{-6}/°F
Young's Modulus	30×10^{6} psi	27.3×10^{6} psi

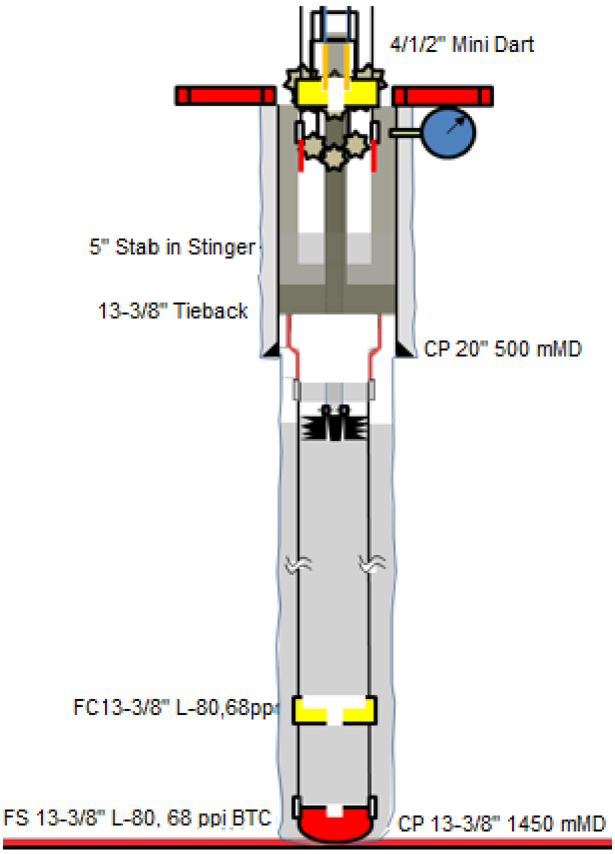

Figure 3: Tie-back cementing (Pertamina Geothermal Energy Team, 2016).

Plastic deformation is the effect of stress on the casing so that the casing will be in an irreversible condition. Thermal stress and plastic deformation are related to yield strength of casing. Yield strength shows the durability of the chasing to maintain its initial shape (not failure) in a state of tension and compression. Value yield strength casing depends on the casing material and will decrease with the increase of temperature. The initial stage of the plastic deformation analysis is to plot the thermal (axial) stress curve and yield strength reduction curve in one chart as shown in Figure 4. Yield strength reduction is a decrease in yield strength casing due to the temperature rise that affect the casing material. The percentages of reduction in yield strength value for this research are given in Table 2. A meeting point between two the curve shows the maximum temperature of elastic deformation of the casing. This maximum temperature is the starting point of the casing to experience the condition of plastic deformation (Berlando and Hernansjah., 2011).

At this maximum temperature, the casing will have a new yield strength value that can be determined using the thermal stress equation (Eq. 3), while percentage of reduction can be seen in Table 2.

Table 2: Percentage of reduction (Δ%) in yield strength values at specific temperatures [1].

T(°F)	Δ%
100	5
200	8.5
300	12.5
400	17
500	22
600	27.5
650	30.5

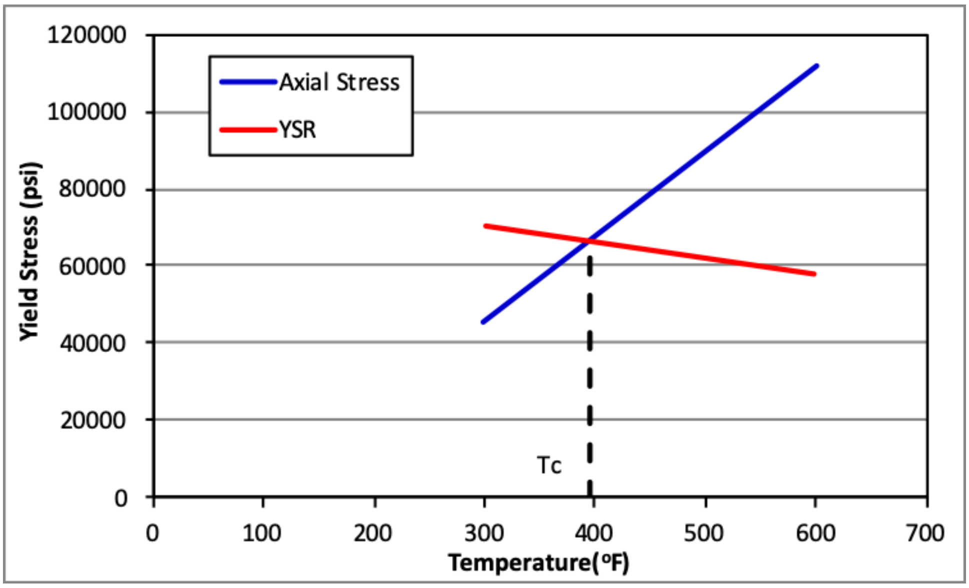

Figure 4: Plots of thermal stress and yield strength reduction.

2.4 Types, functions, and standardization of casing

Casing is a pipe inserted into a borehole. It has several functions that are important both in drilling work (drilling) and in completion work. The functions of the casing include separating and isolating from several formations to minimize drilling problems, to maximize production,to maintain wellbore stability when drilling will be resumed or during well completion operations, and to maintain safety where the pressure control device can be seated. The casing consists of six basic types namely Stove Pipe, Conductor Casing, Surface Casing, Intermediate Casing, Production Casing, and Liner. The American Petroleum Institute (API) has developed standards and specifications for casings which are used in the petroleum and geothermal fields. The length and casing grade based on API rules are given in Tables 3 and 4 (Rabia, 2001).

Table 3: Size of casing length based on API rules.

Range	Length (ft)	Average Length (ft)
1	16-25	22
2	25-34	31
3	Over 34	42

Table 4: Casing grade based on API rules.

Grade	Minimum Yield Strength (psi)	Maximum Yield Strength (psi)	Minimum Tensile Strength (psi)
H40	40	80	60
J55	55	80	70-95
K55	55	80	70-95
N80	80	110	100
L80	80	95	100
C90	90	105	100
C95	95	110	105
P110	110	140	125
Q125	125	150	135

2.5 Geothermal Reservoir

According to Edwards (1982), geothermal reservoirs are divided into four types: hydrothermal reservoir, high pressure reservoir (geopressured reservoir), dry hot rock reservoir (hot dry rock reservoir), and magma reservoir (magma reservoir) (Edwards et al., 1982).. The most utilized reservoir of the four geothermal reservoir types is hydrothermal reservoir (Figure 5). Based on the type of production fluid and the main type of fluid content, the hydrothermal system is divided into two, namely one-phase system and two-phase system. The two phase system can be either water domination system or a steam dominance system. Geothermal systems are often also classified based on fluid enthalpy, namely low, medium and high enthalpy systems. The criteria used as the basis of classification are not in fact based on enthalphy value, but based on temperature since enthalpy is a function of temperature. Table 5 below shows the classification of geothermal systems that is commonly used.

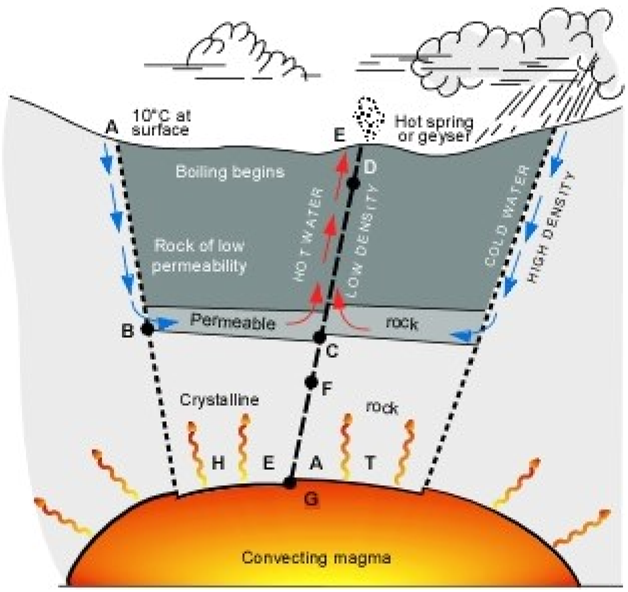

Figure 5: Geothermal system model (White, 1973).

Table 5: Classification of temperature based geothermal systems (Nenny, 1999.).

Classification	Muffer & Cataldi (1978)	Benderiter & Cormy (1990)	Haenel, Rybach & Stegna (1988)	Hochestein (1990)
Low Enthalpy Geothermal System	< 90 °C	< 100 °C	< 150 °C	< 125 °C
Moderate Enthalpy Geothermal System	90 – 150 °C	100 – 200 °C	–	125 – 225 °C
High Enthalpy Geothermal System	> 150 °C	> 200 °C	> 150 °C	> 225 °C

Heat transfer from geothermal wells to its surroundings is not adequately considered because the process that occurs is a single thermal conduction process towards the surrounding formation. However, the heat transfer is more complex because of the heterogeneity in geology, hydrogeology and lithology conditions. One of the limitations of heat transfer to surrounding formations is initial formation temperature (IFT). The process of heat transfer in geothermal wells occurs in tubing, casing, annulus, cement and surrounding formations (Figure 6). Underground systems from geothermal wells consist of production streams, tubing walls, annulus between tubing and casings, casing walls, cement and surrounding formations. The heat transfer in the wellbore is convection which occurs between heat flow and the inside of the production tubing. One the other hand, heat transfer that occurs in the production tubing wall is conduction heat transfer. In addition, heat transfer in annulus is by convection and radiation while, heat transfer on the casing wall and cement is conduction heat transfer (Von and Zhou., 2013.).

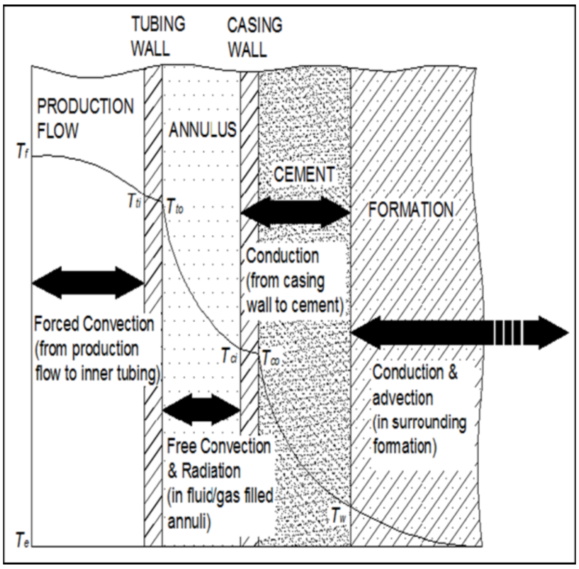

Figure 6: Heat transfer to geothermal production wells (Willhite, 1967).

3. METHODOLOGY

The procedure of this research is indicated by Figure 7. It is started from the identification of problems. The problem identified here is the rise of wellheads, wich is resulted from the casing elongation. The length of the casing elongation is calculated based on the length of casing, temperature, and the coefficient of thermal expansion. In addition, several parameter such as axial thermal stress, yield strength reduction, temperature gradient, temperature at production casing shoe depth, the length of deformed casing and elongation gradient are calculated using Equations 1 to 8. While maximum temperature of elastic casing deformation (critical temperature) and the depth of the lowest casing point which does not undergo deformation (critical depth) are determined using Figure 4 and Figures 8 to 11. The results of the calculations are then analyzed so that a conclusion can be obtained regarding the effective cementing method to minimize the casing elongation in the geothermal well for both vapor-dominated reservoirs and water-dominated reservoirs. The formulas used in the calculations are as follows:

The change in casing length (casing elongation) is defined by

$$\Delta L = L\Delta T\beta \qquad (1)$$

where ΔL, L, ΔT, β are change of casing length (cm), casing length (cm), temperature change (°F), and coefficient of thermal expansion (/°F), respectively.

The axial thermal stress σ_{axial} and yield strength reduction (YSR) are predcited by Equations (2) and (3) (Einstinhard and Hernansjah, 2011):

$$\sigma_{axial} = -224\,\Delta T \qquad (2)$$

$$\text{YSR} = \text{YS} - (\Delta\% \times \text{YS}) \qquad (3)$$

where YS and Δ% are yield strength and percentage reduction of yield strength (given in Table 2), respectively.

Temperature gradient (dT/dZ) and production-casing shoe temperature (T_{pcs}) are defined by Eqs. (4) and (5)

$$\frac{dT}{dZ} = \frac{(T_r - T_s)}{Z_r} \qquad (4)$$

$$T_{pcs} = \left(\frac{dT}{dZ} \times Z_{pcs}\right) + T_s \qquad (5)$$

where T_r, T_s, Z_r and Z_{pcs} are reservoir temperature, surface temperature of steam, reservoir depth, and production casing shoe depth, respectively.

The depth of the lowest casing point which does not undergo deformation (critical depth) is defined as follows

$$Z_c = \frac{T_c - T_s}{dT/dZ} \qquad (6)$$

where T_c is maximum temperature of elastic casing deformation (critical temperature).

The length of deformed casing (L_{dc}) and elongation gradient ($d\varepsilon/dL$) are respectively defined by the following equations

$$L_{dc} = Z_{pcs} - Z_c \qquad (7)$$

$$\frac{d\varepsilon}{dL} = \frac{\varepsilon/L_{dc}}{(T_{pcs} - T_c)} \qquad (8)$$

where ε is elongation measurement of casing.

4. RESULTS AND RESEARCH ANALYSES

Table 5 shows the results of the research analysis. Referring to the results presented in Table 5, it can state that the application of cementing with a two-stage cementing method in the Kamojang Geothermal Field, whose reservoir is predominantly steam, results in casing elongation. This can be seen from the results of actual measurements in K1, K2 and K3 wells, where there is casing elongation (wellhead lifting) of 10 cm, 12 cm and 15 cm, respectively. While K4, K5 and K6 wells which applied the tie-back cementing method do not show wellhead lifting . Logically, there should be an increase in the casing elongation in wells K4, K5 and K6 wells, because the maximum temperature of elastic casing deformation (T_c) is smaller than the steam surface temperature (T_s) and also the deformation occurs along the production casing (Table 5). Tie-back cementing method is able to hold wellhead from lifting due to casing elongation.There are cementing operation differences between two-stage cementing and tie-back cementing. In cementing the two-stage cementing, the casing is completely inserted until a certain depth in a wellbore then two cementing stages are carried out. While, in tie-back cementing method, casing inserted into the drilling well in two stages. Each stage is followed by cementing. If it is associated with the increase in casing length that occurs during production tests, plastic deformation is greater in cementing with the two-stage cementing method compared to the tie-back cementing method.

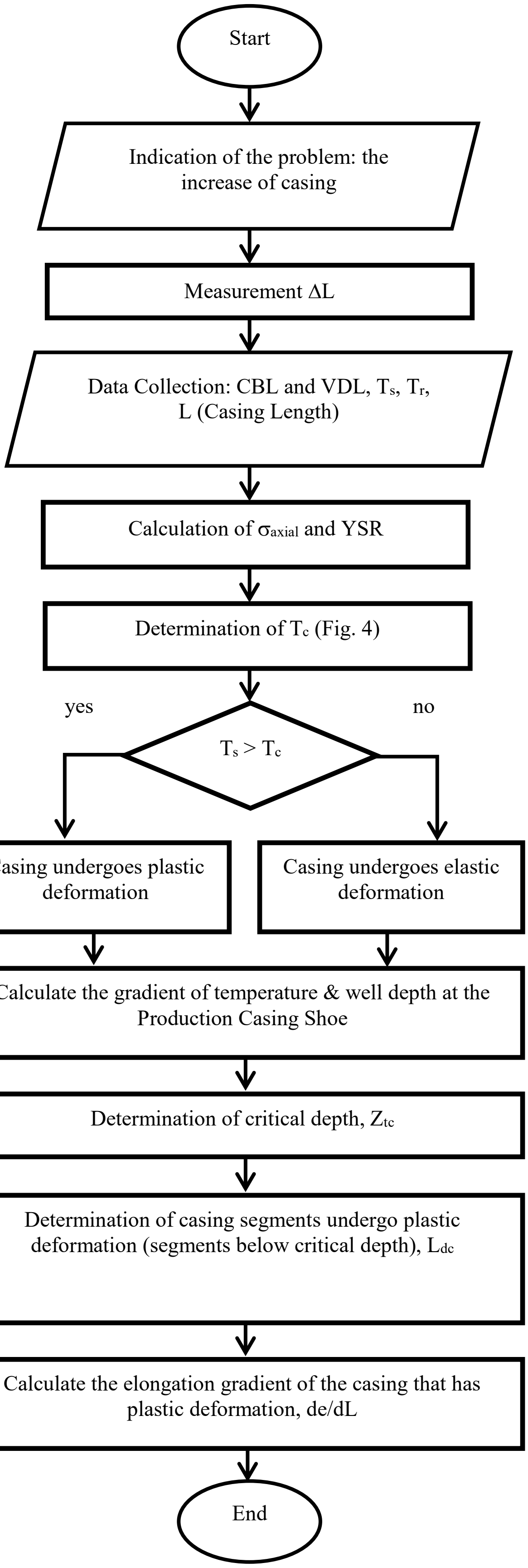

Figure 7: Flow diagram.

Another result obtained from Table 5 is the application of the two-stage cementing method in geothermal wells such as L1, L2, and L3 wells in the Lahendong Geothermal Field, whose reservoir is predominantly water, results in casing elongation as well. The casing elongation based on actual measurements during production tests. The casing elongation of L1, L2 and L3 wells is 13.5 cm, 83 cm, and 11 cm, respectively. While cementing with the tie-back cementing method in L4, L5 and L6 wells does not experience casing elongation (wellhead lifting). As indicated in the table, the length of the casing elongation of the L2 well is much greater than wells 1 and 3. Based on the table, surface steam temperature and production-casing shoe temperature of L2 well are higher than those of L1 and L3 wells. In other word, the temperature gradient of L2 well is lower than that of L1 and L3 wells. While reservoir temperature of L3 well is higher than that of L1 and L2 wells. This means that average temperature along the casing has a greater influence on casing elongation compared to the reservoir temperature. In L3, L4, L5, and L6 wells, the critical depth of the casing is 638.9 m, 545.7 m, 664.7 m, and 806.7 m, respectively. This shows that from the critical depth to the reservoir depth the casings undergo plastic deformation, while above that the casing undergoes elastic deformation. This happens because steam surface temperature (T_s) is smaller than the critical temperature (T_c) of the casing as given in Figures 8, 9, 10, and 11.

Based on Table 6, the relationship among casing elongation, temperature, and length of deformed casing for C95 grade extension and L80 grade is obtained. By using multiple regression analysis the following equation is obtained: $\Delta L_c = -1.555 + 0.002160054\ L - 0{,}000655428\ \Delta T$. The equation is then validated by the measurement results as listed in Table 6. The result differences of the methods are presented in Table 7.

Table 5: Analysis results.

Well	Method	Casing Grade	e (cm)	$T_{ambient}$,°F	T_s(°F)	Z_r (m)	T_r (°F)	Z_{pcs} (m)	T_c (°F)	dT/dZ (°F/m)	T_{pcs} (°F)	Z_c (m)	L_{dc} (m)	de/dL, cm/m/°F
K1	Two-Stage	C95	10	73.6	430.3	1800	458.60	832	423.5	0.015740	443.4	0	832.0	6.051E-4
K2	Two-Stage	C95	15	73.6	459.1	1360	461.37	832	421.5	0.001707	460.5	0	832.0	4.626E-4
K3	Two-Stage	C95	11	73.6	430.7	1485	474.42	671	420.0	0.029479	450.4	0	671.0	5.388E-4
K4	Tie-Back	L80	0	73.6	448.4	2113	459.63	848	375	0.005333	452.9	0	848.0	0
K5	Tie-Back	L80	0	73.6	424.7	1676	452.77	875	375	0.016754	439.4	0	875.0	0
K6	Tie-Back	L80	0	73.6	421.7	1192	450.54	769	375	0.024221	440.3	0	769.0	0
L1	Two-Stage	L80	13.5	72.0	422.2	1478	524.89	832	372	0.069471	480.0	0	831.5	1.504E-4
L2	Two-Stage	L80	83	72.0	469.6	1880	534.25	1008	372	0.034372	504.3	0	1008	6.225E-4
L3	Two-Stage	L80	11	72.0	206.4	1560	603.45	922	369	0.254538	441.1	639.0	283.1	5.394E-4
L4	Tie-Back	L80	0	72.0	223.3	1431	613.27	1100	372	0.272541	523.1	545.7	554.3	0
L5	Tie-Back	L80	0	72.0	206.6	1760	645.91	937	372.5	0.249617	440.5	664.7	272.3	0
L6	Tie-Back	L80	0	72.0	205.7	2136	647.33	1350	372.5	0.206742	484.8	806.7	543.3	0

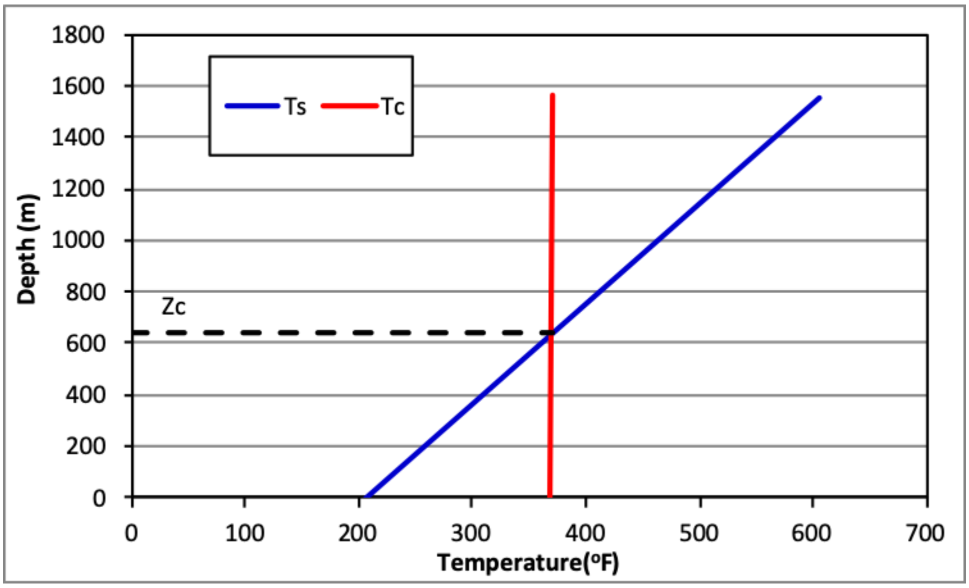

Figure 8: L3 well casing depth experiencing plastic deformation.

Table 6: Relationship between C95 Grade Casing Extension and L80 Grade.

Well Name	Casing Grade	L_{dc} (m)	ΔT (°F)	Casing Elongation (m)
K1	C95	832	13,096	0,1
K2	C95	832	1,421	0,15
K3	C95	671	19,780	0,11
L1	L80	831,5	57,765	0,135
L2	L80	1008	34,647	0,83

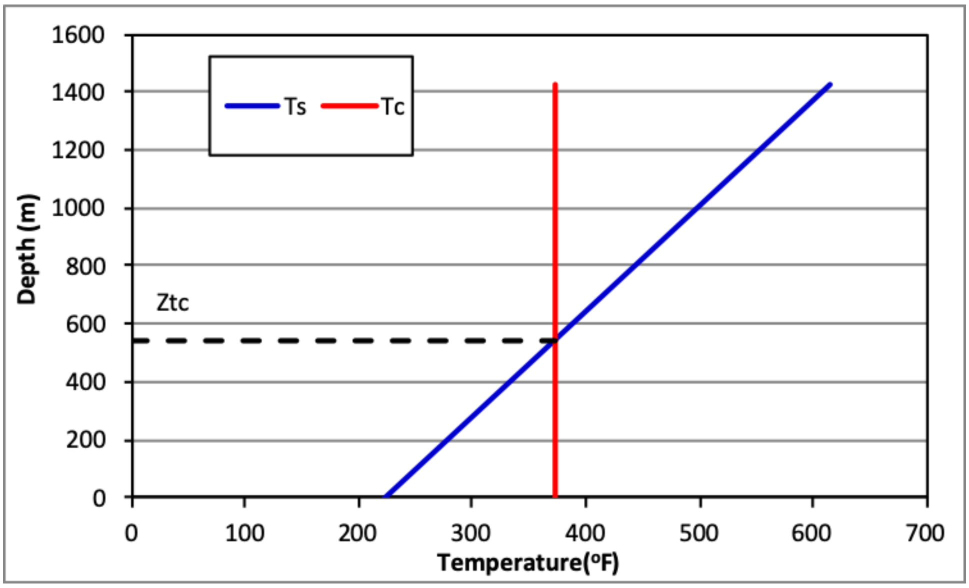

Figure 9: L4 well casing depth experiencing plastic deformation.

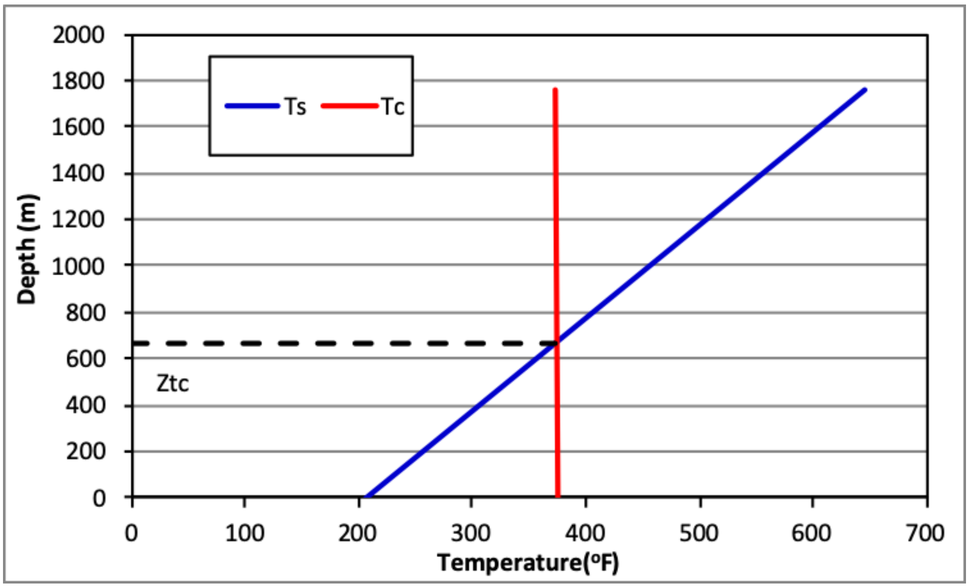

Figure 10: L5 well casing depth experiencing plastic deformation.

Table 7: Relationship between C95 grade casing extension and L80 grade.

Well Name	Casing Grade	L_{dc} (m)	ΔT (°F)	Casing Elongation (m)		
				Measurement	Calculation	Difference
K1	C95	832	13.096	0.1	0.573	0.473
K2	C95	832	1.421	0.15	0.548	0.398
K3	C95	671	19.780	0.11	0.482	0.372
L1	L80	831,5	57.765	0.135	0.669	0.534
L2	L80	1008	34.647	0.83	0.735	0.095

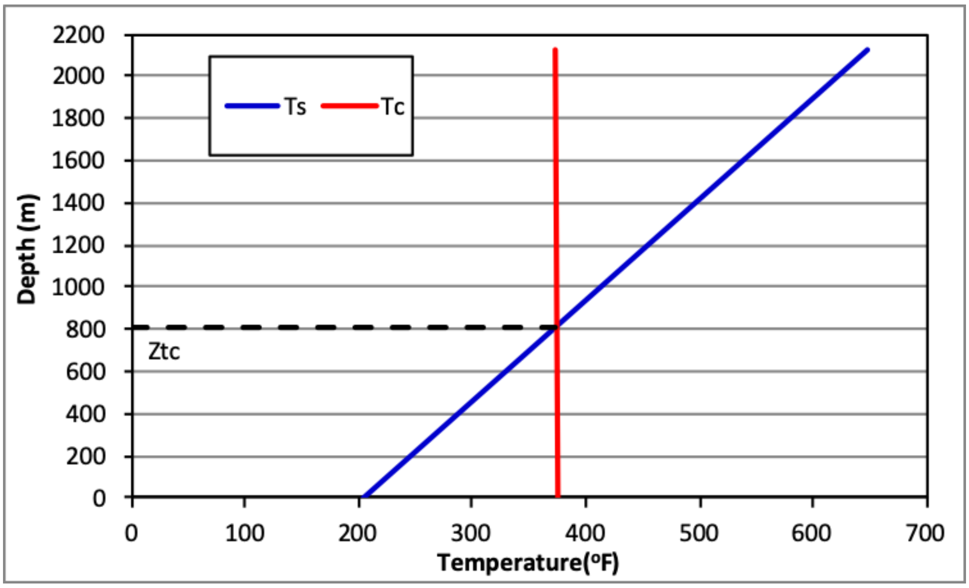

Figure 11: L6 Well casing depth experiencing plastic deformation.

5. CONCLUSIONS

Based on the results and research analyses shown above, several conclusions are made as follows:

1. The application of tie-back cementing methods in geothermal wells in the Kamojang and Lahendong areas effectively preventing wellhead lifting. The application of two-stage cementing results in casing elongation 10-15 cm.
2. The higher the casing grade, the higher the critical temperature (T_c) of the casing. The critical temperature (T_c) of casing with an L80 grade ranges from 369 to 375ºF, while that of casing with the C95 grade ranges from 420 to 423.5ºF.
3. This research can analyze casing segments, which undergo plastic and elastic deformation. Critical depth of L3, L4, L5, and L6 wells range from 545 to 806 m with a critical temperature (T_s) ranges from 369 to 372.5 ºF.
4. The average elongation for the C95 and L80 casing grades is 0.5345 m and 0.8384 m, respectively.

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