Optimization of Steam Pipeline in Geothermal Power Plant Located on Java Island

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Abstract

Optimization of steam pipeline has been conducted using manual calculation and supported by using a simulation of computational fluid dynamic software. Based on the pressure drop analysis, the replacement of T-Junction with Y-Junction would be beneficial as the pressure on the header would be 6.68 kg/cm2, which means that it is above the minimum working pressure requirement. If this scenario is implemented, all of the minimum requirement operating parameter would be fulfilled, where , $P_{operation}$ > 6.5 kg/cm^2, $T_{operation}$ >161^{o}C, and >2750 kJ/kg for enthalpy and it is the best scenario to have minimum energy loss.

As for heat loss, by using manual calculation, the obtained value is 2003.6 kJ/s along the pipeline. The value of heat loss is used as an input of heat flux in the simulation, and therefore the temperature on the header is 164.2 ^{o}C if the pipeline use T-Junction and 165.7 ^{o}C if the pipeline use Y-Junction.

It is must be concered that, although the temperature is above the minimum operating temperature condition, theoritical, with pressure of 6.54 kg/cm^2, it require minimum temperature of superheat 169 ^{o}C which will leads to saturation temperature of 167.8 ^{o}C. It means that a higher temperature is needed to ensure the steam quality. Increasing value of wetness could be hazardous for the turbine that will leads to water droplet and cause erotion.

From the mass balance calculation, there is no significant change of flowrate, where the upstream flowrate from all of the wells is 281.27 ton/hour become 280.259 ton/hour.

Background

Geothermal energy is a form thermal of energy contained underneath the rock and fluid below the surface of the earth. Geothermal energy which is used to generate electricity utilize two physical parameters, enthalpy and mass flow rate from its fluid known as steam, to spin blades of the turbine. Enthalpy and mass flow rate are the main parameters that determine the ammount of energy generated by geothermal power plant, which enthalpy itself is a pressure and temperature dependant parameter.

Steam from the production well is transmitted through pipeline toward the turbine. The problem that commonly occur during the transmission process is energy loss. Energy loss occur in the form of pressure drop, heat loss, and the decrement of flow rate. In order to minimize the energy loss, Pressure drop is caused by various factors, such as friction of the fluid on the inside pipe wall, elevation, elbow,and junction. When major heat loss and pressure drop occur, a low level of steam quality is an unavoidable consequence that leads to several disadvantages, such as a higher risk of water hammer along the pipeline and corrosion on the turbine due to water droplet. All these phenomena would cause to lower output power of the power plant.

Minimimum operating condition was established by PT PLN to ensure the power plant is operating well. In one of the geothermal power plant located on Java Island, it is found that one of its pipelines has an indication of no longer fulfilling the minimum criteria of operating condition, in this case minimum operating pressure and temperature are respectively, $P_{operation}$ > 6.5 kg/cm^2 and $T_{operation}$ >161^{o}C, and >2750 kJ/kg for enthalpy. It is necessary to conducted research related to pressure drop, heat loss, and decrement of steam quality. This research is intended to minimize energy loss by optimizing the pipeline. The output of this research is an engineering recommendation related to production facilities.

Methodology

The first step of conducting this research is to gather information and related data of the actual condition of pipeline. Pressure drop is calculate manualy using Panhandle A equation. This equation is used because in high temperature and superheated condition, the behaviour of steam is relatively simmilar to gas. As consequences, all thermodynamics and hydraulics of gas can be implemented. By calculating pressure using this calculation, pressure as a function of length can be obtained. The general form of the Panhandle equation is expressed in USCS units as follows

$$Q = 435.87E(\frac{T_b}{P_b})^{1.0788}(\frac{P_1^2 - e^s P_2^2}{G^{0.8539}T_f L_e Z})^{0.5394} D^{2.6182}$$

Q = volume flow rate, ft^3/day
E = pipeline efficiency
P_b = base pressure, psia
T_b = base temperature, ^{o}R
P_1 = upstream pressure, psia
P_2 = downstream pressure, psia
G = steam gravity
T_f = average steam flow temperature, oR
L_e = length of pipe segment, m
Z = steam compresibility factor
D = pipe inside diameter, in

Since the equation above cover only the pressure drop due to length of the pipe, elevation, and efficiency of the pipeline, pressure drop due to the effect of elbow and junction are calculated using different equation as shown below

$$h_l = K_l \frac{v^2}{2g}$$

Where each type of the elbow has its own loss coeficient (K_l)

The value of heat loss is calculated through the phenomena of conduction, convection, and radiation that occur along the pipeline. Conduction and convection phenomena occur on the insulation of the pipeline. Heat loss due conduction on the insulation is calculated by using the equation below

$$Q = \frac{2\pi\pi k L}{ln\frac{r_2}{r_1}}(T_{initial} - T_{final})$$

On the other hand, heat loss due to convection on the insulation is calculated by using the equation below

$$Q_2 = \frac{(T_{initial} - T_{final})}{R_h}$$

On the surface of the cladding, radiation occur and could be calculated by using the equation below

$$Q = \sigma\varepsilon(T_{cladding}^4 - T_{ambient}^4)$$

Convection on the surface of the cladding also occur due to interaction of the cladding and wind. This form of heat loss could be calculated by using the equation as follow

$$Q = 1.95(T_{cladding} - T_{ambient})^{1.25}(\frac{v + 0.35}{0.35})^{0.5}$$

The total heat loss is obtained by summing the heat loss due to conduction, convection, and radiaton. This value is useful to run the simulation by using computational fluid dynamic software to give heat flux on the wall of the pipe. For instance, by using the thermodynamics tabel, we can obtain enthalpy of the steam. To have the value of he total entahlpy of the steam the equaation below could be used

$$\dot{H} = \dot{m}\, h$$

And the change of total enthalpy after the total heat loss is calculated, can be obtained by using the equation below

$$\dot{H}' = \dot{H} - Q_{total}$$

By having these there parameters, specific enthalpy can be obtained by using the equation below

$$h' = \frac{\dot{H}'}{\dot{m}}$$

and it can be used to have a comparison between the value of specific enthalpy by using equation as describe below and by calculating the pressure and temperature on the header.

The final step is to calculate the mass balance to figure out the change of the steam flowrate. The principle of mass balance calculation described by the equation below

$$m_{upstream} = \eta_n\{(1 - \eta_{(n-1)})m_c^{(2n-3)} + m_c^{2(n-1)}\}$$

Due to its limitation, these manual calculations are supported by computer modeling using computational fluid dynamic software to study not only the pressure drop and temperature profile but also steam flow pattern.

Operational Data

Table 1. Actual operating condition related to calculate the pressure drop

Well Head	Diameter (inch)	Well Head Pressure (kg/cm^2)	Pipe Pressure (kg/cm^2)	Temperature (^oC)	Debit (ton/hour)
1	24	9,8	9,8	185	58,96
2	16	10,2	7,6	174	26,22
3	12	12,7	7,4	172	27,15
4	10	9,6	7,6	172	11,37
5	14	8,2	7	170	13,74
6	14	13	8	180	49,06
7	14	9,5	7,6	171	18,2
8	10	9,6	9,1	178	36,05
9	24	9,2	7,5	180	14,36
10	10	10,5	7,4	175	26,16

Tabel 2. Actual condition related to calculate heat loss

Wind Velocity (m/s)	0,2
Air Heat Transfer Coeficient (W/m^2K)	4237,83
Insulation Heat Transfer Coeficient (W/m^2K)	35,301
Konstanta Stefan Boltzman (W/m^2K)	5,67E-08
Ambient Temperature (K)	292
Insulation Actual Temperature (K)	296
Steam Temperature (K)	448
Segment of 18 " Pipe (m)	1197,64
Segment of 24 " Pipe (m)	638,748
Segment of 32 " Pipe (m)	159,687
Segment of 40 " Pipe (m)	2212,805
Insulation	Calcium Silicate
Thickness (m)	0,065

Result and Disscussion

There are 10 well head that connected to the pipeline as production well, where each well has its own pressure and temperature. The main pipeline its self consist of 4 segment, in which has its own pipe diameter and length as shown on table 2. Steam from all of the production wells is transmitted to header. In order to know the pressure on the header, pressure is calculated by using Panhandle A. Based on the calculation using Panhandle A equation with the assumption of steam velocity is 30 m/s, pressure profile as a function of length is as below

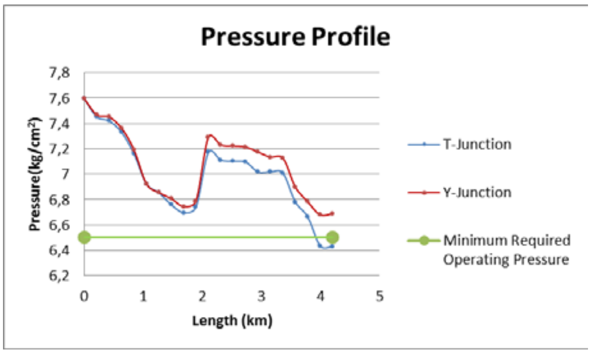

Figure 1. Pressure as a function of length by manual calculation (comparison of pipeline using T-Junction and Y-Junction).

This figure shows us that the pressure is dropping as the length increase. But in the length between 2 and 2.2 km, for pipeline using T-Junction the pressure slightly increase to 7.1 kg/cm^2. The pressure increment occur because in this length, well 9 and 10 are located. It has significant pressure boost because well 9 and 10 have the biggest pressure compared to other wells. The other 8 wells which is located between 0 – 2 Km dont show a significant boost to the pressure profile because they only have small ammount of pressure difference between them. The most important value is the value at the downstream of pipe, refered as header. The pressure on the header is 6.39 kg/cm^2 , which is below the minimum operating condition requirement, 6.5 kg/cm^2. The result of pressure on the header using Panhandle A equation is relatively the same as direct measurement on geothermal field that show the value of 6.4 kg/cm^2.

Figure2. Pressure profile using computational fluid dynamic software

The manual calculation is supported by the model that developed by using computational fluid dynamic software that shows the pressure on the header is in the value of 6.18 atm or 6.38 kg/cm^2 when using T-Junction. One of the possible scenario to minimize the pressure drop is to replace T-Junction with Y-Junction. Pressure profile after replacing T-Junction with Y-Junction is as follow

Based on the figure 1 above, the pressure is relatively higher along the pipeline compared to pressure profile while still using T-Junction. The most important value after replacing the T-Junction is that the pressure on the header is 6.68 kg/cm^2. It means that the pressure on the header is above the meets the minimum operating pressure condition. Based on the scenario above, Y-Junction will give a higher pressure than J-Junction.

Y-Junction would also give a less turbulence flow pattern of the fluid, as shown on figure 3 below.

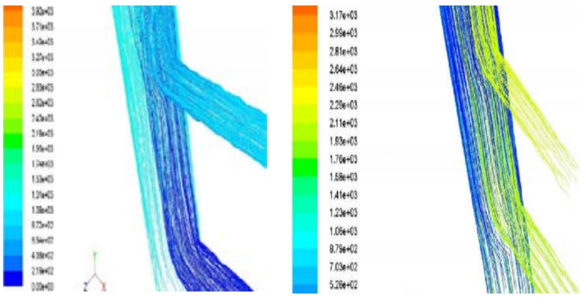

Figure 3. Flow pattern using T-Junction (left) and Y-Junction (right).

Y-Junction would also give a less turbulence flow pattern of the fluid, as shown on figure 3 above. Y-Junction gives a higher pressure due to the smoother flow pattern that cause less turbulence.

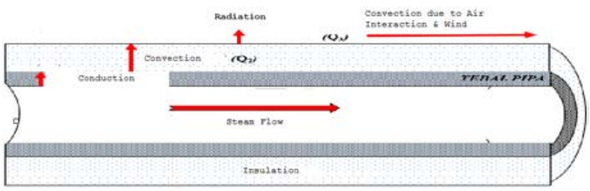

Figure 4. Conduction, convection, and radiation illustration in pipeline

The terms of heat flux due to conduction, convection, and radiation is used to calculate the heat loss along the pipeline. It is assumed that the pressure is constant along the pipeline and the insulation along the pipeline is still good and has no physical defect. With T = 171.6 ^{o}C, mass flow = 280.259 ton/hour, and P = 0.65 Mpa, where T and P is assumed to be constant, using thermodynamics tabel we have enthalpy h = 2776.37 kj/kg and total enthalpy of 216917.78 kj/s. The total heat loss due to convection, conduction, and radiation is 2003.6 kJ/s. Therefore, the change of the total enthalpy is 214134.028 kJ/s and specific enthapy of 2750,58 kJ/kg. This approximation shows that the enthalpy value is slightly above the minimum requirement although the temperature on the header cannot be calculate using this calculation. From the pressure drop information and heat loss calculation, it can be assured that the existing temperature on the header is still > 161 ^{o}C, which mean that the temperature still above the minimum temperature requirement, because the enthalpy and pressure calculation fulfill the minimum requirement. On the other hand, based on the theory of thermodynamics, with pressure of 6.54 kg/cm^2, it requires minimum superheat temperature 169 ^{o}C which will leads to saturation temperature of 167.8 ^{o}C. It means that in the existing condition the steam is not completely dry steam.

From the mass balance calculation, the assumption which used are there are 40 steam trap with 99,99 % of the mass flow rate is steam and 90 % of the condensate mass would come out. There is no significant change of flowrate due to the small ammount of flow rate change, with change from 281.27 ton/hour to 280.25 ton/hour. Therefore, there is no influence of the flowrate change to pressure drop profile, temperature drop, and saturation temperature.

Conclusion

Based on the calculation and the simulation that has been conduted, the replacement of T-Junction with Y-Junction will give a higher pressure on the header that meet the minimum operating condition. The result of manual calculation and simulation is relatively the same, where pressure of the header is 6.4 kg/cm^2 using T-Junction on computational fluid dynamic software and 6.42 kg/cm^2 by manual calculation using Panhandle A equation.

Heat loss along the pipeline is 2003.6 kJ/s by manual calculation. Manual calculation could give a brief view of heat loss. But to its limitation, the temperature profile along the pipeline is hard to be obtained. Using the simulation, a more realistic temperature profile is obtained. By using the simulation, temperature on the header is 164.2 ^{o}C if the pipeline use T-Junction and 165.7 ^{o}C if the pipeline use Y-Junction.

Theoriticaly, with pressure of 6.54 kg/cm^2, it require minimum temperature of superheat 169 ^{o}C which will leads to saturation temperature of 167.8 ^{o}C. It means that a higher temperature is needed to ensure the steam is completely dry. Increasing value of wetness could be hazardous for the turbine that will leads to water droplet and cause erotion.

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