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Pipeline Debottlenecking Project to Maintain Steam Supply of Geothermal Power Plant Unit 1-4 at PGE Lahendong

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ABSTRACT

The Pertamina Geothermal Energy (PGE) operates geothermal steam fields in Lahendong, North Sulawesi, Indonesia. It supplies steam to PLN's GPP Unit 1, 2, 3, and 4 from 6 production clusters, which are clusters 4, 13, 13B, 24, 5, and 37. Steam from clusters 4 and 13 supply the GPP Unit 1&2, while steam from clusters 13B, 24, 5 and 37 supply the GPP Unit 3&4.

By 2017, the steam production from LHD-23 (cluster 5) and LHD-28 (cluster 24) decline after well remedial. Previously, the steam supply mass flow for Unit 3&4 from LHD-23 was 212 ton/h and LHD-28 was 184 ton/h. However, after remedial, the flow reduced to 20 ton/h for LHD-23 and 109 ton/h for LHD-28. The steam supply problem also occurs in the steam pipeline due to a bottleneck from cluster 13B (LHD-48) which has only 14" NPS thus the maximum steam flow limited to 90 ton/h. In contrast, there are three high potential production wells in the cluster (approximately total steam flow of 300 ton/h).

This has led to an alternative solution to fulfill the steam supply for unit 3&4 by developing a new independent pipeline to maximize high potential wells in cluster 13B (LHD-47, 48 and 49). However, the NCG of LHD-47 is higher than the other two wells, so we did a simulation to mix the fluids from those three wells and designed the pipeline interconnection between the new and existing lines. The new pipeline design is 24" NPS and was built in parallel with the existing pipeline. This pipeline accommodates the steam produced from three wells at cluster 13B and the NCG value meets the steam supply requirements of GPP Unit 3&4.

1. INTRODUCTION

Pertamina Geothermal Energy (PGE) operates geothermal steam fields in Lahendong, North Sulawesi. PGE operates the steam field to supply steam for GPP units 1-4 which are operated by PLN. PGE should deliver the steam to PLN's turbine to generate a total of 80 MW for units 1-4. There are some conditions that PGE should meet for the stream quality, such as the composition of non-condensable gas (NCG), Total Dissolve Solid (TDS), dryness, and the mass flow of the steam.

2. BACKGROUND

Steam to GPP unit 1-4 is supplied from six production clusters, which are clusters 4, 13, 13B, 24, 5, and 37. GPP units 1&2 are supplied from clusters 4 and 13, while the GPP units 3&4 are supplied from clusters 5, 13B and 24. Due to the natural production decline from the wells in clusters 5, and 24, and a remedial on the wells, the steam supply for GPP became limited. Thus PGE became at risk of handed fine (DoP) from PLN if it's failed to meet the requirement of the amount of electricity generated by the GPP unit 3&4. Steam production from clusters 5 and 24 before and after remedial is shown in the table below.

Table 2.1 Steam Flow Before and After Remedial

Well	Steam flow before remedial	Steam flow after remedial
LHD-23 (cluster 5)	209.16 t/h	21.91 t/h
LHD-28 (cluster 24)	143.64 t/h	123.64 t/h

To fulfill the steam demand, PGE Lahendong needs to optimize other monitoring wells or drill several new wells. There are three wells in cluster 13B that have not been optimized, which are LHD-47, LHD-48, and LHD-49. Production test data in 2017 is shown in table 2.2.

Previously, the steam supply from the cluster 13B only supplied the LHD-48 with mass flow approximately 100 t/h, which is above production test data in 2017. The other two wells are estimated to have more potential steam production. In 2018, PGE conducted a production test for LHD-47 and LHD-49 to get the new data. Thus, PGE does not have to drill a new well but only need to optimize the production from these wells. The new production test data is shown in table 2.3.

Table 2.2 Production Test Data 2017

Wells	P separator (bar g)	Flow rate (t/h)			Dryness (%)
		Steam	Brine	Total	
LHD-47	10	67.91	4.21	71.12	94.16
LHD-48	10	49.21	2.97	52.18	94.31
LHD-49	10	24.32	0.37	24.69	98.50
Total steam flow (t/h)		**141.44**			

Table 2.3 Production Test Data 2019

Wells	Wellhead Pressure (bar g)	Flow rate (t/h)			Dryness (%)
		Steam	Brine	Total	
LHD-47	8	130	7	137	94.89
LHD-48	25	115	14.03	129.1	89.13
LHD-49	10.9	94.5	121	215.5	43.85
Total steam flow (t/h)		**339.5**			

Steam produced from LHD-47, LHD-48, and LHD-49 wells can be used to supply units 3&4 and also can be used to supply steam units 1&2. At present, there are interconnection pipelines that connect clusters 13 and 24, but the existing interconnection pipeline is only designed for a flow rate of 90 t/h. Therefore, in order to fully utilize the full potential of steam produced by LHD-47, LHD-48 and LHD-49 wells, the new production facilities will be built from cluster 13 to cluster 5. The design plan for the new facilities is interconnection pipeline connecting the cluster 13 and cluster 5, which has a length of ± 3000 m.

Figure 2.1 Layout Plan

From figure 2.1 above, there is an existing pipeline shown in a yellow line which only has 14" pipeline from cluster 13B to cluster 24 and connect to an existing 24" pipeline from cluster 24 to cluster 5. These connections limit the steam supply from the production cluster 13B. Thus, the production of the wells cannot be optimized. The red line is the proposed new pipeline to solve the problem regarding the lack of steam supply for units 3&4.

3. PROBLEM-SOLVING

This problem has led to an alternative solution to fulfill the steam supply for units 3&4 by developing a new independent pipeline to maximize a high potential in production wells in cluster 13B (LHD-47, LHD-48 and LHD-49). However, the NCG content of LHD-47 is higher than the other two wells. Thus the simulation was to mix the fluids from those three wells and design the pipeline interconnecting between the new and existing lines. The new pipeline design is 24" NPS and was built in parallel with the existing pipeline.

3.1 Simulation

From the new production test data, the PGE did simulation using Aspen HYSYS to get the process design as shown below.

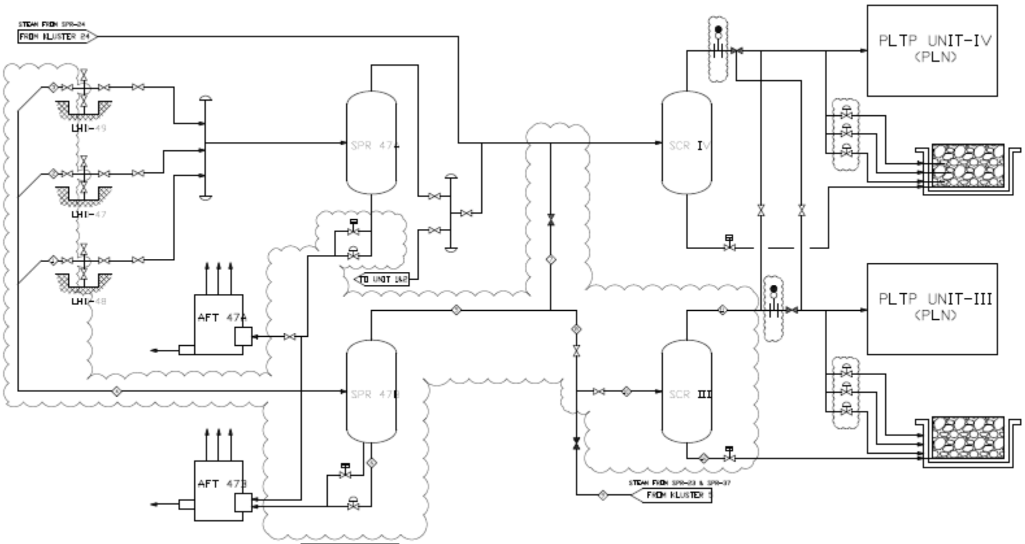

Figure 3.1 Process Flow Diagram

From simulation, heat, and mass balance for this project obtained and shown in table 3.1 below.

Table 3.1 Heat & Mass Balance

STREAM		1	2	3	4	5	6	7	8	9	10	11	12
VAPOR FRACTION	-	0.6	0.8	0.8	0.71	1	0	1	1	1	1	1	0
PRESSURE	bar	13	13	15	12.93	12.92	12.92	12.92	12.92	10.8	8.513	8.057	8.057
TEMPERATURE	°C	191.5	191.7	198.5	191.4	191.3	191.3	191.3	191.3	183.2	175.2	175.2	175.2
ENTHALPY	kJ/kg	1671.25	2228.32	2231.9	2785.24	2785.24	813.42	2785.21	2785.21	2779	2769.95	2767.75	722.23
MASS FLOW RATE	Ton/Hr	150	150	20	320	226.6	93.35	0	0	40	226.6	226.6	0
DENSITY	kg/m3	10.79	8.106	9.276	9.119	6.473	863.1	6.473	6.473	5.459	4.336	4.336	0
NPS	inch	18	18	16	24	24	10	14	14	30	30	30	6
VELOCITY (LIQUID)	m/s	0.1548	0.0073	0.0098	0.1159	–	0.6484	–	–	–	–	–	–
VELOCITY (VAPOUR)	m/s	29.26	39.15	4.53	37.51	55.88	–	55.88	55.88	4.902	41.17	41.19	–
H2O	% mass	99.1	99.7	99.5	99.2	98.9	100	98.9	98.9	99	98.9	98.9	100
NCG	% mass	5.5	0.3	0.5	0.8	1.1	0	1.1	1.1	1	1.1	1.1	0

Two-phase fluid from each well is throttled at a throttle valve to set the steam separator operating pressure 13 bar g. The set pressure at the separator is assumed in order to gain 7 bar for turbine inlet pressure at the downstream. Assuming the new pipeline has vertical and horizontal loops after the separator with a length of approximately 3000 m, the calculated steam velocity is 41.17 m/s and the pressure drop from cluster 13B to cluster 5 is 5.69 bar.

3.2 Determining the Pipe Size

To determine the pipe sizing, the calculation data from fluid velocity (v) with the following assumptions:

- Total steam flow rate 226 t/h;
- Separator pressure 12.92 bar and temperature 191.3 ^{0}C;

Next, to calculate fluid velocity by using the assumption pipe size is 24" SCH 40 and fluid physical properties as below.

Table 3.2 Wall Thickness Calculation

P outlet Separator (Bar g)	Temp (°C)	Viscosity (cP)	Volume (m^3/kg)	ρ (kg/m^3)	Pipe Diameter (inch)	SCH	Thk (mm)	Do (m)	Di (m)
12.92	191.3	1.196e-002	0.1545	6.473	24	40	17.48	0.6096	0.5746

Calculate the pipe area with this equation :

$$Ai = 1/4 \ \text{x} \ \pi \ \text{x} \ di^2$$
$$= 1/4 \ \text{x} \ 3.14 \ \text{x} \ (0.5746)^2$$
$$= 0.2594 \ m^2$$

Calculate the velocity of the fluid in the pipe with the fluid velocity for steam flow 300 t/h :

$$v = \dot{m}/(Ai \ \text{x} \ \rho g) = (226 \ \text{x} \ 1000)/(0.2594 \ \text{x} \ 6.473 \ \text{x} \ 3600) = 37.385 \ m/s$$

From the calculation of the fluid velocity in the pipeline with size 24" SCH 40, the steam rate at operating conditions meets the one phase minimum fluid velocity condition limitation based on the "***Recommended Fluid Velocities for steam through Pipes (Piping Handbook 7th)***" which is 31 m/s < x < 51 m/s (saturated steam).

The maximum steam flow for 51 m/s is :

$$\dot{m} = v \ \text{x} \ Ai \ \text{X} \ \rho g = 51 \ \text{x} \ 0.2594 \ \text{x} \ 6.473 \ \text{x} \ 3.6 = 308.28 \ t/h$$

Furthermore, to make sure if the 24" SCH 40 pipe is still within the thickness requirement limit of **ASME B31.1 Power Piping**, we can calculate the thickness with the operating pressure, which is 12.92 bar. The pressure is multiplied by 1.4 to calculate the pipe wall thickness, then the pressure design of the pipe is 18.09 bar with the value of mill tolerance for API 5L pipe is 12.5% of the minimum thickness of the pipe.

$$t_m = \frac{\left[\frac{P.D_o}{2(SE + Py)} + CA\right]}{(1 - MT/100)}$$

Note:
- tm = minimum pipe wall thickness needed [in]
- P = design pressure = 1,4 x Operating Pressure
- Do = nominal outside diameter
- S = maximum allowable stress
- E = connection efficiency
- y = material coefficient
- CA = corrosion allowance
- MT = mill tolerance

Table 3.3 Wall Thickness Calculation

PIPE DIAMETER (Inch)	Design Pressure (Bar)	Design Pressure (Psi)	Temp (°C)	CA (mm)	CA (in)	S (Psi)	E	Y
24	18.09	262.37	191.3	3	0.118	17100	0.85	0.4

Table 3.4 Material coefficient (ASME B31.1)

Table 104.1.2(A) Values of *y*

Material	Temperature, °F (°C)							
	900 (482) and Below	950 (510)	1,000 (538)	1,050 (566)	1,100 (593)	1,150 (621)	1,200 (649)	1,250 (677) and Above
Ferritic steels	0.4	0.5	0.7	0.7	0.7	0.7	0.7	0.7
Austenitic steels	0.4	0.4	0.4	0.4	0.5	0.7	0.7	0.7
Nickel alloys UNS Nos. N06617, N08800, N08810, N08825	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.7

Table 3.5 Joint efficiency (ASME B31.1)

Table A-1 Carbon Steel (Cont'd)

Spec. No.	Grade	Type or Class	Nominal Composition	P-No.	Notes	Specified Minimum Tensile, ksi	Specified Minimum Yield, ksi	*E* or *F*
Electric Resistance Welded Pipe and Tube (Cont'd)								
API 5L	A25	I & II	C	1	(1)(14)	45	25	0.85
	A	...	C	1	(1)(2)(14)	48	30	0.85
	B	...	C Mn	1	(1)(2)(14)	60	35	0.85
A 587	...	...	C	1	(1)(2)	48	30	0.85

$$tm = \frac{PDo}{2(SE+Py)} + CA$$

$$tm = \frac{262.37 \text{ x } 24}{2(17100 \text{ x } 0.85 + 262.37 \text{ x } 0.4)} + 0.118$$

$$tm = 0.2158 + 0.118 = 0.3338 \text{ in} = 8.4785 \text{ mm}$$

$$t_{nom} = \frac{tm}{1-0.125} = \frac{8.4785}{0.875} = 9.6897 \text{ mm}$$

From the calculation above, the minimum thickness required based on the **ASME B31.1** is 9.6897 mm. With the calculated thickness, the assumption of using pipe size 24" SCH 40 is allowed because thickness for pipe 24" SCH 40 is 17.48 mm.

Next, to determine the rating of flange we use in the pipeline, refers to **ASME 16.5 Piping Flange and Flange Fitting Standards**. The material used for the flange is **ASTM A105**. The design pressure of 13.9 bar is equal to 262.37 Psi with a temperature of 191.3 °C is equal to 376.34 °F.

Table 3.6 List of Material Specification ASME B16.5

(a) TABLE 1A LIST OF MATERIAL SPECIFICATIONS

Material Group	Nominal Designation	Pressure–Temperature Rating Table	Applicable ASTM Specifications[1] Forgings	Castings	Plates
1.1	C–Si C–Mn–Si C–Mn–Si–V	2-1.1	A 105 A 350 Gr. LF2 A 350 Gr. LF6 Cl. 1	A 216 Gr. WCB	A 515 Gr. 70 A 516 Gr. 70 A 537 Cl. 1
1.2	C–Mn–Si C–Mn–Si–V 2½Ni 3½Ni	2-1.2	A 350 Gr. LF6 Cl. 2 A 350 Gr. LF3	A 216 Gr. WCC A 352 Gr. LCC A 352 Gr. LC2 A 352 Gr. LC3	A 203 Gr. B A 203 Gr. E
1.3	C–Si C–Mn–Si 2½Ni 3½Ni	2-1.3		A 352 Gr. LCB	A 515 Gr. 65 A 516 Gr. 65 A 203 Gr. A A 203 Gr. D

Table 3.7 Pressure & Temperature Rating ASME B16.5

TABLE 2-1.1 RATINGS FOR GROUP 1.1 MATERIALS

Nominal Designation	Forgings	Castings	Plates
C–Si	A 105 (1)	A 216 Gr. WCB (1)	A 515 Gr. 70 (1)
C–Mn–Si	A 350 Gr. LF2 (1)		A 516 Gr. 70 (1)(2) A 537 Cl. 1 (3)
C–Mn–Si–V	A 350 Gr. LF6 Cl. 1 (4)		

WORKING PRESSURES BY CLASSES, psig

Class Temp., °F	150	300	400	600	900	1500	2500
–20 to 100	285	740	990	1480	2220	3705	6170
200	260	675	900	1350	2025	3375	5625
300	230	655	875	1315	1970	3280	5470
400	200	635	845	1270	1900	3170	5280
500	170	600	800	1200	1795	2995	4990
600	140	550	730	1095	1640	2735	4560

To determine the flange rating according to **ASME 16.5** above, the flange rating used for this new pipeline is flange with rating #300.

4. CONCLUSION

To solve the lack of steam supply problem for units 3&4, we need to build a new independent pipeline to deliver steam from cluster 13B to cluster 5. The size and thickness of the pipe used for a new pipeline which will supply steam approximately 300 t/h is pipe 24" SCH 40 and the flange rating used rating #300. The new pipeline will fulfill the steam demand from GPP unit 3-4 owned by PLN, thus preventing PGE from DoP fine by PLN. The pipeline should be connecting between units 1&2 and units 3&4, so PGE can maintain the steam supply for units 1-4 using this **Pipeline Debottlenecking Project**.

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