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PROPOSE MODEL OF GATHERING SYSTEM OPTIMIZATION ON UNIT-G4 GEOTHERMAL POWER PLANT

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ABSTRACT

The nature of geothermal heat is a decrease in pressure, temperature, and steam flow. Based on Exaquantum observation data, one of the geothermal power plants in West Java experienced a reduced steam supply for the Geothermal Power Plant (GPP) Unit-G4, which decreased production capacity. This study aims to analyze the existing conditions and make models and simulations on the optimum Steam Gathering System (SGS) at GPP Unit-G4. The stages in this research are modeling using Aspen Hysys software on the existing conditions of SGS as a basis for finding alternative optimum solutions. The second stage was to design a model and simulation by interconnecting the K-21X production well with the PL-X05 production. Furthermore, the simulation of adding steam by 25%, 50%, 75%, and 100% in the interconnection process was carried out. Existing steam gathering modeling and simulation results show that the deviation between actual steam field parameters is ≤ 2% (can be used as a simulation baseline). The modeling and simulation results of adding steam from the K-21X production well to the PL-X05 production well are optimum at 100% and 75% steam addition. From the simulation, adding 25% and 50% steam cannot be applied because the net power does not reach the unit rate capacity of 60.856 MW.

Keywords: Geothermal; Pipeline; Simulation and Modelling; Steam Gathering System.

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INTRODUCTION

The large potential of Indonesia's geothermal energy, estimated at 23.7 GW, encourages the government to establish geothermal working areas (WKP) & preliminary survey and exploration assignment areas (WPSPE) that are ready to be developed [1]. So, it needs to be seriously developed aspects of geothermal resources (speculative and hypothetical) into reserves, and maintain the capacity already installed. Naturally, the geothermal characteristics that have been utilized tend to decline and require drilling new wells or engineering surface facilities to obtain make-up wells to maintain production [2].

The PLTP was commercialized in 2008 with a steam supply using eight production wells and can produce 60,854 MW Net, whose electricity is sold by one buyer to PLN through a Power Purchase Agreement (PJBL) contract [3]. Along with the operation in 2013, there was an additional well, K-3G; in 2015, there were two additional production wells, K-2G and K-1G. Until now, there has been a decrease in capacity of 5 MWe or equivalent to 40 tonnes of steam, based on the engineering documents of PLTP Unit-G1, 2, and 3 have steam reserves of 5 MWe so that they can be used optimally overcome the above problems, an alternative solution is needed to optimize generation so that it is maintained by the initial design, following up on the above issues, the author plans to model the existing conditions of SGS and interconnection with the K-21X well.

The nature of geothermal heat, namely a decrease in pressure, temperature, and steam flow, is very common in all geothermal work areas. This also occurs in one of the GPPs in West Java; from the results of the author's observations based on data from Exaquantum on the Distribute Control System (DCS), there was a decrease in steam supply for GPP Unit-G4 where Net generation reached a minimum load of 54.7 MW per month from March to September 2023, if allowed to continue it will potentially be exposed to Delivery Or Pay (DOP) while the Unit Rated Capacity (URC) results are 60. 854 MW as the basis for the DOP and Take Or Pay (TOP) determination contract between the parties (Power Purchase Agreement PLTP Unit-G4).

As in any other business, geothermal energy trading activities are also based on a contractual agreement that binds the developer as the energy seller and PLN as the buyer. Generally, this contract is known as the Power Purchase Agreement and Power Purchase Agreement. The legal provisions governing the power purchase agreement between PT PLN (Persero) and the developer are further regulated specifically in the Regulation of the Minister of Energy and Mineral Resources Number 10 of 2017 concerning the Principles of the Power Purchase Agreement, in the Power Purchase Agreement it is regulated regarding the rights and obligations of the developer and PLN, including the developer is obliged to provide energy and PLN is obliged to buy a certain amount of energy that the developer has provided.

We need to consider that the Geothermal Power Plant (GPP) has a turbine inlet pressure of 11 bara and a temperature of 183 degrees centigrade, in contrast to other GPPs. GPP Unit-G4 has a turbine inlet pressure of 6.5 bar and a temperature of 170 degrees Celsius, and GPP Units-G1, 2, and 3 have a Manifold pressure of 7.35 bar, making it difficult to interconnect the nearest Steam Gathering System. On the power plant header side, and the Drilling Campaign Program is still far away, the estimated potential loss per year is 45,552,000 KWh / year, or equivalent to 4,673,635 USD per year.

The previous research by Chairi modified the flow of the header pipe network and installed PCV in parallel to reduce the pressure drop in the header pipe network so that the decrease in pressure drop will increase the pressure in the header, with an increase in pressure in the header it will be possible to adjust the Well Head Pressure (WHP) if the Well Head Pressure drops then the flow will increase from each well[4-5]. In addition, Nugroho Ady's research optimized production capacity by modelling and simulating a new borehole planned for 2X20 MWe, after modelling and simulation were obtained at 57.02 MWe[6]. Purwono's research entitled ‘Comparison and Selection of A Steam Gathering System in Ulubelu Geothermal Project, North Sumatra, Indonesia’ shows that the hybrid pipe installation system provides an optimal solution for channelling well fluid to the power plant [7].

In response to the mentioned problems, the author plans several alternative solutions by modelling the existing conditions of SGS to find relevant alternative solutions using Aspen Hysys software as a calculation approach to actual conditions. The reason for using this software is that the process simulation in Hysis software can develop, analyze and optimize the technical process, which imitates the actual system as needed in solving this problem. The modelling and simulation of Pipeline PL-X05 use two modelling processes: the first model models the existing conditions, and the second model models the conditions after the addition of steam from K-21X. This second modelling used several calculations carried out four times, where conditioned from 0%, 25%, 50%, 75%, and 100% conditions to achieve maximum generation according to design.

ASPEN HYSYS SOFTWARE

Aspen Hysys is a software by Aspen Technologies Inc. that is very useful in the measurement and simulation process. Aspen Hysys can model a process system in detail. In contrast to MATLAB, Aspen Hysys has provided industrial system objects equipped with transfer functions for each object. Users can use the various objects in the material palette by specifying the object specification parameters and some process variables [8-9]. If the desired object is not available in the toolbox, users can use the transfer function block to represent the object [10].

Aspen Hysys is one of the process simulation software or a Process Simulator. This software is recommended for use in the fields of Refinery, Hydrocarbon, Oil & Gas [11]. This software is used to help analyze thermodynamic processes, especially to find energy and mass balance. The conditions used in this tool consist of two, namely Steady State & Dynamic. Aspen Hysys can be used to design equipment for a new plant to be established (sizing) or evaluate the performance of equipment in an existing plant (rating). This research uses Aspen Hysys to perform simulation modelling to build a new system, namely the K-21 well piping tie-in at PL-X05. Process simulation in Hysys software can develop, analyze, and optimize technical processes that imitate the actual system.

This simulation has several property packages that are used according to the fluid type content of the simulation. A property package is a collection of special methods to calculate component properties and parameter values. Some types of property packages in Hysys are ASME Steam, Peng Robinson, etc. The simulation in Hysys helps a system that, in reality, cannot be operated because it is still in the design stage or to check the safety side of a system [12]. Some specific inputs needed for this simulation are the fluid type and its content, pressure, temperature, flow rate, pipe length, and pipe size. These specific parameters are critical for simulation because they directly influence the accuracy and reliability of the modelled system's behaviour. The fluid type and composition determine the thermodynamic and transport properties essential for predicting heat and mass transfer phenomena. Pressure and temperature are crucial for defining the system's phase behaviour and operational limits, while flow rate governs the energy and mass balance. Pipe length and size impact flow dynamics, pressure drops, and heat losses, key factors in assessing system efficiency and performance.

THERMODYNAMIC EQUATION

Energy conservation is an effort made to improve energy efficiency. The first law of thermodynamics is the source of energy efficiency calculations without considering the quality of energy [13][14][15]. This law states: 'Heat and mechanical lab are interchangeable'. According to this law, it takes a certain amount of mechanical lab to produce a certain amount of heat, and vice versa. This law can also be expressed as: 'Energy cannot be created or destroyed, but it can be converted from one form to another'. According to this law, the energy provided by heat must be equal to the external work done plus the internal energy gain due to the increase in temperature [16][17][18]. The equations used for thermodynamics and energy balance can be seen in equations 1 and 2.

$$E_{in} = E_{out} \tag{1}$$

$$CapQ_{in} + W_{in} + \Sigma\dot{m}_{in}(h_{in}) = Q_{out} + W_{out} + \Sigma\dot{m}_{out}(h_{out}) \tag{2}$$

Where is:
Q : heat transfer
W : work done in units of heat
$\dot{m}$: mass flow rate
h : enthalpy

PRE-MODELLING AND SIMULATION CALCULATIONS

A simulation model is a model that mimics a certain system and has the same characteristics as the system. The simulation model must reflect the important properties of the actual system. The objectives of the simulation model include Studying a system that is difficult to do directly. The modelling and simulation of PL-X05 used two modelling runs, where the first model modelled the existing conditions, and the second model modelled the conditions after the addition of steam from K-21X for this second modelling run using several modellings runs. Calculations were carried out 4 times in modelling, where the conditions were 25%, 50%, 75%, and 100% of the Wellhead.

Calculation of heat mass balance

The mass balance calculation was carried out to determine the mass flow by simulating the division of the flow into the existing flow (path to PL-X01) and the new flow (path to PL-X05). The curve provides information that the greater the pressure, the smaller the flow rate. Likewise, when the pressure is smaller, it will provide a greater flow rate; the pressure fulfils the condition that the pressure must be greater than 11.8 bara when entering the PL-X05 flow. The pressure calculation will consider the piping pressure drop. The initial assumption for the HMB calculation is that the wellhead will operate at a pressure of 17 bara. The current study determined a pressure of 17 bar based on calculations at the pre-modelling stage from the PL-X05 operational pressure of 11.8 bar plus a total pressure drop of 3.15 bar and a safety factor of 12%, so a value of 17 bar was obtained. Overpressure is taken from 11% of the operational pressure, which means the pipe will be active safety (PSV & RD) if there is a pressure fluctuation of 11% of the operational pressure, so a safety factor of 12% is taken above 1% of the operational pressure. Simulations were conducted for pipe size selection, which was limited to velocities of 20 - 55 m/s [19]. The process that occurs during throttling of the MOV is assumed to be an isoenthalpy process.

Line sizing calculation

Line sizing is done to obtain pipe diameter size specifications for fluid (steam) transport. Some references used for line sizing calculations are as follows:

1. Provide enough spare room for fluctuations in the steam rate from the well (K-G21). Measurements were made for several flows and pipe sizes to determine if they met the linear velocity criteria.
2. The velocity criteria for steam pipeline design are 20 - 55 m/s.
3. The calculation of the line size in the bypass flow was done at a flow equal to 100% of the main flow. An assumption is that if the main flow MOV fails, the entire flow can get through the bypass flow.

The design of a pipeline is done through the following stages [20]:

1. Fluid Conditions, Fluid: Steam from well, Mass flow rate: 79200 kg/hour (100% healthy head flow), Density: 8.57 kg/m3, Operating Temperature (Top): 204.31℃, Operating Pressure (Pop): 17.00 bara.

2. Determination of linear velocity (v)

   The linear velocity used is in the range of 20 - 55 m/s.

3. Volumetric flow rate (Q)

   The volumetric flow rate of a fluid flow is taken from the mass rate data divided by its density [13]:

$$Q = \frac{F}{\rho} \tag{3}$$

   Where is:

   Q : Volumetric flow rate (m^3)

   F : mass rate (kg)

   ρ : fluid density (kg/m^3)

4. Pipe Cross-Sectional Area (A)

   The pipe cross-sectional area (A) [21-22] is calculated from several different diameters. 10‘, 12’, 14’ and 20’

$$A = \frac{1}{4}\pi d^2 \tag{4}$$

   Where is:

   A : Cross-sectional area (m^2)

   d : diameter (m)

5. Linear velocity (v)

   Velocity checks were carried out for several different pipe sizes and then evaluated and selected for the pipe size that met the highest velocity criteria [23]. (velocity criteria 20-55 m/s)

$$v = \frac{Q}{A} \tag{5}$$

   Where is:

   Q : Flow rate (m^3/hour)

   v : Linear velocity (m/s)

   A : Cross-sectional area (m^2)

Pressure drop calculation

The pressure drop is calculated to confirm whether the pressure from the wellhead is sufficient for the inflow to the PL-X05 flow connecting line. The initial wellhead pressure assumption was 17 bara. The formula for pressure drops in long pipes is calculated as follows [24,25]:

$$\Delta p = \frac{\mu . l . v^2 . \rho}{2d} \quad (6)$$

Where is:

Δp : Pressure loss (Pa)

μ : Coefficient of friction = 0,016

l : pipe length (m)

v : velocity (m/s)

d : Inner diameter (m)

ρ : Density (kg/m^3)

The pipe length (ℓ) is calculated from the straight pipe length and the equivalent lengths of elbows, gate valves, and Tees passing through the pipe

The expander pressure drop is calculated using the following formula:

$$\Delta p = N_e \frac{V}{12} \left(\frac{G}{10^5}\right)^2 \quad (7)$$

Where is:

Ne : Enlargement Loss factor (from the curve)

V : Specific volume ($ft^3/h.ft^2$) = 1,8688 ft/lb

G : Mass flux ($lb/h.ft^2$)

METHOD

The simulation and modeling research of the Steam Gathering System at GSG Unit-G4 for Generation Optimisation uses data analysis techniques in the form of a preliminary survey and design stage.

Preliminary survey

At this stage, a field survey was conducted to observe and examine the parameter measurements used to design the K-21X to PL-X05 pipeline connection, including the Operational parameters and production facilities of production wells K-21X and PL-G01, the operational parameters and production facilities of production well PL-X05.

The design stages

The second stage is performing data analysis, calculation, design modelling, and simulation of the parameters that have been inventoried previously, with the following stages:

(1) Prepare PFD design and input values in ASPEN Hysys software. When all data is available, a modelling simulation will be conducted on the software.
(2) Comparing the results of existing hysys simulation conditions with actual data in the field.

(3) Calculating and designing piping systems using Microsoft Excel 2016 software.
(4) Comparing the Hysys simulation results after adding steam from tie-in K-21X to PL-X05 for this second modeling using several calculations. The calculation was carried out 4 times, modeling where the conditions were 25%, 50%, 75%, and 100% of the Wellhead.

RESULTS AND DISCUSSION

The present authors collected a sample of data in 2023 to be used as the basis for simulation, modeling, and data analysis. The data of pressure, mass flow rate, and steam temperature at the production well to the Unit-G4 PLTP header in 2023 are described in Table 2.

Table 1. Steam production well of KMJ-21G

Main Header						
Upstream PCV Header			Delta Pressure Upstream PCV Header VS Line System	Down Stream PCV Header After Separator		Delta Pressure Upstream PCV Header VS Downstream PCV Header After Srubber
Flow FI151 (T/j)	PU 151 (Barg)	TT 151 (°C)	(Barg)	PI 203	TI 201 (°C)	(Barg)
402,75	10,77	185,69	**1,97**	10,24	183,74	**0,63**

The data in Table 1 is obtained based on daily reports with an average gross electrical energy generated of 57.21 MW and a net of 55.11 MW with a parasitic load of 2.09 MW. Simulation results were obtained after data analysis and simulation using Hysys V.12 software. The simulation provides a deviation between the actual field parameters, and the simulation results are not significant. Therefore, the simulation is valid (deviation ≤ 2%) and feasible to be used as a baseline simulation. The 2% deviation is obtained from the comparison between the actual parameters measured at the power plant in 2023 and the Hysys modelling results. A deviation of <2% is taken for the standard deviation in the geothermal industry. The simulation results can be seen in Table 2. The deviation of ≤ 2% matches [26] those that state Variations of 1–3% are used to characterize the isobaric heat capacity in liquid and gas phases and 3–7% in the supercritical zone.

Table 2. Simulation Results

Condition	**Main Header**			**Scrubber**	
				Pressure	Temperature
	Flow FI151 (T/j)	PU 151 (Barg)	TT 151 (°C)	PI-203 (Barg)	TI-201 (C)
Actual	402,75	10,77	185,69	10,24	183,74
Simulation	402,80	10,67	186,80	10,24	185,6
Deviation	-0,01	0,74	-0,60	0,00	-1,01

Condition	**Metering**		**Condensor**				
	Metering Gross	Metering Netto	Exhaust Steam Temp (A)	Exhaust Steam Temp (B)	Condenser Pressure (A)	Condenser Pressure (B)	Condenser Pressure (C)
	[MW]	[MW]	TI-255 (C)	TI-253 (C)	PI 255 A [bara]	PI 255 B [bara]	PI 255 C [bara]
Actual	57,21	55,11	54,97	55,10	0,16	0,16	0,16
Simulation	57,22	55,13	55,35			0,16	
Deviation	-0,02	-0,04	-0,57			0,00	

Heat mass balance and simulation modeling

The mass balance calculation is carried out to determine the mass flow by simulating the division of the flow into the existing flow (path to PL-X01) and the new flow (path to PL-X05). The curve in Figure 1 provides information that the greater the pressure, the smaller the flow rate. Similarly, when the pressure is smaller, it will provide a greater flow rate. The pressure meets the requirement to be greater than 11.8 bar when entering the PL-405 flow. The pressure calculation will consider the piping pressure drop. The initial assumption of heat mass balance calculation is that the wellhead will operate at a pressure of 17 bar as follows:

(1) Simulations were conducted to select pipe sizes that were limited to velocities of 20 - 55 m/s.

(2) Mass balance diagram using a process flow diagram

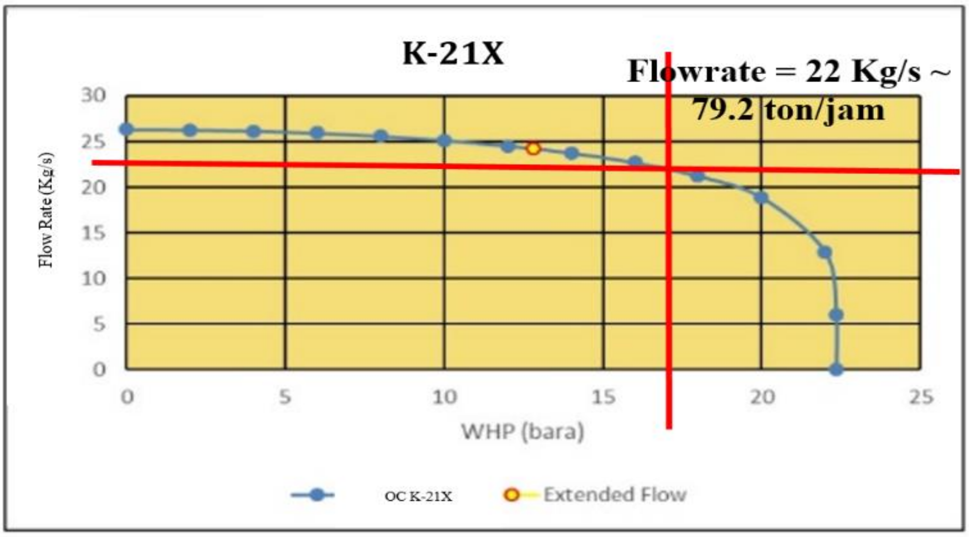

Figure 1. A well curve that provides the relationship between pressure and flow rate

(3) The process during throttling at the MOV is assumed to be an isoenthalpy process

Mass balance simulation is carried out to determine the mass flow by simulating the division of existing flow (path to PL-X01) and a new one (path to PL-X05), with the provisions referring to the rate of change of flow rate against pressure as shown in the well curve graph in Figure 1

Line sizing calculation result

Line sizing calculations are carried out to obtain pipe diameter specifications for fluid (steam) transport. The partial pressure drop calculation results can be seen in the calculation below, where the pipe length is calculated based on Table 3. Speed examination was performed on several variations of pipe size and several flows.

Table 3. The length of the pipe and its equivalent length are used as a reference for calculating partial pressure drop.

Section	Le/d	Le	Total	L(m)
Straight pipe				336,91
Elbow 90°	20	5,97	25	149,23
Elbow 45°	15	4,48	1	4,48
Gate valve	8	2,39	3	7,16
Tee run through	20	5,97	2	11,94
	Total			**509,72**

The pressure drop is calculated to ascertain whether the pressure from the wellhead is sufficient for the inflow to the PL-X05 flow tie-in. The initial wellhead pressure assumption is 17 bara. The pipe length (ℓ) is calculated from the straight pipe length and the equivalent length of the elbow, gate valve, and Tee passing along the pipe. The expander consists of two units: one located at the position after tapping from the wellhead pipe from the 10 ‘pipe to 12’ and another located at the end of the pipe when entering the tie-in, from the 12 ‘pipe to the 14’ pipe. The results of the pressure drop calculation on expander 1 are presented in the following description

$$\Delta P = N_e \, \frac{\mathrm{V}}{12}\left(\frac{G}{10^5}\right)^2 = 0{,}07 \; \frac{1{,}8688\,\frac{ft^3}{lb}}{12}\left(\frac{231876\,\frac{lb}{h.ft^2}}{10^5}\right)^2 = 0{,}059\; psi = 0{,}004\; bar$$

Using the same calculation, the pressure drop of expander 2 is obtained as equal to ΔP = 0,084 psi =0,006 bar.

The pressure drop of the total expander = 0.004 bar + 0.006 bar = 0.01 bar. A pressure drop occurs when the flow passes through the control valve (MOV), which is 1 bar. The orifice pressure drop is 58199 Pa = 0.58 bar and can be seen in Table 4.

Table 4. The total pressure drops while the flow passes through a control valve

Device part	Pressure
Pipe and fittings	1,56 bar
Expander	0,01 bar
MOV*	1,00 bar
Orifice*	0,58 bar
TOTAL *PRESSURE DROP*	3,15 bar

**Data from instrument doc*

The results of the calculation of the probability of pressure drop, as shown in Table 4, show that the total pressure drop that will occur is 3.15 bar. This means that the minimum pressure that must be supplied is 11.8 bar + 3.15 bar = 14.95 bar. Simulation modelling calculations after the addition of steam were performed four times, with the following results, as shown in Table 5.

Table 5. Summary of simulation results varying the vapour flow rate from the wellhead

Simulation	Main Header			Scrubber	
				Pressure	Temperature
	Flow F151 (T/j)	PU 151 (Barg)	TT 151 (oC)	PI-203 (Barg)	TI-201 (C)
100%	481,90	10,69	186,80	10,24	185,60
75%	462,20	10,69	186,80	10,24	185,60
50%	442,40	10,69	186,80	10,24	185,60
25%	422,60	10,69	186,80	10,24	185,60
Simulation	Metering		Condensor		
	Gross	Netto	Exhaust steam temp	Condenser Pressure (A)	
	[MW]	[MW]	TI-255 (C)	PI 255 (bara)	
100%	68,47	66,38	55,35	0,16	
75%	65,65	63,56	55,35	0,16	
50%	62,84	60,75	55,35	0,16	
25%	60,03	57,94	55,35	0,16	

The simulation results in Table 5 show that the 100% simulation, 75% flowrate from the wellhead of the K-21X production well to PL-X05 shows a realistic simulation to maintain the URC at 60.856 MW, and the 50% simulation is still below 0.1 MW from the URC value. However, the 50% simulation is close to the URC value, and the 25% simulation cannot return to the URC of 60.856 MW; it still needs additional steam to cover the generation shortfall of 2.91 MW.

CONCLUSION

The modelling and simulation results of the Existing Steam Gathering System show that the deviation between the actual parameters of the field and the simulation results of Hysys V.14 is not significant. Therefore, the simulation results are valid (deviation ≤ 2%) and feasible as a baseline for modelling and simulating the addition of steam from the K-21X production well to PL-X05. Modelling and simulation of the addition of steam from the production well K-21X to pipeline PL-X05 show that at 25% and 50% steam addition, the netto power is still below the URC of 60.856 MW, making it less relevant for the application. However, at 75% and 100% steam addition, the netto power reaches 63.56 MW and 66.36 MW, respectively, which exceeds the URC, making this simulation applicable. These achievements have a significant bearing because GPP unit-G4 can be reconnected to the nearest steam gathering system and overcome the potential loss problem, which is estimated at 45,552,000 KWh/year. Development of this research can be conducted by matching field data in the following years, namely 2024 and 2025.

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