ANALYSIS OF THE Z WELL PRODUCTION TEST USING THE HORIZONTAL LIP PRESSURE METHOD AT PT. PERTAMINA GEOTHERMAL ENERGY ULUBELU AREA

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ABSTRACT

The Ulubelu geothermal field operated by PT. Pertamina Geothermal Energy produces two-phase hot fluids dominated by water and has a generation capacity of 2 x 110 MW. To assess the well's condition, reservoir characteristics, production capacity, and enthalpy contained in the well fluids, a well production test is necessary before directing the fluids to the power generation unit. This paper presents the horizontal lip pressure method developed by Russell James to test the Z well. This method involves measuring the pressure difference across the horizontal lip installed in the wellbore and the fluid flow rate to determine the well's production capacity. The test aims to optimize production by adjusting the throttle valve opening to match the power generation unit conditions. Parameters obtained from the test, including dryness fraction, fluid mass flow rate, enthalpy, and generation, are processed to generate a deliverability curve showing the well's production capacity at different wellhead pressures. The results of this study provide valuable information for managing the geothermal field and optimizing power production.

Keywords: Production test, lip pressure data, throttle valve, delivery

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1. Introduction

Indonesia is a country rich in natural resources, including geothermal energy. The estimated potential of geothermal energy in Indonesia is 29.51 GWe, which accounts for approximately 40% of the world's reserves. The performance of geothermal power plants (PLTP) is highly dependent on the maintenance of well production during the exploitation process. This research paper focuses on well production testing, specifically the horizontal lip pressure method.

Several methods are employed for well production testing, including lip pressure, separator, and orifice methods. The lip pressure and separator methods are usually used in wells with water dominance, while the orifice method is used in wells with steam dominance. Lip pressure testing can be performed vertically or horizontally. Although all well-production testing methods have the same objective, the selection of the testing method needs to be carefully planned, taking into account the accuracy and cost of the method. The separator method is the most accurate but also requires a higher cost. Therefore, the horizontal lip pressure method was chosen as the testing method in the Ulubelu field, as it is more economical than other testing methods and can be performed routinely, although its accuracy is lower than that of the separator method.

The objectives of this journal article are to increase knowledge in the field of geothermal energy, specifically in production testing using the horizontal lip pressure method, to identify the parameters obtained from geothermal well testing, to understand how to process and calculate data from horizontal lip pressure tests to produce relevant production output data, and to apply the theory to fieldwork.

2. Materials and methods

This research was conducted at PT Geothermal Energy Area Ulubelu, which is administratively located in Ulubelu District, Tanggamus Regency, Lampung, approximately 90 km to the south of Bandar Lampung city at an elevation of 800 meters above sea level. The ambient temperature is around 23-26°C with rainfall between 1500-2300 mm per year. The geographical boundaries are X =104°C 27'25", 104°C 43'31" East; Y = 05°C 31'29" South, with a maximum temperature of 104°C [1]. The process is carried out in several stages, namely:

A. The general process of converting hot steam fluid into electricity.

The process of converting hot steam fluid from the earth into electricity is carried out through several stages (**Figure 1**). First, the steam is supplied from the production well through the steam transmission system and enters the steam receiving header as a steam collector medium. From the steam receiving header, the steam is then directed to a separator that functions to separate pure steam from hot water. The hot water is directed to a temporary storage pool before it is finally reinjected into the injection well.

After that, the steam enters the steam scrubber (cyclone type), which functions to separate moisture and clean the steam so that the steam that enters the turbine is expected to be clean. Then, the steam is divided into two and passes through the steam strainer to filter out contaminants that can damage the turbine. The steam then enters the turbine, causing a conversion of energy from the heat contained in the steam into kinetic energy that is received by the turbine blades. The coupled turbine and generator cause the generator to rotate as the turbine rotates, resulting in a conversion of kinetic energy into mechanical energy.

The rotating generator produces electrical energy. The output from the steam turbine consists of exhaust steam and non-condensable gas, which will be condensed in the condenser by contacting it with cooling water from the cooling tower. Non-condensable gas is differentiated from exhaust steam using a gas extraction system

The non-condensable gas (NCG) from the condenser is drawn by the first ejector and subsequently flows into the inter-condenser, where it serves as a cooling and NCG trapping medium. The steam carrying NCG and cooling water is then returned to the condenser. The NCG is then drawn again by the second ejector and introduced into the after-condenser as a cooling medium before being discharged into the atmosphere through a pipe located near the cooling tower fan, using a liquid ring vacuum pump. The condensed exhaust steam, cooling water, and remaining water from the Gas Extraction System (GES) are conveyed to the cooling tower through a hot well pump.

Within the cooling tower, the water is cooled. Furthermore, the cooled water from the cooling tower is recirculated back into the condenser to serve as a cooling medium. Some of the water in the cooling tower is also utilized to cool other components, known as the Auxiliary Cooling Water System. The Auxiliary Cooling Water System is comprised of two systems, namely the primary auxiliary cooling water system and the secondary auxiliary cooling water system. The primary auxiliary cooling water system is employed to cool the inter-condenser, condensate on the atmospheric flash vessel, and the mechanical seal on the hot well pump. Meanwhile, the secondary auxiliary cooling water system is utilized to cool the generator and turbine. Any surplus water in the cooling water system will be collected and reinjected into the reinjection well.[2]

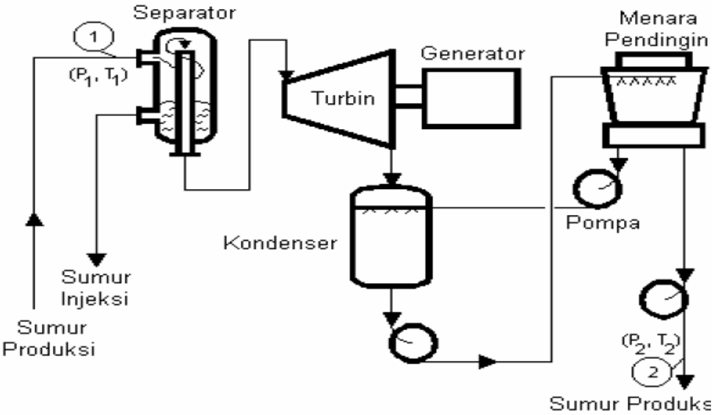

Figure 1. Flow Diagram of the triumph of water domination [3]

B. Production Test

After drilling a geothermal well, one of the necessary well tests to be conducted is the production test. The production test is conducted to determine the well characteristics based on the mass flow rate (of steam and brine) and fluid enthalpy at varying wellhead pressures (WHP). This data is essential in deciding the WHP at which the wells should be operated, and the mass flow rate and fluid enthalpy data will be valuable in calculating the potential of the wells at different WHPs.

One of the outcomes of the production test is the production curve, which illustrates the well's production capability in the form of a graph that shows the relationship between the total mass flow rate, steam mass flow rate, enthalpy, and vapor fraction or dryness. Generally, the production test method can be classified into single-phase measurement methods using a weir box or orifice, and two-phase measurement methods such as calorimeter, separator, and lip pressure methods.[3]

C. Single-phase Measurement Method

The single-phase measurement method comprises measuring low-enthalpy wells and high-enthalpy wells. For wells with temperatures lower than the boiling point of water at the wellhead or reservoir, only water is produced, and the enthalpy is determined only from the steam tables based on the temperature and pressure at the wellhead. If the water does not boil at atmospheric pressure, the mass flow rate (production rate) is determined by measuring the flow rate passing through a sharp-edged weir (ISO 143/I). The measured mass flow rate of water is the one that comes out of the atmospheric separator (silencer). There are three types of weir boxes commonly used, namely rectangular, suppressed, and triangular.

On the other hand, wells with temperatures lower than the boiling point of water, wells that produce from a steam-dominant reservoir, produce saturated hot steam or superheated steam with high temperature. Enthalpy and mass flow rate can be determined simply by measuring the flow rate using an orifice (BS 1024) and measuring the temperature (BS 1041). The flowing enthalpy is determined by plotting the pressure and temperature conditions on the Mollier Chart, as shown in the **Figure 2**.[3]

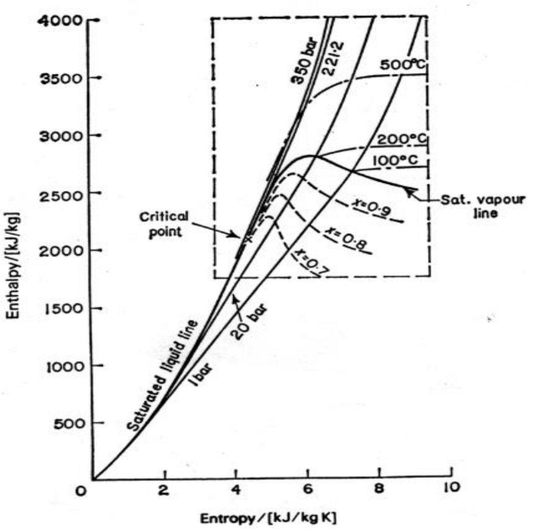

Figure 2. Mollier diagrams[3]

D. Two Phase Measurement Method

In the two-phase measurement method, four tests can be conducted, namely the calorimeter test, separator test, vertical lip pressure test, and horizontal lip pressure test. The calorimeter method is commonly used to measure the flow rate of wells that are expected to have a small flow rate. A calorimeter with a capacity of no more than 1.5 m^3 can be easily transported using a trailer and has a maximum test capacity of around 30 tons/hour, which is dependent on the fluid enthalpy.

In the calorimeter method (**Figure 3**), measurement is carried out by flowing fluid from the well into a calorimeter containing cold water with a known volume and temperature for a certain period of time. Afterward, the well is closed, and the volume and temperature of the fluid in the tank are measured. The flow rate and fluid enthalpy are then calculated from the increase in volume and temperature. To obtain accurate data, the test should be carried out at least three times. Usually, the test is conducted at several wellhead pressures to determine the well's production capability at different wellhead pressures.[3]

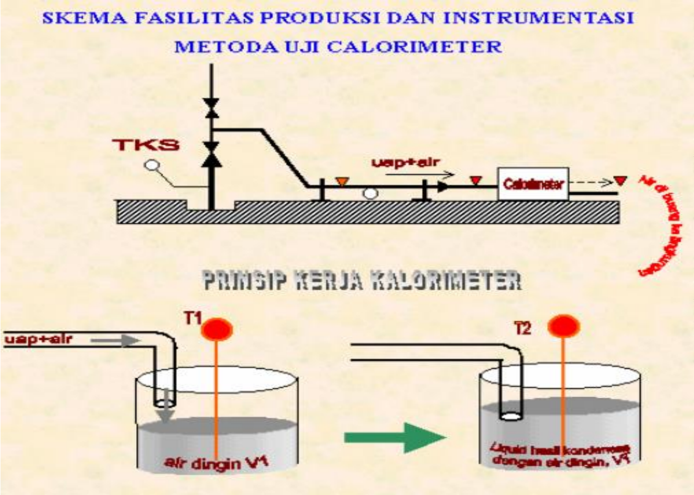

Figure 3. Calorimeter Tank [3]

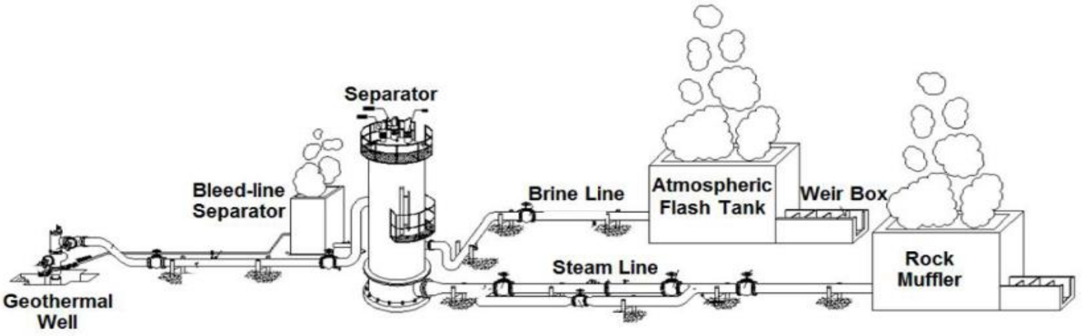

Figure 4. Separator production test model [4]

The separator test is the most accurate method for measuring two-phase flow from geothermal wells, using a cyclone separator, which is the most common type of separator. The separator separates the vapor phase from the liquid phase at the separator pressure. The size of the separator depends on the estimated mass flow rate. As depicted in **Figure 4**, the fluid from the geothermal well initially flows into the bleed-line separator to reduce pressure and separate gas from the liquid. Subsequently, the liquid that passed through the bleed-line separator proceeds to the main separator.[4]

In the main separator, the fluid is segregated into two streams, namely the brine line and the steam line. The brine line conveys the brine fluid to the atmospheric flash tank, which suddenly reduces the pressure causing a part of the brine liquid to evaporate, allowing dissolved gases to escape. The brine liquid that has undergone the atmospheric flash tank then flows into the weir box, acting as a shelter before eventual disposal or further processing. [5]

Conversely, the steam line directs water vapor to the rock muffler, serving as a noise suppressor and reducing steam pressure before releasing the vapor into the environment. The rock muffler can also function as a trap to collect solid particles that water vapor may carry. [6]

The flow rate of the steam is measured with a flow meter, while the flow rate of the brine itself is measured using a weir box. The orifice meter measures the flow rate of the steam leaving the separator outlet. Using Bernoulli's law, the steam rate can be calculated. [4]

$$M = 0.001252\ x\ C\ x\ Z\ x\ E\ x\ \ \in x\ d^2 x\ \sqrt{dp\ x\ \rho} \qquad (1)$$

Where,

M : Steam flow rate (t/h)
C : Basic coefficient
Z : Correction factor
∈ : Expansion factor
E : Velocity factor
ΔP : Differential pressure upstream and downstream of orifice (kg/cm^3)
P : Density of steam (kg/m^3)

The third test is the vertical flow test, as seen in **Figure 5**. This test is conducted when the geothermal well is first opened to obtain a rough idea of its power generation potential. Additionally, this test is useful for cleaning the well from dirt and drilling mud. The wellhead pressure (WHP), lip pressure, and lip pipe diameter are the measured quantities. Pressure testing on the lips in a vertical position on a device or system. The first step in this test is to measure the initial pressure (baseline) within the system before the pressure of the lips is raised. Furthermore, the pressure of the lips is gradually increased using special equipment such as a pump or compressor, and the pressure in the system is periodically measured during the testing.[8]

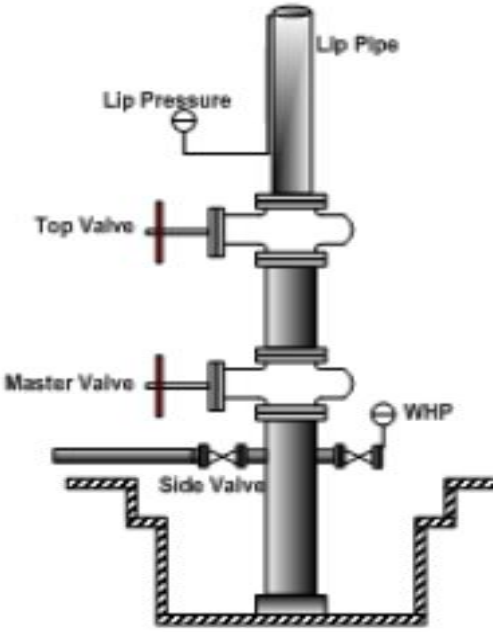

Figure 5. Upright lip test illustration[7]

During the testing period, it is crucial to ensure that the pressure in the system is continuously monitored and recorded to maintain the sustainability of the resulting lip pressure. These tests play a crucial role in ensuring that the system or equipment can withstand the desired pressure without any leakage or damage to the lips. After the specified testing time has elapsed, the pressure in the system is reduced back to the initial pressure, and the test results are recorded and evaluated.[9]

The James formula is commonly used to calculate the well output, which considers the mass flow rate, flowing enthalpy, pipe lip area, and lip pressure. Assuming that the condition from the reservoir to the lip pipe is isenthalpic, the total mass flow rate can be determined.

$$M = \left(\frac{0.184}{h^{1.102}}\right) x \, A_{lip} \, x \, P_c^{0.96} \, x \, 3600 \qquad (2)$$

The assumption of compressed liquid condition applies when the water level is above the production casing shoe (PCS) and the relative permeability is high. On the other hand, the assumption of compressed liquid condition does not apply when the injectivity is low and the water level is below the PCS because during flowing, the water level will decrease and the water volume will decrease while the temperature remains the same, resulting in a shift from a static position of compressed liquid.

$$Dryness = \frac{h-hf}{hfg} \times 100\ (\%) \qquad (3)$$

If the vapor fraction is known, the vapor and brine flow rates can also be determined:

$$M_{uap} = Dryness \text{ x } M_{total} \qquad (4)$$

By assuming steam consumption for generating 1 MW, the well's generating capacity can be determined:

$$Generation = M_{uap} \text{ x } Specific\ Steam\ Consumption \qquad (5)$$

Simply put, the calculation can be explained in **Figure 6**, which begins with ensuring that the lips are in good condition and positioned vertically. The fluid flow is then initiated, and the appropriate flow meter equipment is used to measure the flow rate of the fluid. During the testing, the fluid flow can be adjusted according to the desired parameters, such as flow rate or pressure, and the flow data is recorded and analyzed.

Throughout the test, it is important to visually monitor the condition of the lips and check for any leakage or damage. If any issues are observed with the lips, the test can be stopped, and necessary repairs or replacements can be performed before resuming the testing.[10]

Once the specified test time is completed, the fluid flow is stopped, and the final measurement is taken to obtain the final data. The test results are then recorded and evaluated to determine whether the lips can withstand fluid flow according to the desired parameters.[11]

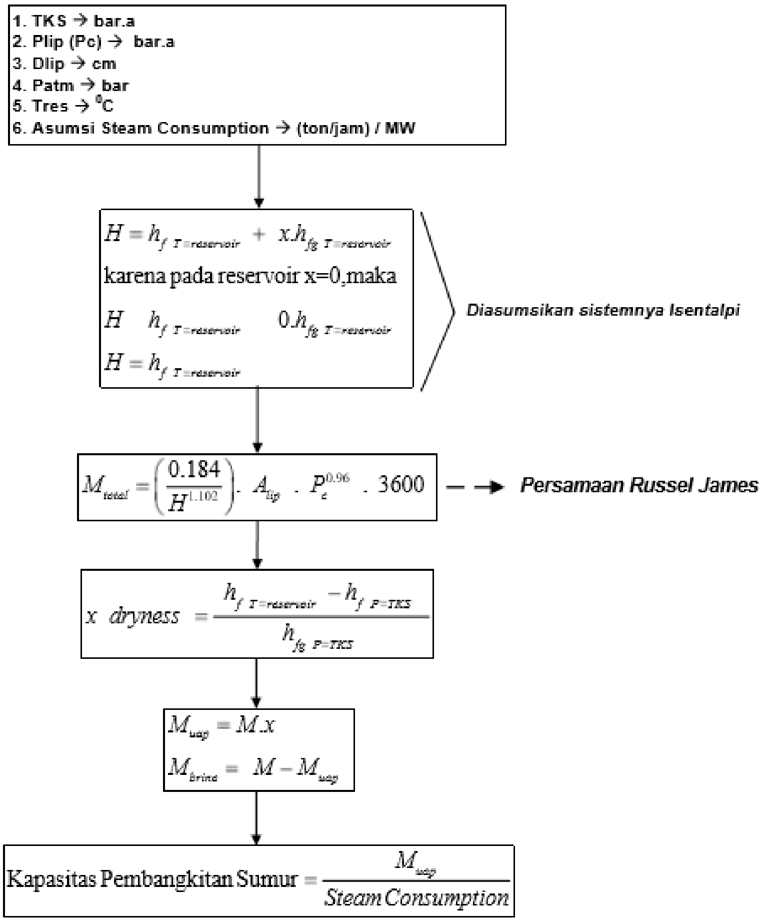

Figure 6. Vertical lip test flow chart [4]

Legend:
TKS = Wellhead Pressure (bar)
Pc = Choke Pressure (bar)
Dlip = Choke Pipe Diameter (cm)
Patm = Atmospheric Pressure (bar)
X = Vapor Fraction (dryness)
h = Enthalpy (kJ/kg)
Mtotal = Total Mass Flow Rate (tons/hour)
Muap = Vapor Flow Rate (tons/hour)
Mair = Water Flow Rate (tons/hour)
Tres = Reservoir Temperature (°C)
Q = Well Potential (MW)

To calculate the well output, James's formula is used, which relates the mass flow rate, flowing enthalpy, pipe lip area, and lip pressure. Assuming that the condition from the reservoir to the lip pipe is isenthalpic, the total mass flow rate can be determined. The reservoir temperature is determined from the Main Feed Zone (MF) temperature, which can be calculated from several pressure and temperature measurements where the P-line (Pivot Point) intersects at a certain depth, and the temperature at the intersection is taken.

It is important to note that a fatal error can occur if the reservoir temperature is taken from the maximum temperature, as this can affect the total enthalpy value obtained and the analysis of the well's production characteristics.[4]

The last test method is the horizontal lip test. In principle, the horizontal lip test is similar to the vertical test, with the only difference being the position of the lip, which is changed from vertical to horizontal. However, in the horizontal lip test, the two-phase fluid is flashed in the silencer. The silencer functions to reduce noise and flash the hot two-phase fluid from the geothermal well. The principle of calculating the well potential is the same as the horizontal lip test method.

The silencer contains a weir box equipped with a V-Notch that measures the brine rate, while the flashed steam and brine are directed to the atmosphere through the silencer stack. This test method can be used not only to provide an overview of the well potential, but also to determine the total enthalpy (h) value of a well. By modifying the Russell James equation, the enthalpy value can be obtained.

The horizontal discharge production test requires several equipment, including an atmospheric flash tank (AFT), weir box, and a short pipeline that connects the AFT to the wellhead. Additionally, a pond is required to contain the produced brine, which should be supported by facilities for brine injection. The equipment arrangement for the horizontal discharge production test can be seen in **Figure 7.** This test is performed to ensure the performance of the lips in handling fluid pressure in the horizontal system.

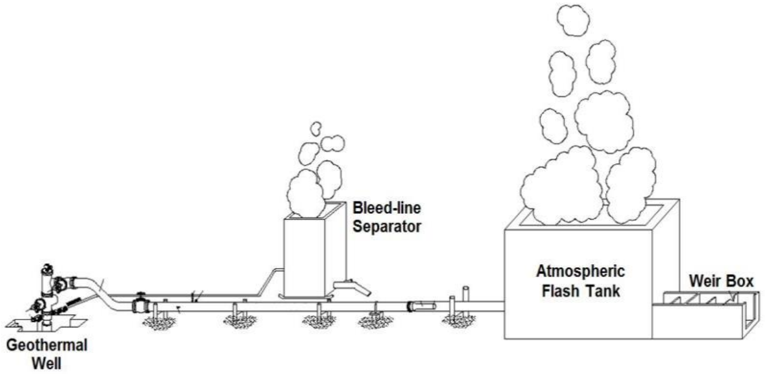

Figure 7. Horizontal lip pressure test circuit [7]

At the onset of the test, fluids from the geothermal well flow into the bled line separator, which serves to reduce fluid pressure and separate the gas from the liquid. Subsequently, the liquid that has passed through the bled line separator flows into the atmospheric flash tank. In the atmospheric flash tank, the pressure is suddenly lowered, causing some of the liquid to vaporize, and dissolved gases to come out. The fluid that has passed through the atmospheric flash tank then flows into the weir box, which serves as a shelter before being discarded or further processed.[12]

During the test, the fluid pressure is adjusted according to the desired parameters, and the tested lips face the pressure of fluid in a horizontal position. Periodic measurements of fluid pressure and lip condition are performed during the test. Test data is recorded and analyzed to evaluate the performance of the lips in coping with fluid pressure horizontally.[13]

The parameters that need to be observed and continuously measured are the wellhead pressure, lip pressure, and brine level in the weir box. By knowing these parameters, the flowing enthalpy and mass flow rate can be determined using available formulas. [14]

Simply put, the calculation begins by determining the flow rate of brine in the weir box (**Figure 8**). The flow rate of water in the weir box can be calculated using the Hirowatari equation.[7]

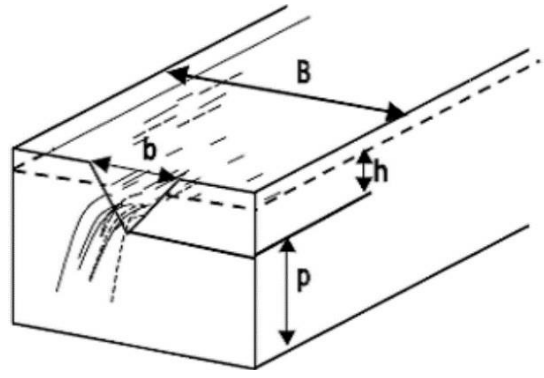

Figure 8. *V-notch Weir Box* [4]

1. $K = 81{,}2 + \frac{0{,}24}{h} + \left(\frac{12}{\sqrt{D}} + 8.4\right) x \left(\frac{h}{B} - 0.09\right)^2$ (6)
2. $\rho f = \frac{1}{Vf}$ (7)
3. $W\ (atm) = K \times h^{2{,}5} \times \rho f \times 0{,}06$ (8)

Where:
K = Discharge coefficient
h = Height of brine in weir box from orifice (m)
D = Height of brine from bottom of weir box to lip of v-notch (m)
B = Width of weir box (m)
W (atm) = Rate of brine at atmospheric conditions (tonnes/hour)
ρf = density of brine (kg/m^3)
Vf = Specific volume (m^3/kg)

After obtaining the brine rate at atmospheric conditions, the calculation of the total flow rate and enthalphy from the test results can be calculated using the following method:[15]

1. Calculate the price of Y with the equation:
   $Y = \frac{Watm}{A\ x\ P^{0.96}}$ (9)
2. Calculate the enthalpy H using the equation:
   $h = \frac{hg+(925+Y)}{1+(7.85+Y)}$ (10)
3. Calculating the mass flow rate M with the equation:
   $M = \left(\frac{0.184}{h^{1.102}}\right) x\ A_{lip}\ x\ P_c^{0.96}\ x\ 3600$ (11)

Where:
Y = James Factor
Watt = Mass of Brine (tonnes/hour)
A = Lip pipe area (cm^2)
P = Lip pipe pressure (bar)
h = Flowing Energy (kJ/kg)
hg = Enthalphy of steam at atmospheric pressure (kJ/kg)
hfg = Difference in enthalphy of steam and fluid at atmospheric pressure (kJ/kg)
M = Total Mass Flow Rate (tonnes/hour)

The calculation of steam mass flow rate, dryness, and generation can be calculated using the following equation:[15]

1. $Dryness = \frac{h-hf}{hfg} \times 100\ (\%)$ (12)

Where hf and hfg are the fluid enthalpies at the separator pressure.

2. M uap = M total X *Dryness* (13)

3. $Generation = \frac{M\ uap}{Specific\ Steam\ Consumption}$ (14)

The V-notch Weir Box is a device commonly used for measuring the discharge or fluid flow in geothermal systems, as shown in Figure 8. This Weir box is shaped like a "V" notch, which is used to measure the height of the liquid surface and calculate the flow discharge based on the difference in the high surface of the fluid before and after passing through the V-notch on the weir box.[16]

When the fluid flow from the geothermal system passes through the Weir box, the height of the fluid surface rises and reaches the highest point in the "V" gap [17]. Using the measurement scale on the weir box, the height of the liquid surface at the highest point of the "V" gap can be measured and used to calculate the fluid outflow passing through the Weir box[14]. These measurement data can be used to monitor the performance of geothermal systems, calculate fluid flow rates in the production process, or control flow settings in geothermic systems [13].

3. Results

Geothermal energy production at PT Pertamina Geothermal Energy Area Ulubelu is part of the Hydrothermal Energy System. In this system, fluid circulation originates from meteoric water that enters the subsurface through fractures or permeable rocks. Due to the high temperature of the subsurface, the water changes phase into vapor, and it moves upwards. If the geological structure allows, the water will flow through fractures and/or permeable rocks and emerge on the surface as hot springs.[15]

The Hydrothermal system at PT Pertamina Geothermal Energy Ulubelu Area is a water-dominated two-phase system based on the type of production fluid and the type of main fluid content. This system produces a mixture of water vapor. In water-dominated systems, it is hypothesized that water fills cavities, open channels or fractures.

For the geothermal power plant system, PT Pertamina Geothermal Area Ulubelu uses a separate steam system. The separated steam system is initiated when the geothermal fluid flows out of the wellhead as a two-phase fluid mixture (steam phase and liquid phase), and the combustion process is performed on the fluid first. The fluid is passed through a separator where the vapor phase is separated from the liquid phase. The steam fraction produced from the separator flows to the turbine, where it is converted into kinetic energy, and then used to turn the generator to produce electrical energy.

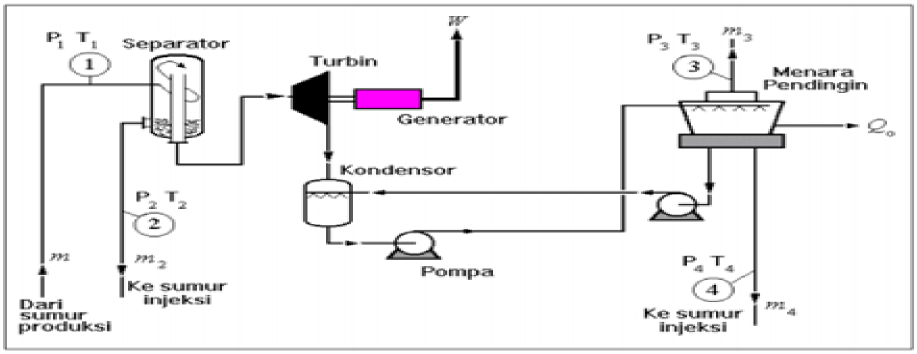

Figure 9. Ulubelu Area Geothermal Power Plant Flow Diagram [2]

The fluid flow in the geothermal power generation system in the Ulubelu region begins at the production well, and then proceeds to the separator where the fluid is separated into two lines. **Figure 9** illustrates the schematic diagram of the fluid flow. On the first route, a portion of the fluid is directed to the injection well to return the earth heat fluid that has been reused in the geothermal reservoir. This line is intended to maintain the availability of the earth's heat source for sustainable electricity production.[2]

On the second line, some of the fluid is directed to the turbine to generate electricity. The earth heat fluid that flows into the turbine is utilized to move turbines connected to the generator, which generates electricity. After passing through the turbine, the used fluid is directed to the condenser to condense back into liquid. [18]

After leaving the condenser, the fluid is directed to the pump to be re-pressurized and returned to the system and the injection well to be inserted again into the geothermal reservoir. Some of the liquid is also directed to the cooling tower to remove the heat generated during the power generation process.[19]

The Ulubelu Area steam field and PLTP development activities have succeeded in transferring 2 x 55 MW of geothermal steam to PLTP units 1 & 2 owned by PT PLN and PLTP units 3 & 4 of 2 x 55 MW owned and operated directly by PT Pertamina Geothermal Ulubelu Energy Area. Unit 3 began commercial operations (Commercial Operating Date/COD) on July 26, 2016, and was formally inaugurated by the President of the Republic of Indonesia Indonesia on 27 December 2016 and PLTP unit 4 started COD on 25 March 2017, so that the total installed capacity of PT Pertamina Geothermal the Ulubelu Energy Area is 220 MW.[20]

A. Production Test of Horizontal Lip Pressure Z-Well

1. Z-well Test Data

The production test using the horizontal discharge lip pressure method was conducted on the Z-well over a 12-day period, from 17 February 2020 to 28 February 2020. Hourly recordings were taken of the existing parameters, resulting in 268 data points. However, only 220 data points were usable due to the production test for Well-Y not starting at 12.00 WIB and finishing at 06.00 WIB, and some data not being recorded for the Z-Well test.

The test was conducted by adjusting the throttle valve at the wellhead, which was connected to the lip pipe, and varying the opening to affect the lip pressure and water level in the weir box. There were five variations of throttle valve opening used in the measurement, namely 100%, 51%, 39.7%, 30%, and 25%. The equipment used in the test included lip pipes, pressure and temperature gauges, weir boxes, atmospheric flash tanks, gas detectors, blowers, and standard safety equipment (**Figure 10**).

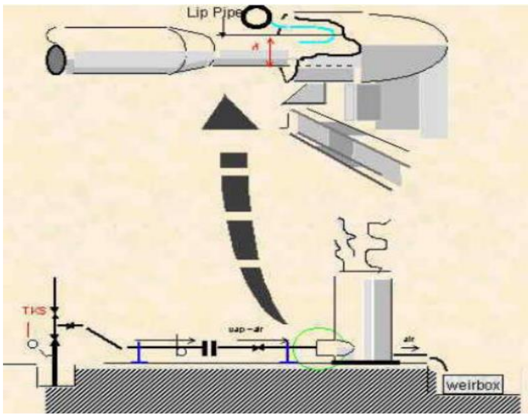

Figure 10. Horizontal lip pressure pipe[3]

The Horizontal Lip Pressure Pipe, depicted in **Figure 10**, is a pipe system designed to accurately measure pressure in a horizontal pipe. The unique shape of these pipes facilitates precise pressure measurement.[21] As seen in the image, the horizontal pipe comprises two primary parts: the top and the bottom. The top of the pipe features a V-shaped notch that serves as a high-water measurement point within the pipeline. The bottom of the pipe has an outlet that is used to flow water to the destination or to the next part of the system.[22]

The pressure measurement process using this horizontal pipe system involves measuring the water height inside the V-notch at the top of the pipe. The water height is then used to calculate the pressure in the pipes based on the principles of hydrostatics. The higher the water in the V-notch, the higher the pressure in the pipe.[23]

There are several steps involved in processing the existing data for use in calculations. It can be made by referring to the steps in the literature review for the horizontal lip pressure test. The analysis of the data obtained from the production test using the horizontal discharge lip pressure method was conducted to determine the stable point. As mentioned in [4], there were 5 samples of data from various throttle valve openings that were taken from the lip test check sheet. However, fluctuations in the wellhead pressure at each opening of the throttle valve resulted in some data being outliers, which were not suitable for forming the deliverability curve.

To determine the stable point, a graph was plotted for all data obtained for each variation of throttle valve opening, as shown in Figure 9. It was observed that determining the stable point through the mass flow rate would be difficult as it produced stable mass flow rate values for each throttle valve opening. Therefore, the stable point was determined by looking at fluctuations in the wellhead pressure at each opening of the throttle valve, which were quite stable and representative, as shown in **Figure 11**.

It should be noted that at the throttle valve opening of 30%, three different openings were recorded at different timeframes. Thus, the data taken from the three different timeframes were considered representative. For other throttle valve openings, it was enough to observe the wellhead pressure, which remained quite stable throughout the test

The graph of total mass rate versus test time in **Figure 11** showed the trend of the total mass rate fluctuating during the test, with a drop in the overall mass rate measured over a given time interval. This fluctuation may indicate changes in the flow of the tested fluid or the influence of other factors during the test.

Furthermore, the graph of wellhead pressure versus test time in **Figure 12** showed how the well pressure on the test well changed during the test. The chart showed a trend of change in well pressure on the test well during testing, with rising well pressure drops at a certain time interval. This fluctuation may indicate changes in production or injection conditions in the test well.

The use of the horizontal discharge lip pressure method provided valuable data in understanding the performance of the Z-well. The stability of the wellhead pressure and the fluctuation in total mass rate during the test provided insights into the changes in the flow of the tested fluid and other factors that influenced the test. After determining the 5 stable points, the Z-Well test obtained 5 stable point data as shown in **Table 1**.

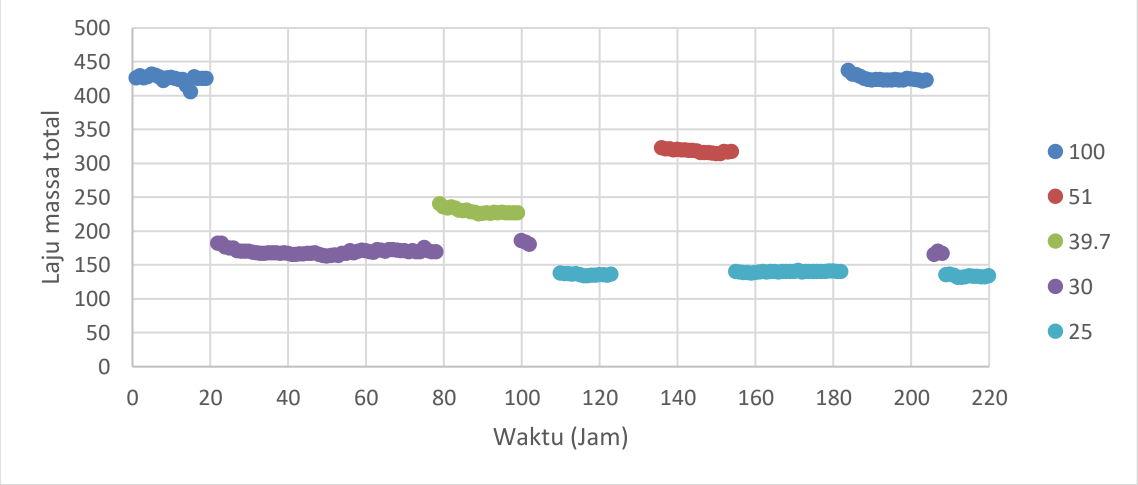

Figure 11. Graph of total mass rate vs test time [4]

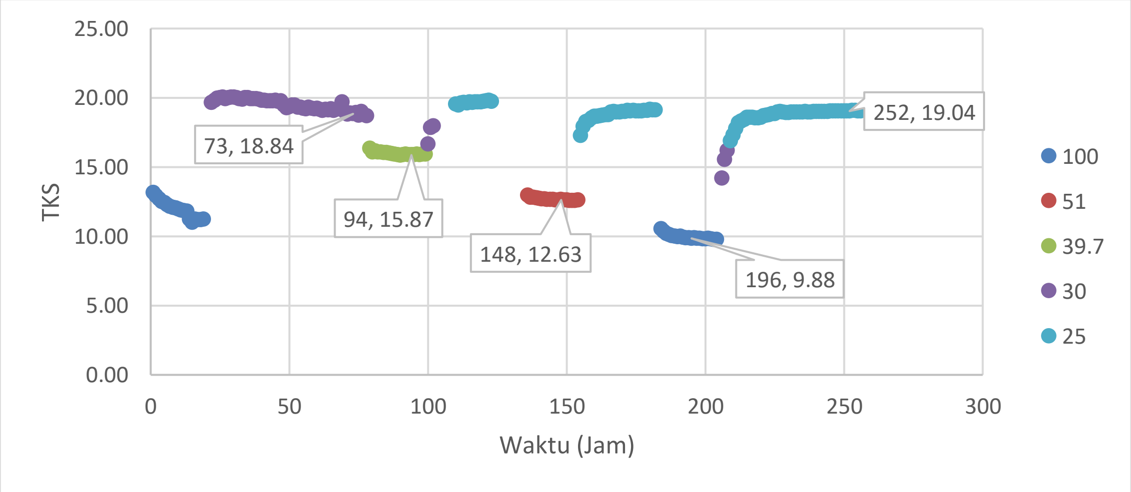

Figure 12. Graph of wellhead pressure vs test time [4]

Table 1. Lip and weir box measuring parameter data [4]

Throtle Valve	**WHP**	**$P_{separation}$**		**P_C**		**$h_{V\text{-}Notch}$**	**T_{Brine} @Weirbox**
***Open* (%)**	**(barg)**	**(Barg)**	**(Bara)**	**(Barg)**	**(Bara)**	**(m)**	**(°C)**
100	9.88	10.0	10.9	3.03	3.95	0.30	81.0
51	12.63	10.0	10.9	2.18	3.10	0.26	78.0
39.7	15.87	10.0	10.9	1.40	2.32	0.22	76.0
30	18.84	10.0	10.9	0.77	1.69	0.20	74.0
25	19.04	10.0	10.9	0.39	1.31	0.18	70.0

Production tests using the horizontal lip pressure method at the Z-Well were carried out to obtain some data including steam rate, brine rate, total mass rate, dryness, enthalpy, and generation for each variation of throttle valve opening.

The data obtained from 5 samples for each opening can then be entered into the Russell James equation. With the horizontal lip pressure method, two-phase fluid from the well flows through the lip and AFT pipes. The brine flow rate can be calculated by using a 90o V-notch weir box and the total flow rate can be calculated by the equation of Russel James. The following is an example of calculating the brine rate, total flow rate, enthalpy, dryness, and generation resulting from one of the data, namely at 100% opening.[4]

2. Horizontal Lip Pressure Production Test Calculation

The following is the calculation stage for the lip pressure test on the 100% valve opening example. The weir box used in this production test is a 90^o V-notch which is installed after the atmospheric flash tank and the data obtained for the weir box is as follows:

Weir box height to v-notch (D) = 0.405 meter
Weir box width (B) = 1.205 meters
Brine height at v-notch (h) = 0.30 meters
Tbrine = 81 ^{o}C
Pc (lip) = 3.9 embers
A(lip) = 508.8 cm^2

Based on these data, the brine flow rate in the weir box can be calculated in the following steps:

a. Calculate the discharge coefficient.

$$K = 81{,}2 + \frac{0{,}24}{h} + \left(\frac{12}{\sqrt{D}} + 8.4\right) x \left(\frac{h}{B} - 0.09\right)^2 = 82.68$$

b. Calculating the density of brine based on the fluid temperature in the weir box, then connecting it to the steam table so that the specific volume is obtained.

$$\rho f = \frac{1}{Vf} = \frac{1}{0.00103} = 971.61 \ kg/m^3$$

c. Calculating the brine rate at atm conditions.

$$W(_{atm}) = K \times h^{2.5} \times \rho_f \times 0.06 = 233.66 \text{ ton/ jam}$$

d. Calculating the James Factor

$$Y = \frac{Watm}{A \times P^{0.96}} = 0.123$$

e. Calculate fluid enthalpy

$$h = \frac{hg_{atm} + (925+Y)}{1+(7.85+Y)} = 1.419 \ kJ/\ kg$$

f. Calculate the total mass flow rate of the fluid

$$M_{total} = \left(\frac{0.184}{h^{1.102}}\right) x\, A_{lip}\, x\, P_c^{0.96}\, x\, 3600 = 423.09 \text{ ton/jam}$$

g. Calculate Dryness, M steam, M brine and Generation
Assuming flashing on P Separation = 10 barg
hf = 778.93 kJ/kg
hg = 2781.19 kJ/kg
hfg = 2002.26 kJ/kg

$$\text{Dryness} = \frac{\text{h}-\text{hf}}{\text{hfg}} \times 100\ (\%) = 31.97\%$$

h. Calculate M_{uap}
M_{uap} = M total X Dryness = 135.26 ton/jam

i. Calculate M Brine
$M_{brine} = M_{total} - M_{uap}$ = 287.84 ton/jam

j. Calculate Generation
$$\text{Generation} = \frac{\text{M uap}}{\text{Specific Steam Consumption}} = 16.9\ \text{MWe}$$

3. Analysis of Production Test Data

Russell James first tested the production of horizontal lip pressure pipes of various diameters. Based on the assumption that the absolute pressure at the end of the lip pipe is proportional to mass flowrate and enthalpy, Russell James made a correlation between enthalpy (h0) and w/p 0.96 which finally resulted in a formula connecting mass flow rate, fluid enthalpy and critical pressure at the end of the pipe lip. The accuracy of this test is not as accurate as the separator test, but this method is the most economical especially for production tests which are carried out routinely every certain period. Based on the production test conducted on the Z well, **Table 2** representative production data is obtained for each opening.

Based on the **Table 2**, the enthalpy contained in the total fluid has an average of 1515.3 kj/kg with an average dryness of 36.78% which indicates that the well fluid is a two-phase fluid with water dominance. It can also be seen that the maximum total mass flow rate is when the throttle valve is open by 100%, at the lowest wellhead pressure of 9.88 barg which results in a total mass flow rate of 423 tons/hour, brine rate of 287.84 tons/hour and steam rate 135.26 tons/hour. However, it can be seen that the lowest dryness is when the total mass rate is maximum but still produces the greatest electric potential, namely 16.9 MWe.

Table 2. Z-well production yield data at each opening [4]

Valve Open (%)	*WHP*	*Steam* (T/h)	*Brine* (T/h)	Total (T/h)	h (kJ/kg)	*Dryness* (%)	*Generation* (MWe)
100	9.88	135.26	287.84	423.09	1,419.0	31.97%	16.9
51	12.63	113.54	201.75	315.29	1,500.0	36.01%	14.2
39.7	15.87	89.17	139.22	228.39	1,560.7	39.04%	11.1
30	18.84	65.54	103.42	168.96	1,555.7	38.79%	8.2
25	19.04	50.85	82.72	133.57	1,541.2	38.07%	6.4

For optimal production, it is important to adjust the throttle valve opening by adjusting the pressure in the header and separator installed in the field, namely 10 barg so that the flow in the pipe from the well to the separator matches the designed setting.

Thus, optimal production is found between the throttle valve opening 51 to 100% so that the pressure received by the separator is in accordance with the settings that have been set. The following is a deliverability chart of the 5 samples taken.

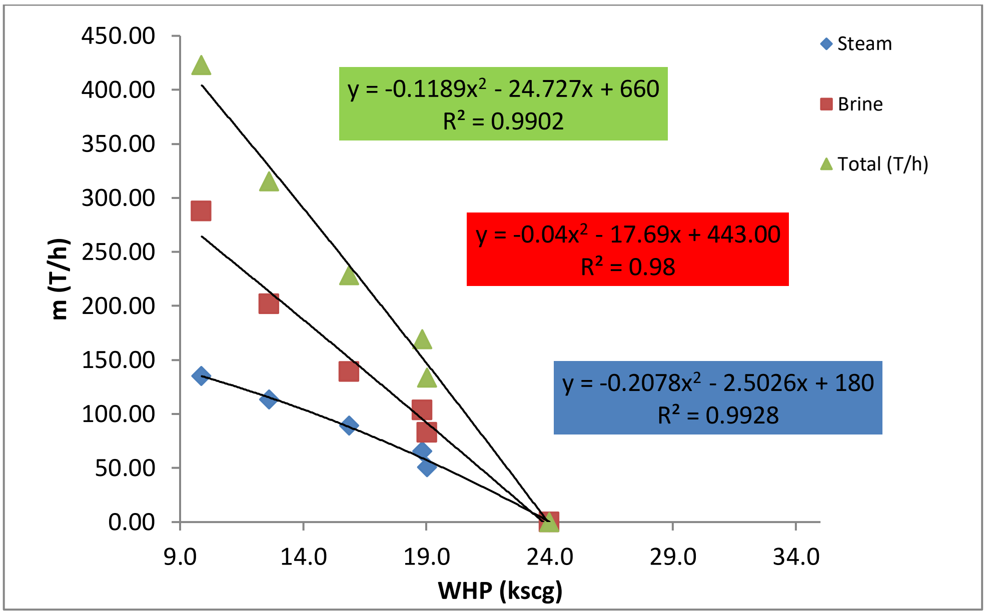

Figure 12. *Deliverability curve* [4]

From the relationship in the **Figure 12**, it can be seen that the lower the wellhead pressure, the higher the well fluid flow rate caused by the diameter of the valve opening where when it is opened to the maximum, more fluid discharge will flow because the fluid discharge is directly proportional to the area flow cross section.

4. Conclusion

Based on the results of the research conducted, several conclusions can be drawn:

1. The geothermal separation system at PGE Area Ulubelu field is a single flash system with a centralized separator and has 4 power plants, where units 1 & 2 belong to PLN and units 3 & 4 belong to PGE, each with a capacity of 55 MW.
2. The horizontal lip pressure production test conducted was tabulated in 5 types of throttle valve openings, namely 100%, 51%, 39.7%, 30%, and 25%.
3. The enthalpy contained in the total fluid has an average of 1515.3 kj/kg with an average dryness of 36.78%, indicating that the well fluid is a two-phase fluid dominated by water.
4. The maximum deliverability was obtained when the throttle valve was fully open (100%) at the lowest wellhead pressure of 9.88 barg with a total mass flow rate of 423 tons/hour, brine flow rate of 287.8 tons/hour, steam flow rate of 135.26 tons/hour, and has an electrical potential of 16.8 MWe.
5. The optimal production is between 51% to 100% throttle valve openings to ensure that the pressure received by the separator is in accordance with the set setting.
6. The lower the wellhead pressure, the higher the flow rate of the well fluid.

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