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Modified Isochronal Testing in Patuha-2 Geothermal Project, West Java, Indonesia

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ABSTRACT

Modified Isochronal Testing (MIT) was employed in the two production wells 2-X and 4-X in Patuha-2 Geothermal Project, West Java, Indonesia, to test its applicability as an alternative option of determining the Bore Output Curve (BOC) or well deliverability of production wells. Test results were in good agreement with the flow parameters derived from standard Medium-Term Discharge (MTD) Test using Tracer Flow Test (TFT) measurements and orifice pressure drop measurements. Test duration is the key difference between Modified Isochronal Testing and Medium-Term Discharge Test. The MTD Test usually requires 30 days to complete while the MIT method can accomplish the same objective in 3 to 4 days allowing timely utilization of the well to produce revenue. The deliverability or Bore Output Curves of Patuha wells were obtained in about 4 days using MIT method, significantly reducing programmed test duration by about 85%. This would also translate to considerable cost savings to the project.

1. BACKGROUND

The steam dominated Patuha Geothermal Field is located in West Java province of Indonesia and about 50 kilometers southwest from Bandung city. The Indonesian government assigned PT Geo Dipa Energi (GDE) in 2002 to continue development of Patuha after the financial crisis in 1998. GDE constructed the surface gathering system in 2011 and commissioned the first 55 MWe Patuha-1 power plant in September 2014. GDE has lately embarked on the 55 MWe Patuha-2 expansion and started the drilling campaign in December 2021.

Production wells 2-X and 4-X are the initial wells drilled and tested to address the steam requirement of Patuha-2 power plant. The back pressure method is usually applied to determine the output curve from both steam wells. However, it was found to be time consuming for the project, hence the applicability of Modified Isochronal Testing method was considered. This method aims to reduce the time used in testing the wells.

2-X was initially flowed on 10 March 2023 with the Flow Control Valve (FCV) at 42% well opening, after bleeding the Non-Condensable Gas (NCG) present in the well, through the 2-in bleed line. There is no brine flow recorded during the discharge test and pure steam discharge was observed in Low Emission Compact Muffler (LECM) with estimated discharge enthalpy 2,700 kJ/kg. Figure 1 below shows the discharge monitoring parameters at FCV 42%, 28% and 18% well openings. It can be seen the wellhead physical parameters stabilized quickly in a just a couple of days.

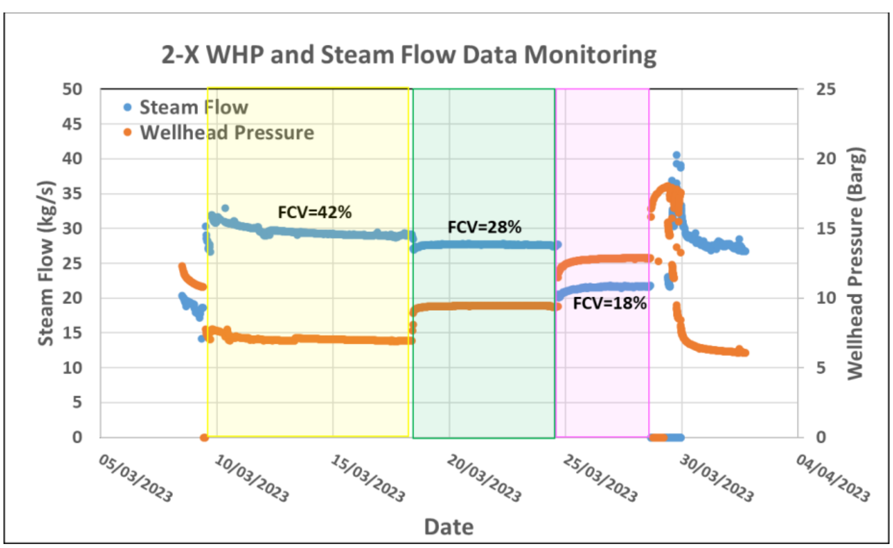

Figure 1: 2-X discharge monitoring parameters at FCV 42%, 28% and 18% well openings.

4-X was flowed at 100% FCV well opening on 16 May 2023 after bleeding the NCG through the 2-in bleed line. There is about 14–18% brine flow recorded during discharge test and high enthalpy two phase fluid discharge was observed in LECM with estimated discharge enthalpy 2,300 kJ/kg. Figure 2 below shows the discharge monitoring parameters at FCV 100% and 6% well openings. It can be seen the wellhead physical parameters also stabilized quickly within few days.

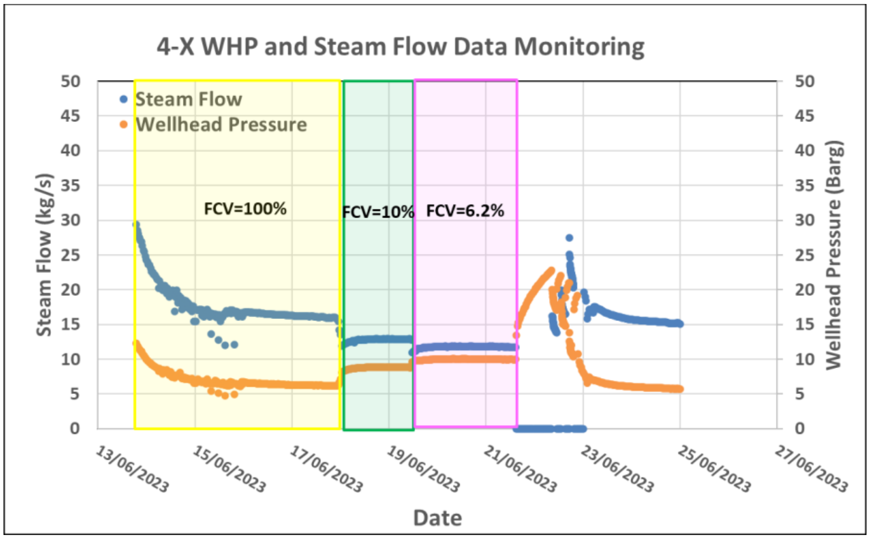

Figure 2: 4-X discharge monitoring parameters at FCV 100% and 6% well openings.

Here, we aimed to validate and confirm the applicability of Modified Isochronal Testing (MIT) method for steam dominated wells, as successfully applied in gas wells in the oil industry. We can then determine the 2-X and 4-X well output deliverability curve from the results of MIT method of analysis. Successful application of the MIT method would provide GDE the option to test the Patuha wells at shorter duration of less than 1 month.

2. MODIFIED ISOCHRONAL TESTING

2.1 Basis

The deliverability of gas wells is the capability of the gas to flow against a specific flowing bottomhole pressure (BHP). This is similar to the 'Bore Output Curves' (BOC) in the geothermal space. However, the BOC's employ wellhead pressures (WHP) in lieu of the BHP's. The MIT method aims to establish the output curve of 2-X and 4-X as the steam behaves like a perfect gas. Steam wells have near vertical pressure gradient, such that pressures at the wellhead approximate or reflect the bottomhole pressures of the well.

2.2 Methodology

The Modified Isochronal Testing MIT method is a shortened version of the original Isochronal Testing method, and the rate and pressure histories are presented in Figure 3 below.

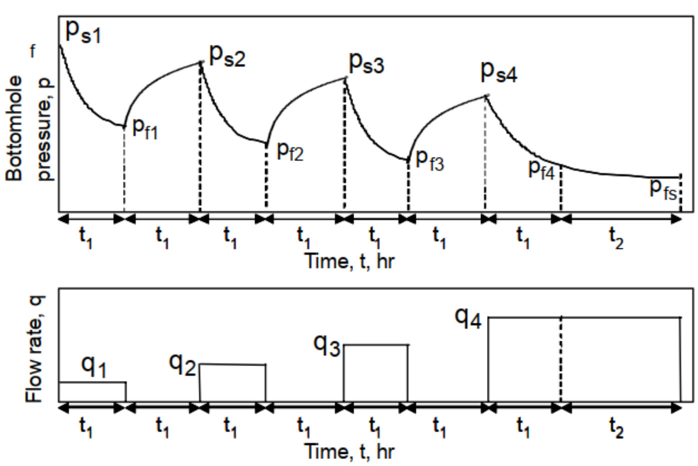

Figure 3: Modified Isochronal Testing MIT Methodology.

The well is flowed initially at small rate q_1 for time t_1 and the final flowing pressure (WHP) pf_1 is recorded. The well is then shut equivalent to time t_1 and the final shut-in pressure ps_2 is observed. The procedure is repeated for a total of 3 or 4 discharge rates. The final flow period in which the well approaches stabilization is desirable. Here the well is flowed to stable conditions at 100% FCV well opening and shut-in for the PBU test. The isochronal test in its modified form has the objective of eliminating the need to wait for the well to fully stabilize, especially in large or low permeability systems. This would then result to shorter test duration where significant time and cost is conserved.

2.3 Empirical Method of Analysis

Studies have shown that gas flow rate at surface condition is empirically related to flowing bottomhole pressure and average reservoir pressure by

$$q = C\left(p^2 - p_f^2\right)^n \quad (1)$$

where C, n are a form of productivity index and empirically determined exponent, respectively.

Equation 1 can be analyzed by plotting (p^2-pf^2) against q in logarithmic form. Figure 4 below shows typical plot of (p^2-p_f^2) against q where data points fall on a straight line with slope 1/n. The location of the line depends on the flow period. The points for the different rates define the straight line and the single stabilized point defines the location of the stabilized output curve.

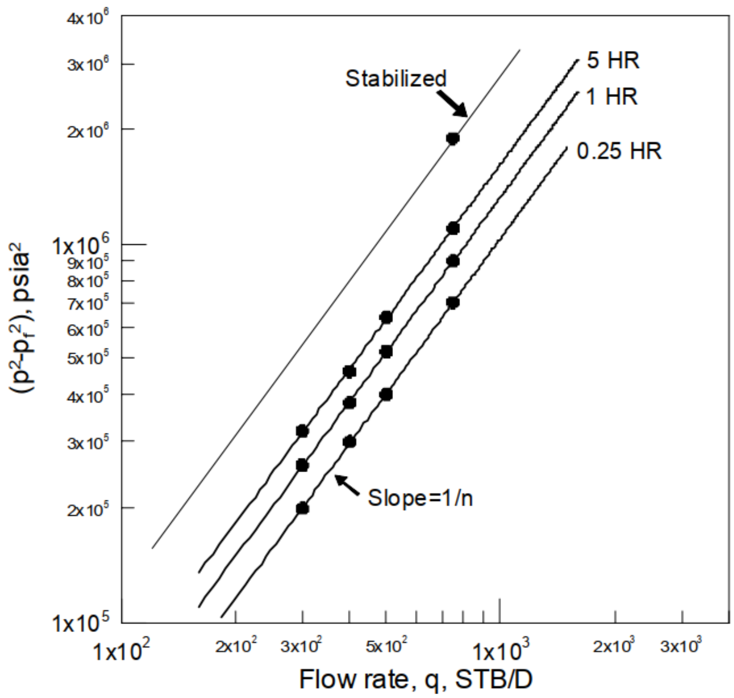

Figure 4: Log-Log Plot for the Empirical MIT Method of Analysis.

The stabilized output curve can then be entered as set values (p^2-pf^2) to estimate well flow rate for given drawdown. Alternatively, the plot can be used to estimate C (as intercept of stabilized curve) and n and the corresponding flow rate is calculated using Equation 1. For the modified isochronal test, shut-in pressures occurring immediately before the flow rate, are used instead of the average reservoir pressure. The constants C and n in Equation (1) depend on fluid properties such as pressure and therefore time dependent. If this type of deliverability curve is used, periodic retesting of the well will show changes in C and n.

Modified Isochronal Testing was then conducted in 2-X on 29-30 March 2023 with three FCV well openings starting from 18% FCV well opening to 28% FCV and 42% FCV well openings. Two (2) hours flow period and shut-in period were employed to address any wellbore storage effects during MIT. The well was then flowed at 100% FCV well opening for about 2.0 days prior to PBU test. A stable shut-in pressure of around ~18.0 barg is used and a stable steam flow of about ~28.0 kg/s is applied at 100% FCV well opening. Figure 5 below shows the wellhead pressures and estimated steam flows during the Modified Isochronal Testing.

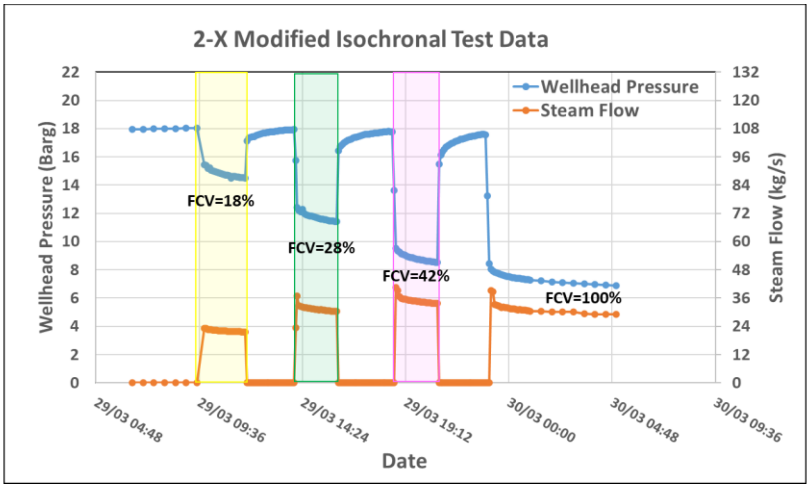

Figure 5: 2-X Modified Isochronal Test Data.

Modified Isochronal Testing was also conducted in 4-X on 22 – 24 June 2023 with three FCV well openings starting from 10% FCV well opening to 15% FCV and 25% FCV well openings. Two (2) hours flow period and shut-in period were also employed to address any wellbore storage effects during MIT. The well was then flowed at 100% FCV well opening for about 2.0 days prior to PBU test. A stable shut-in pressure of around ~22.0 barg is used and a stable steam flow of about ~15.0 kg/s is applied at 100% FCV well opening. Figure 6 below shows the wellhead pressures and estimated steam flows during the Modified Isochronal Testing.

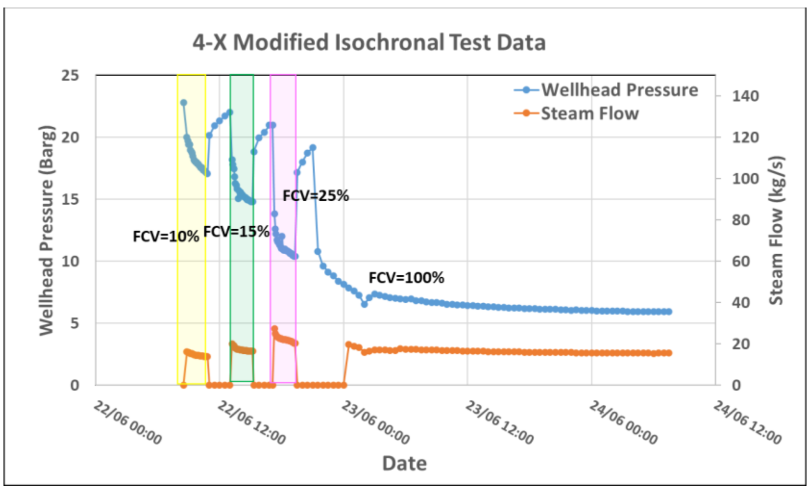

Figure 6: 4-X Modified Isochronal Test Data.

2.4 Results

Table 1 summarizes the 2-X data to be used in Modified Isochronal Test analysis. We employed standard SI units for Pressure in kPa and steam flow q in kg/s.

Table 1: 2-X Modified Isochronal Test Data Analysis.

% FCV	ΔP WHP (barg)	ΔP SF (kg/s)	SF (kg/s)	P Shut In (kPag)	P Flow (kPag)	p^2-p_f^2 $(kPaa)^2$	log SF	log ($p^2 - p_f^2$)
18	12.87	21.70	21.65	1805	1451	1153353	1.3355	6.0620
28	9.36	27.60	30.37	1793	1142	1912026	1.4824	6.2815
42	6.95	29.00	33.69	1778	852	2437287	1.5275	6.3869
100	n/a	n/a	28.00	1800	608	2872791	1.4472	6.4583

For convenience, the MIT data were plotted in linear axes for log (p^2-p_f^2) against log q (or log SF) from which the constants n and C can be obtained. Figure 7 shows the plot of 2-X Modified Isochronal Test data.

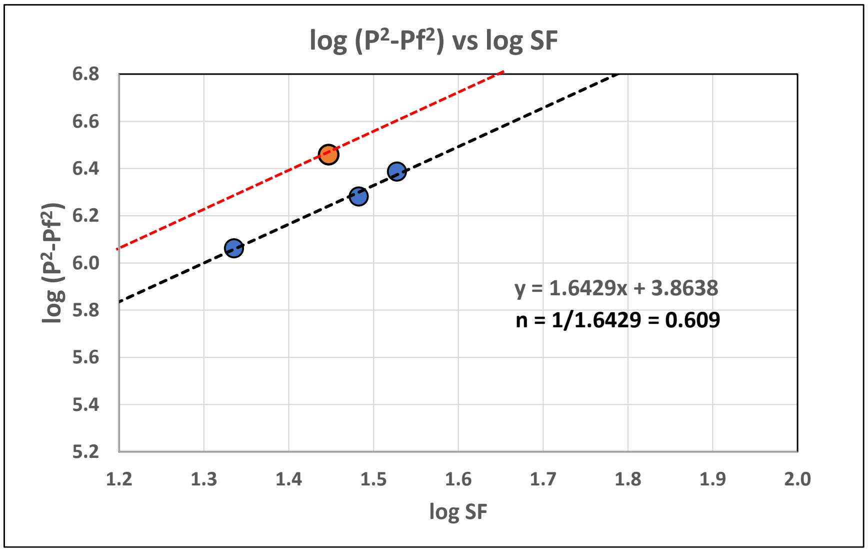

Figure 7: Plot of 2-X Modified Isochronal Test Data.

The slope of the best straight line will give n = 0.609. The y-intercept of the line with same slope passing through the stabilized point determines the constant C. Therefore,

$$C = \frac{q}{(p^2 - p_f^2)^n} = 3.27x10^{-3}$$

The empirical deliverability equation for steam flow becomes:

$$q = 3.27x10^{-3}[1800^2 - WHP^2]^{0.609}$$

Table 2 also summarizes the 4-X data to be used in Modified Isochronal Test analysis. We also employed standard SI units for Pressure in kPa and steam flow q in kg/s.

Table 2: 4-X Modified Isochronal Test Data Analysis.

% FCV	ΔP WHP (barg)	ΔP SF (kg/s)	SF (kg/s)	P Shut In (kPag)	P Flow (kPag)	p^2-p_f^2 (kPaa)^2	log SF	log ($p^2 - p_f^2$)
10	n/a	n/a	13.86	2282	1707	2292535	1.14	6.36
15	n/a	n/a	16.47	2200	1479	2651686	1.22	6.42
25	n/a	n/a	20.31	2100	1038	3332980	1.31	6.52
100	6.18	16.04	15.08	1917	571	3347502	1.18	6.52

The MIT data were also plotted in linear axes for log (p^2-p_f^2) against log q (or log SF) from which the constants n and C can be obtained. Figure 8 shows the plot of 4-X Modified Isochronal Test data.

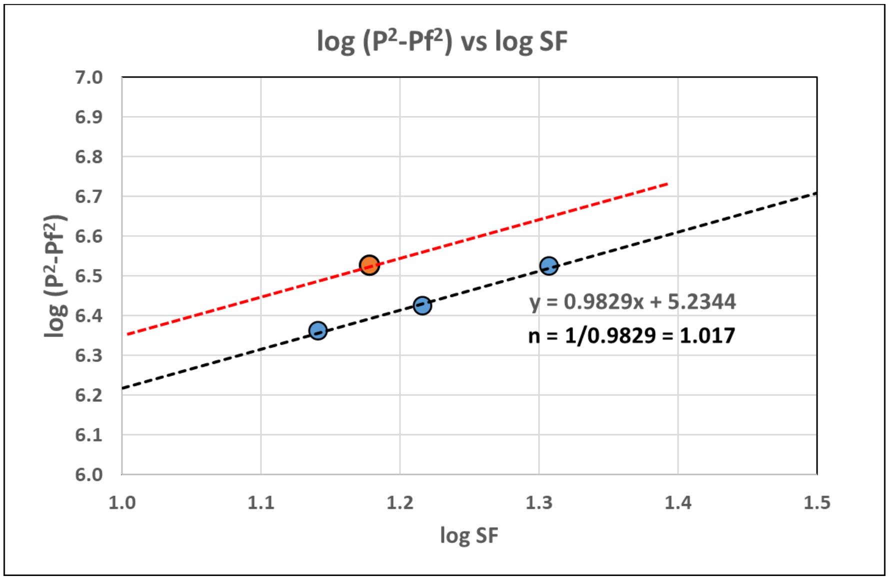

Figure 8: Plot of 4-X Modified Isochronal Test Data.

The slope of the best straight line will give n = 1.017. The y-intercept of the line with same slope passing through the stabilized point determines the constant C. Therefore,

$$C = \frac{q}{\left(p^2 - p_f^2\right)^n} = 2.77x10^{-2}$$

The empirical deliverability equation for steam flow becomes:

$$q = 2.77x10^{-2}[2282^2 - WHP^2]^{1.017}$$

3. DELIVERABILITY OUTPUT ESTIMATES

Figure 9 shows the 2-X estimated deliverability output curve generated for given WHP. The output curve showed conservative estimates of steam flows using MIT method compared to the steam flows derived from orifice ΔP measurements (FCV well openings 18%, 28% and 42%). Moreover, the output curve produced very good match to the steam flows calculated from TFT measurements.

2-X is estimated to produce a steam flow at around ~25.0 kg/s at target delivery pressure of about 10 Barg. This steam flow translates to a potential power output at around ~12.0 MWe assuming a nominal steam conversion rate SR=2.1 kg/s steam per 1 MWe output generated.

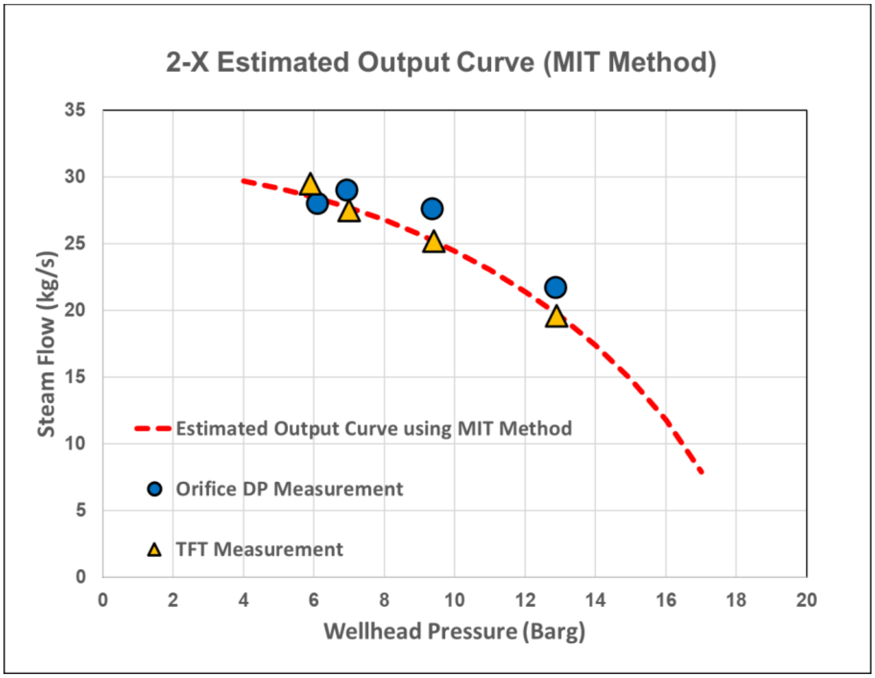

Figure 9: Plot of 2-X Estimated Output Curve.

Figure 10 also shows the 4-X estimated deliverability output curve generated for given WHP. The output curve showed conservative estimates of steam flows using MIT method compared to the steam flows derived from orifice ΔP measurements (FCV well openings 100% and 6%). Moreover, the output curve also produced quite good match to the steam flows from ΔP measurements and calculated from TFT measurements. Comparing with 2-X which doesn't produce brine during discharge test, 4-X produced a little amount of brine that would explain the differences of estimated steam flow between MIT method, TFT and ΔP measurements.

4-X is estimated to produce a steam flow at around ~13.0 kg/s at target delivery pressure of about 10 Barg. This steam flow translates to a potential power output at around ~6.1 MWe assuming a nominal steam conversion rate SR=2.1 kg/s steam per 1 MWe output generated.

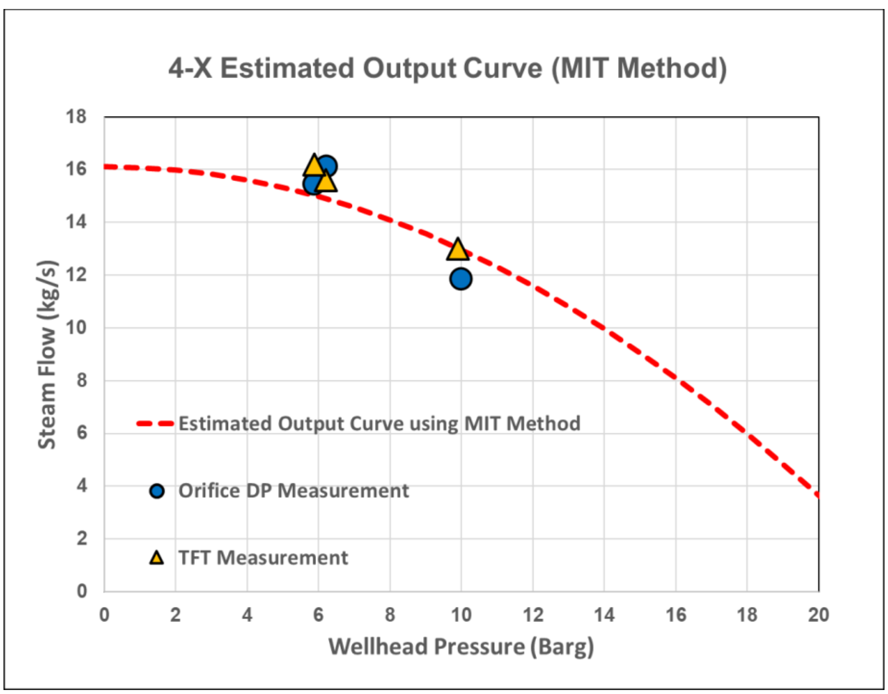

Figure 10: Plot of 4-X Estimated Output Curve.

4. MIT RESULTS SUMMARY

The following salient points are obtained from the conduct of Modified Isochronal Testing MIT method to determine the deliverability output curve of 2-X and 4-X:

a. The applicability of Modified Isochronal Testing MIT method was successfully demonstrated to steam dominated geothermal well.
b. The deliverability output curve derived from empirical method of analysis gave very good match to the TFT steam flow data and ΔP measurements for 2-X and quite good match for 4-X.
c. 2-X is estimated to produce a steam flow at around ~25.0 kg/s at target delivery pressure of about 10 Barg. This steam flow translates to a potential power output at around ~12.0 MWe assuming a nominal steam conversion rate SR=2.1 kg/s steam per 1 MWe output generated. Meanwhile, 4-X is estimated to produce a steam flow at around ~13.0 kg/s at target delivery pressure of about 10 Barg. This steam flow translates to a potential power output at around ~5.7 MWe assuming a nominal steam conversion rate SR=2.1 kg/s steam per 1 MWe output generated .
d. It can be shown the MIT method could only take about ~25% of the planned discharge test duration to characterize the steam well and obtain the output curve thereby saving GDE appreciable time and cost in conducting the flow test.
e. The applicability of MIT method can be validated in highly two-phase Patuha wells with discharge enthalpies >2,400 kJ/kg.

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