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Utilizing Vertical Discharge Tests as an Effective Means for Well Decision Making at the Darajat Geothermal Field, Indonesia

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ABSTRACT

Vertical Discharge Tests using James' Lip Pressure formula has been employed at the Darajat Geothermal Field during the 2007 – 2008 make-up well drilling program. The tests proved to be highly useful in providing preliminary estimations of newly drilled wells' likely deliverability relatively quickly. These preliminary deliverability rates, resulting from four vertical discharge tests, were utilized in the make-up well decision making process. The ability to estimate new well flow rates in a timely manner has significantly improved the make-up well decision making quality, allowing for the efficient use of available capital.

Limitations of the application of James' lip pressure formula were experienced, as the tests were carried out using 10" and 12" diameter pipes for the tests, larger than the proscribed maximum size (8") for James' formula to apply. The objective of using larger diameter pipes was to minimize the restriction effects of a smaller diameter throat and to reduce potential vibration caused by the anticipated high rate steam discharges. These expected high initial flow rates were based on historical Darajat field data, where the average initial well rates in the field are capable of producing 20 MWe at a wellhead discharge pressure of 17.5 bara. Comparisons of vertical discharge and modified multi-rate isochronal tests results were undertaken out to quantify the error in measured flow rates between the two methods. This paper will make some attempt to optimize the use of the James' formula for larger diameter pipes for future well flow rate testing capacity determination.

1. INTRODUCTION

The Darajat geothermal field is located in Garut Regency, West Java Province, Indonesia, about 35 km southeast of Bandung (capital city of West Java Province). The field has now been under commercial exploitation since November 1994 and currently generating 259 megawatts of electricity which is fed into the national electrical grid system. Figure 1 shows the location of Darajat field and its adjacent geothermal fields, Kamojang geothermal field to the northeast and Wayang Windu field to the west.

Vertical discharge testing of newly drilled geothermal well has been a common practice in geothermal industry, but recently such test has been avoided due to noise and environmental issues associated with the noise.

During the drilling campaign 1996-1998, Darajat field utilized vertical discharge testing at 2 out of 12 wells drilled to quickly estimate the deliverability of the drilled wells to improve the decision making process made while the drilling program was in progress.

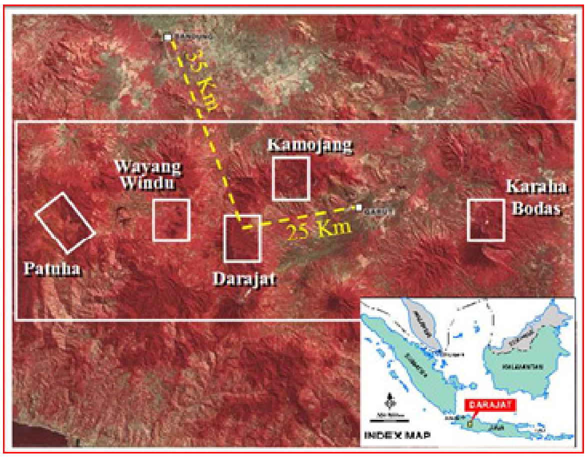

Figure 1: Location of the Darajat geothermal field relative to other volcanic activities and other geothermal fields.

A similar approach was used during Darajat Make up Well Drilling Campaign 2007 – 2008. Seven make up wells were drilled to meet the demand of steam as a result of the commercial operation of the Unit-III power plant (110 MW). At least three wells were tested with the vertical discharge method and followed by regular multirate isochronal flow tests to develop deliverability curves of individual wells, prior to connecting the wells into the steam gathering system.

2. FLOW TESTING PRACTICE AT DARAJAT

After the drilling program had been completed, the completion test is conducted on the wells to measure the capacity of the wells. The purpose of this completion test is to get the information about: the productive zones (feed zones), the reservoir type, the temperature and pressure along the well bore, the well capacity, and the fluid and gas characteristics. The sequence of the completion test is explained below:

- Injection Pressure and Temperature Spinner Survey

This survey is performed by injecting cold water into the well with a constant rate to measure the pressure and temperature in the well bore to get information about the P and T well profile during the injection test. In Darajat, usually use two injection rates, 20 BPM and 25 barrels per minute (BPM). Using the pressure and temperature (P and T) profiles and the relative spinner revolution count in the well bore, the location of the productive zones and the well productivity (Productivity Index) can be determined.

- Heat Recovery PT Survey

Heat Recovery tests are conducted by measuring the P and T data in the well bore using PT tools, to gauge the feed zones' permeability, as a function of heat recovery rate. These surveys are performed at the following intervals after injection has stopped: 24 hr, 3 days, 5 days, and 11 days onward until such time as the wellbore completely heats up and has attained reservoir pressure and temperature. If the well attains reservoir P and T quickly, it means that the well has a good rock permeability. Below is the example of the heat recovery result from Well DRJ-27.

- Modified Isochronal Test

The purpose of this test is to get the flow rate data for developing the output curve (well deliverabilty curve). The other purpose is to collect geochemistry data, such as steam purity, steam quality, total NCG, and also condensate.

In analyzing data, an approach has been utilized, using the method known as AOFP (Absolute Open Flow Potential), commonly referred to as “Deliverability”. The estimation of the deliverability is based on field measured data during the flow test.

Using an empirical equation adopted from gas well engineering practices, the production data are calculated to construct a deliverability of each individual well and in determining other parameters, such as values of C (an empirical constant) and n (turbulence factor, between 0.5 to 1).

Assuming steam is dry saturated and behaves like the perfect gas, the following empirical equation, adapted from gas well engineering practices applies:

$$W(AOFP) = C\left(P_{shut-in}^2 - P_{wf}^2\right)^n \quad (1)$$

Where AOFP (W) is Absolute Open Flow Potential, Steam production rate (kg/s)

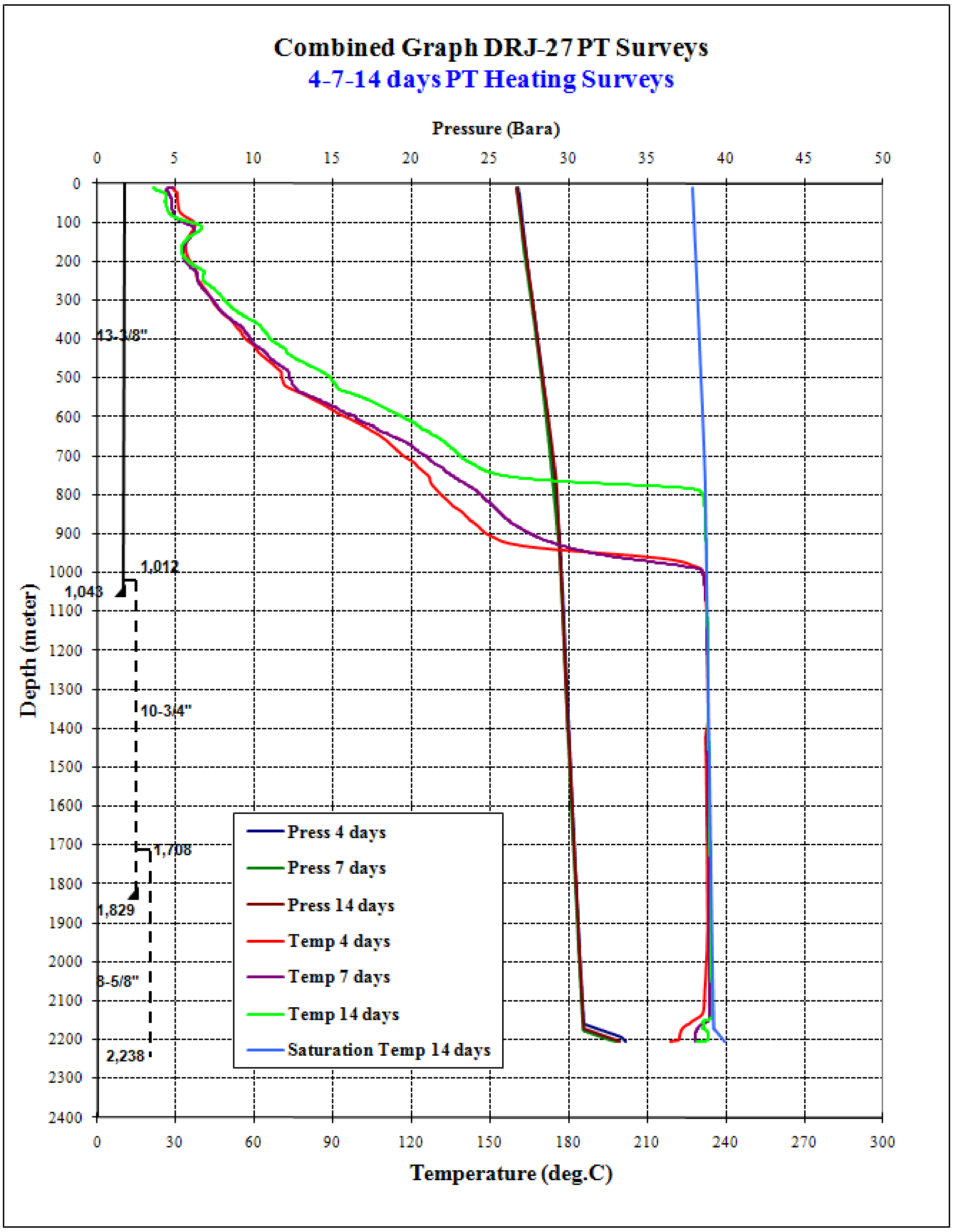

Figure 2. DRJ-27 Heat Recovery Survey.

$$\Delta P^2 = P_{shut-in}^2 - P_{wf}^2 \qquad (2)$$

Where P shut-in, Pwf, n, C (empirical parameters) are Shut-in pressure (bara), Pressure flowing at the bottom of the wells (in Darajat field using Wellhead pressure, bara), An empirical parameters, often known as the turbulence factor, Lying between, $0.5 < n < 1$, where $n = 0.5$ is turbulent; $n= 1$ is laminar flow and constant, depend on the unit of W and Pressure.

The test method that usually employed in Darajat is the Modified Isochronal Test. The well is tested for a fixed period of time and pressure is measured at the end of that period. The procedure is then repeated at other rates, and ended with extended flow for pressure stabilization. The well is discharged horizontally through a rock muffler and shut in for the same duration, 12 hrs discharge to atmosphere and 12 hrs for shut in. Orifice plate method is used for the flow rate calculation.

The data below is the result from DRJ-27 Modified Isochronal Test.

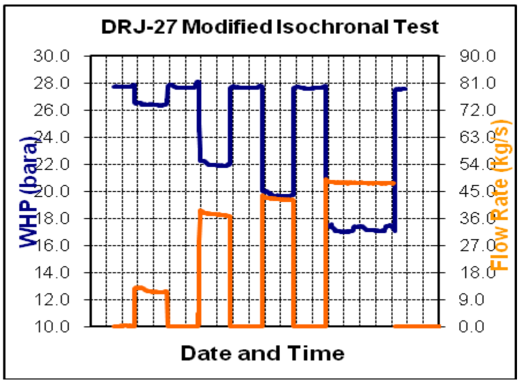

Figure 3. DRJ-27 Modified Isochronal Test Result.

From the data above, the deliverability curve can be generated to get the capacity of the well. The calculation to generate deliverability curves is explained in section 3.2. Below is the deliverability chart for DRJ-27.

-Flowing Pressure and Temperature Spinner Survey

Basically this test is performed to get the feed zone data and flow contribution of the feed zones. From the PT Spinner flowing data, feed zones can be detected from the change of the spinner rotation of the tools. For example in figure 5, possible feed zones can be estimated at 1158 m and 1417 m. And also the fraction flow of each feed zones can be determined. Finally the calculation result from this PT Spinner flowing data will be compared with the result from injection PT Spinner to determine whether there is any changes in the feed zone and fraction flow.

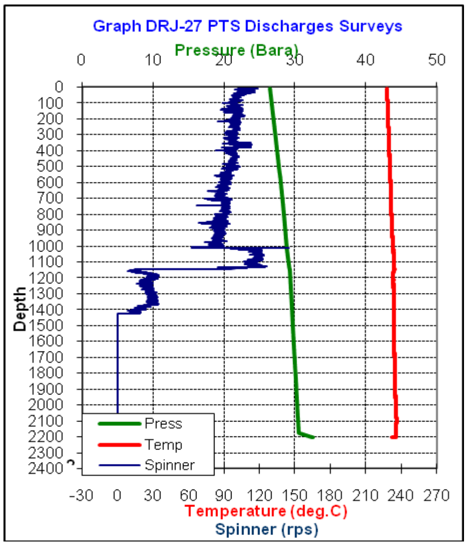

Figure 5. DRJ-27 PT Spinner Survey

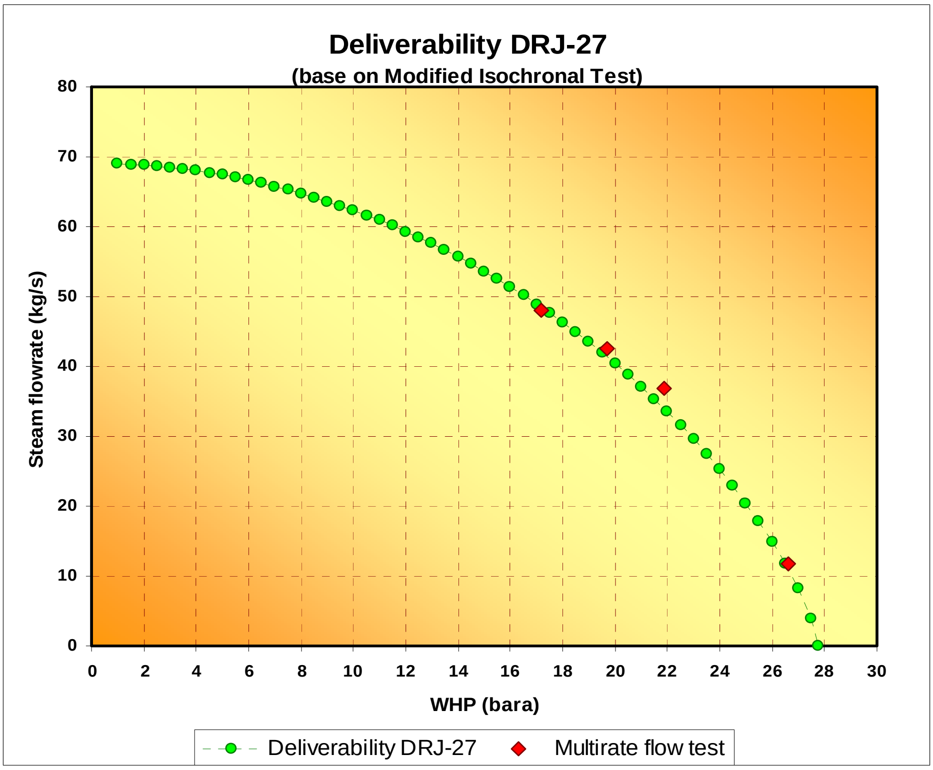

Figure 4. DRJ-27 Deliverability curve.

3. VERTICAL DISCHARGE TEST USING JAMES LIP PRESSURE METHOD

Different than horizontal test, in the vertical discharge test the steam discharges directly to atmosphere through a lip pipe. Basically this is aimed to clean up the well and also to know the capacity of the well by measuring the flow rate using lip pressure data.

The method that was used for flow rate (discharge) calculation is derived from Russel James' equation. Russel James equation has the following formula:

$$W = \frac{\left(1.444 \cdot 10^{6} \cdot Pc^{0.96} \cdot dc^{2}\right)}{ho^{1.102}} \qquad (2)$$

Where W, Pc, dc, ho are total mass flow rate in kg/s, critical Pressure in bar absolute, inside diameter of lip pipe in meter, enthalpy in kJ/kg.

The flow test for this well is open about 2 hours. The well is opened starting from high wellhead pressure then to the lower wellhead pressures. For each wellhead pressure the well is adjusted around every 15 minutes. And for the lowest wellhead pressure (15 bara) is opened around 25 minutes.

3.1 Test Objective

Utilization of vertical discharge test in Darajat has very important for the decision making process. With the commencement of operations in 2007 of the 110 MW Unit III power plant, additional steam supply capacity was required to maintain all units at their rated capacities. To obtain reliable information about the steam capacity of newly drilled wells, the sequence of completion testing had to be performed in the most time efficient manner, but achieving qualitative and quantitative results. Using Modified Isochronal testing, would have taken about 2-3 weeks to get a complete data set to characterize the production flow profile. The use of vertical discharge testing provided an alternative to getting the data about the well's capacities, while reducing the information cycle time. Use of the vertical discharge test allowed for gathering the required data in less than 1 day. This was preferable, as long as the data quality was acceptable. The results of the vertical well tests are discussed below.

3.2 Flow Test Result

Vertical discharge were conducted at several wells at Darajat in 2007-2008, namely DRJ-28, DRJ-29 and DRJ-30. The last vertical discharge test prior to this was conducted at DRJ-13 in 1996. This test is one of the most economical and simple methods to determine flow rate in geothermal well testing. The vertical discharge test used lip pipe with 12 inch inside diameter. Lip pipes were installed directly above the master valve at the top of the well head. During this test, we let the steam flow directly to the atmosphere through the lip pipe. From the test, we can gather the lip pressure data that will be use to determine the flow rate of the steam.

The first well that was tested was DRJ-29. This well was opened on 17 November 2007. This test was conducted for only 2 hours. The short length of the test was required for safety reasons, due to the drilling rig being on an adjacent well. Drilling was suspended for a few hours to accommodate the test and gather the desired flow rate data. The well was adjusted to several wellhead pressures at relative quick intervals. The well opening was started from high wellhead pressure then to the lower wellhead pressure. The opening test pressure for discharge started from 30 bara, then down in increments to the lowest wellhead pressure of 15 bara. For the calculation, a shut in pressure of 32.91 bara was used.

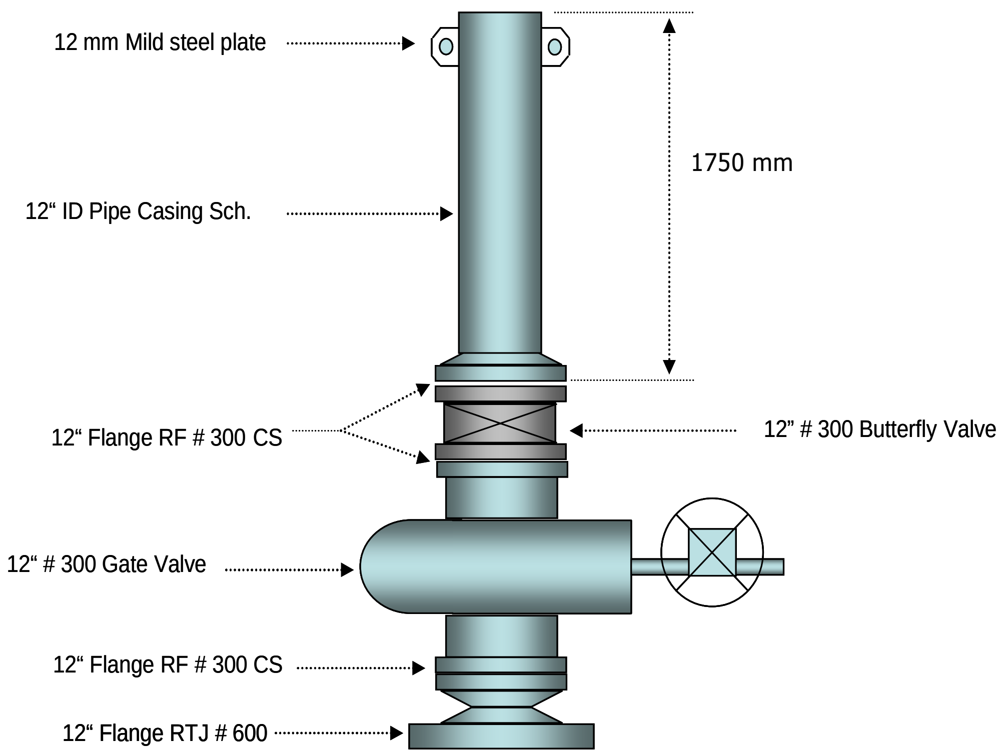

Figure 6. Vertical Discharge Test Configuration.

From the flow test program, data for each well head pressure was collected and then was used to calculate the flow rate of steam. The average flow rate for each well head pressure can be seen in the Table 1 below.

Table 1. DRJ-29 Vertical Discharge Test Result

Flow	Duration minutes	Pflow bara	Steam rate Kg/s
1	15	27.10	23.12
2	15	25.12	27.77
3	15	21.82	33.27
4	15	20.11	35.59
5	15	17.66	37.13
6	25	15.07	42.68

For the data acquisition, a data logger was used to compile support data for mass flow calculation. The supporting data consisted of Well Head Pressure in Bara, Lip Pressure in Bara, and Temperature in degrees Celcius. Figure 7 below is the raw data from the data logger:

The next two wells which were tested are DRJ-28 and DRJ-30. Different from the previous well, these wells used a 10 inch lip pipe diameter. Using the smaller diameter, it was expected that the accuracy data could be increased, based on the work by James. Below are the data from DRJ-28 and DRJ-30.

Table 2. DRJ-28 Vertical Discharge Test Result

Flow	Duration minutes	Pflow bara	Steam rate Kg/s
1	15	24.41	27.95
2	15	20.64	36.19
3	15	17.54	46.44

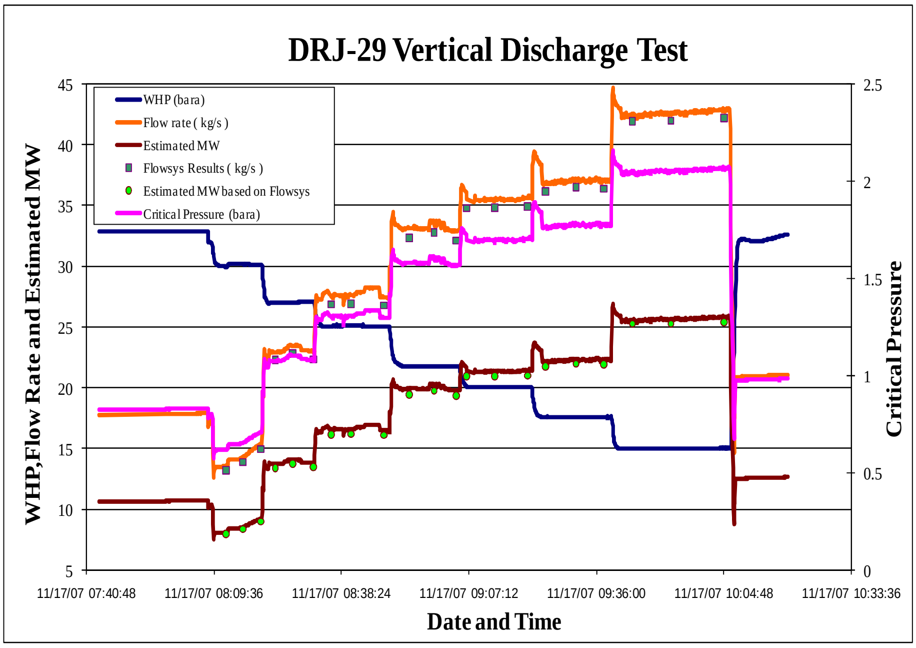

Figure 7. DRJ-29 Vertical Discharge Test Data.

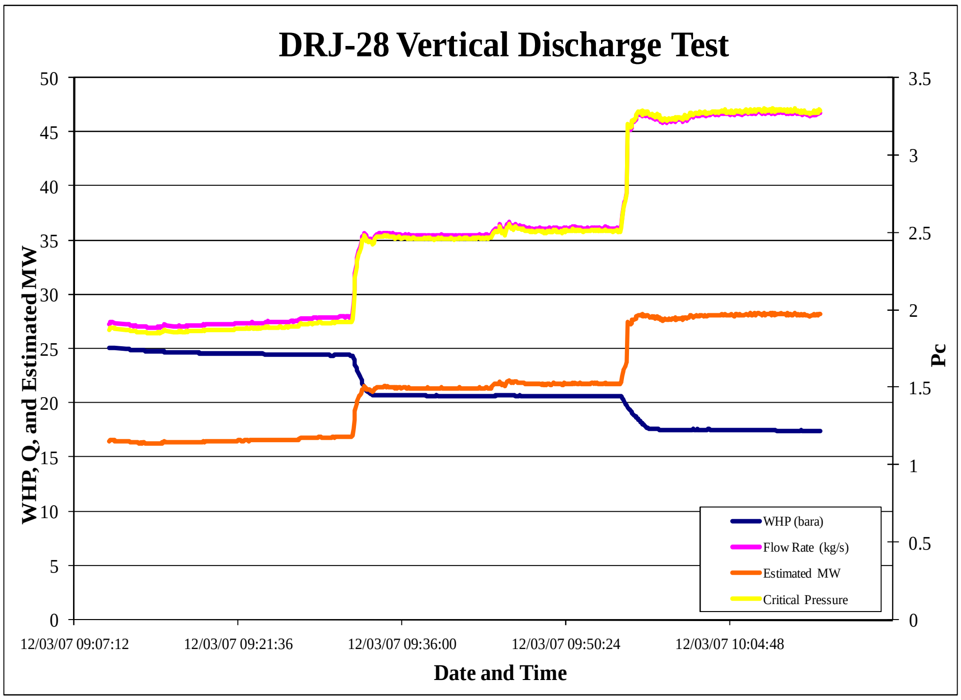

Figure 8. DRJ-28 Vertical Discharge Test Data.

Table 3. DRJ-30 Vertical Discharge Test Result

Flow	Duration minutes	Pflow bara	Steam rate Kg/s
1	15	20.00	34.55
2	15	17.57	38.78
3	15	24.95	21.60
4	15	27.99	15.37

3.3 Data Analysis

Using the plot of log (Q) and log (ΔP^2), the C and n value for deliverability equation can be determined. The intercept is equal to log C and the slope represents n value.

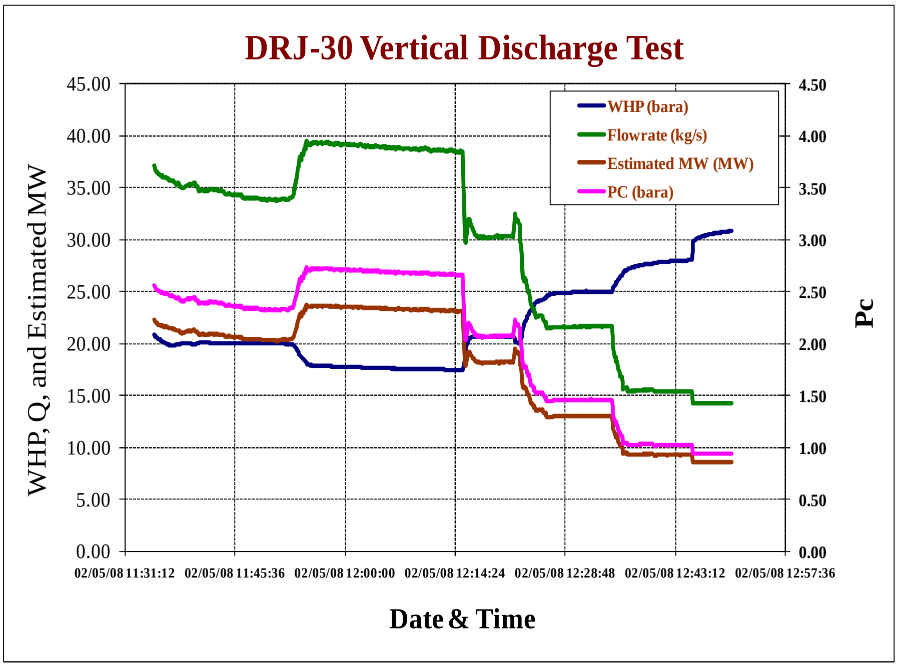

Figure 9. DRJ-30 Vertical Discharge Test Data.

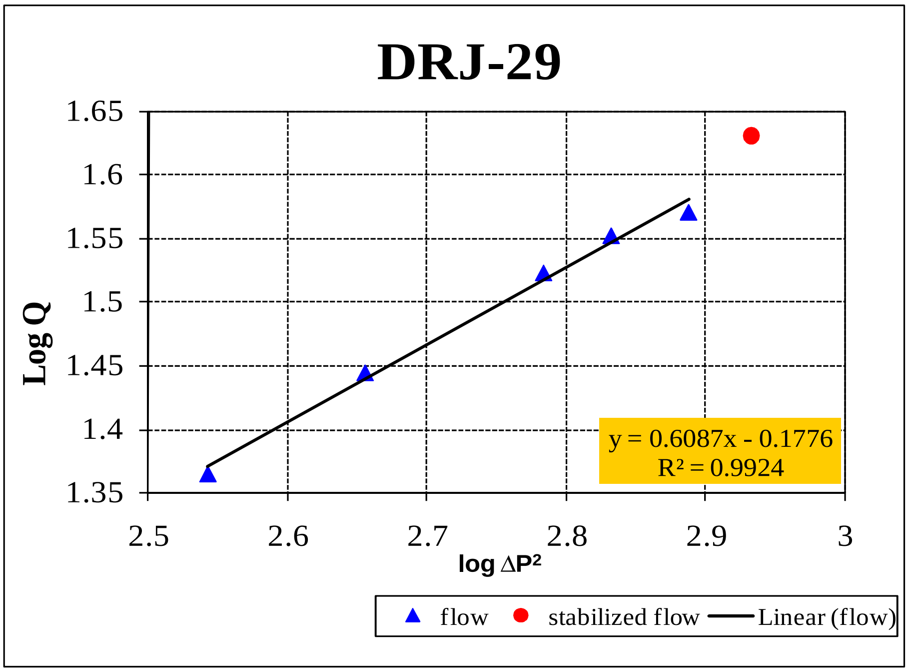

Figure 10. DRJ-29 Log-Log Plot Calculation.

Based on the log-log plot above, the deliverablity of DRJ-29 based on Vertical Discharge :

$$Q = 0.70023\left(P_{shut\ in}^{2} - WHP^{2}\right)^{0.6087} \quad (3)$$

And the deliverablity graph is shown below

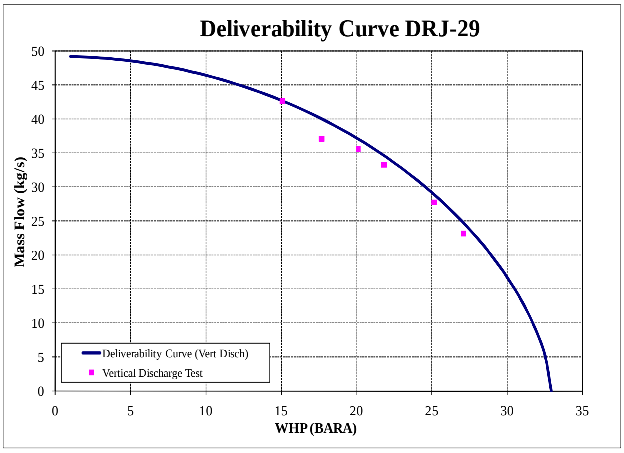

Figure 11. DRJ-29 Deliverability Curve.

With the same calculation procedure, below are the deliverability curves for DRJ-28 and DRJ-30.

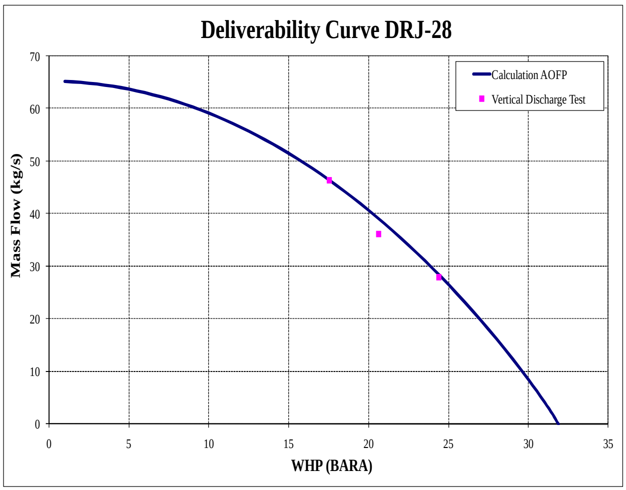

Figure 12. DRJ-28 Deliverability Curve.

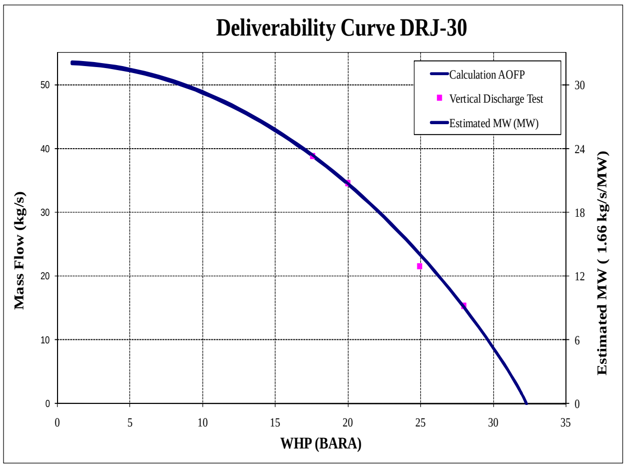

Figure 13. DRJ-30 Deliverability Curve.

4. THE COMPARISON OF VERTICAL DISCHARGE TEST VS ISOCHRONAL TEST

After the vertical discharge tests had been completed, the modified isochronal test were still conducted to get more accurate data of the steam capacity of each well. From these results comparisons were made with the vertical discharge tests. Below are the comparison deliverability curves of DRJ-29, DRJ-28, and DRJ-30.

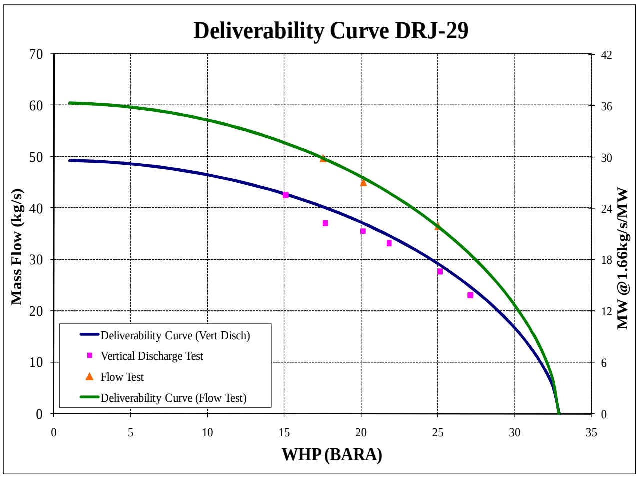

Figure 14. DRJ-29 Comparison Curve.

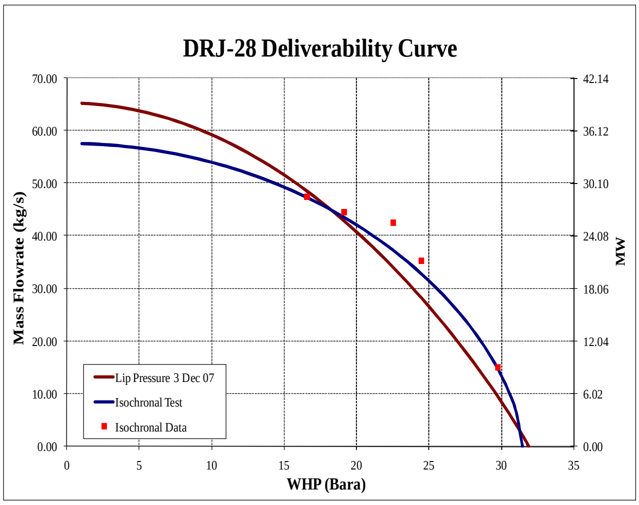

Figure 15. DRJ-28 Comparison Curve.

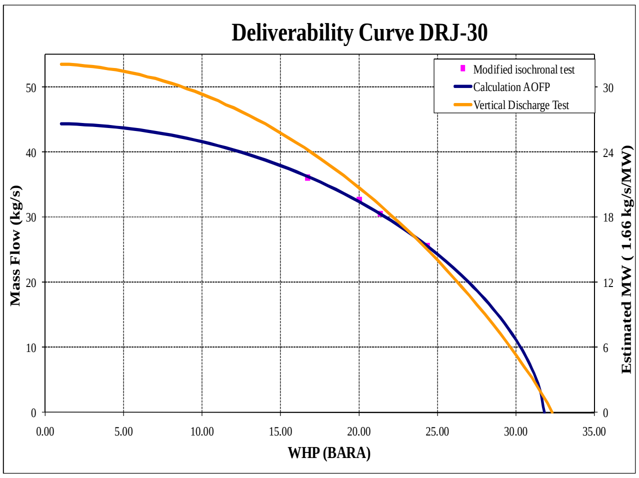

Figure 16. DRJ-30 Comparison Curve.

As mentioned before that there is a different lip pipe diameter size for those 3 wells. DRJ-29 used a 12 inch pipe, while DRJ-28 and DRJ-30 use a 10 inch pipe. The reasoning behind the use of the smaller diameter for DRJ-28 and DRJ-30, was because during the test at DRJ-29, the parabolic plume shape of steam just above the lip pipe was not well developed.

From the comparison curves, it can be seen that for DRJ-29 the discrepancies between the vertical discharge test and the modified isochronal test results is relatively larger than DRJ-28, and 30. The table below illustrates the discrepancies of each well.

Table 4. DRJ-29 Comparison Table.

Mod Iso Test		Vertical Dis Test		% Discrepancies
WHP (bara)	Q (kg/s)	WHP (bara)	Q (kg/s)	
1	60.42	1	49.23	-18.52
4	59.92	4	48.81	-18.55
7	58.82	7	47.88	-18.60
10	57.10	10	46.43	-18.68
13	54.71	13	44.42	-18.80
16	51.58	16	41.80	-18.96
19	47.62	19	38.48	-19.18
22	42.65	22	34.35	-19.48
25	36.41	25	29.17	-19.88
28	28.29	28	22.50	-20.47
31	16.58	31	13.04	-21.36

From the table above, it can be seen that at all WHPs, the Vertical Discharge result is under the Modified Isochronal Test. This is probably due to the inaccuracy of the data due to using the 12 inch lip pipe.

Table 5. DRJ-28 Comparison Table.

Mod Iso Test		Vertical Dis Test		% Discrepancies
WHP (bara)	Q (kg/s)	WHP (bara)	Q (kg/s)	
1	57.63	1	65.22	13.16
4	57.10	4	64.31	12.62
7	55.92	7	62.30	11.41
10	54.06	10	59.20	9.49
13	51.48	13	54.97	6.79
16	48.10	16	49.62	3.18
19	43.79	19	43.12	-1.53
22	38.37	22	35.43	-7.67
25	31.45	25	26.48	-15.82
28	22.18	28	16.16	-27.17
31	6.48	31	4.10	-36.68

Table 6. DRJ-30 Comparison Table.

Mod Iso Test		Vertical Dis Test		% Discrepancies
WHP (bara)	Q (kg/s)	WHP (bara)	Q (kg/s)	
1	44.27	1	53.29	20.39
4	43.86	4	52.59	19.93
7	42.94	7	51.06	18.91
10	41.50	10	48.67	17.28
13	39.50	13	45.43	15.00
16	36.89	16	41.30	11.94
19	33.59	19	36.26	7.95
22	29.46	22	30.27	2.76
25	24.24	25	23.25	-4.08
28	17.38	28	15.06	-13.37
31	6.72	31	5.31	-20.99

For the DRJ-28 and 30 comparison tables, it shows that the average discrepancy is less than DRJ-29, due to use of the 10 inch lip pipe diameter, which is close to James' equation based on his experiments using 8 inch. The discrepancies tend to decrease when the WHP is in the mid range of wellhead pressures. The larger deviations at higher wellhead pressures may be due to the plume being less well developed and not achieving the expected parabolic shape near the pipe lip. For lower wellhead pressures and higher flow rates the inaccuracy may be due to the high vibration rates experienced at the top of the discharge pipe resulting in poorer data at these very high flow rates. It is interesting to note that while the average error is largest when using the 12 inch lip pipe in DRJ-29, the overall variation in error is significantly less.

5. SUMMARY

Use of the vertical discharge method was a highly efficient mechanism is quickly assessing some of the newly drilled Darajat Geothermal field wells during the drilling program in 2007-2008. The initial 2007-2008 drilling program plan called for drilling 8 additional wells during that program to achieve the required steam supply. The steam capacity of each newly drilled well was very important data. Use of the vertical well testing method assisted in deciding whether the drilling program would be continued or not. The ability to quickly assess well deliverability was instrumental in facilitating the making of informed decisions. As a result of the vertical well tests, drilling was halted after 7 of the planned 8 wells. With the information for the vertical well tests, additional new well drilling was avoided saving millions of dollars in capital costs.

Accuracy of the data from the DRJ-28 and 30 vertical discharge tests utilizing the 10 inch lip pipe were within approximately 10% or less of the horizontal tests using orifice plate measurements at the expected wellhead operating range of 17.5 to 22 bara. This level of accuracy was acceptable in the decision making and planning process for the drilling campaign and the vertical discharge testing will be used again in the future when the situation warrants.

Further work needs to be done and more data collected in future test to improve on the accuracy of the data and incorporated into the James empirical equation for use in larger diameter lip pipes. The near consistent error in the data when using the 12 inch lip pipe is an interesting phenomenon that needs further exploration. This consistent deviation would lend itself more to a modification of the James' equation than the spread on the deviations when using the 10 inch lip pipe.

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