

A Comprehensive Well Testing Implementation during Exploration Phase in Rantau Dedap, Indonesia

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ABSTRACT

This paper describes the implementation of comprehensive well testing programs during the 2014-2015 exploration drilling in Rantau Dedap Geothermal Field. The well testing programs were designed to provide reliable data as foundation for resource assessment as well as useful information for decision making during drilling. A series of well testing survey consisting of SFTT, completion test, heating-up downhole logging, discharge test, chemistry sampling was conducted to understand individual wells characteristics such as thermodynamic state of the reservoir fluid, permeability distribution, well output and fluid chemistry. Furthermore, interference test was carried out to investigate the response of reservoir to exploitation.

1. INTRODUCTION

Rantau Dedap Geothermal Field is located in South Sumatera; Indonesia. The prospect is situated in the northern east of the Great Sumatra Fault. Abundant of fumaroles and chloride springs defined the presence of geothermal potential in the area. The later geologic, geochemical, and geophysical surveys delineated the potential extension of the geothermal system. Figure 1 presents the location of Rantau Dedap field and the surface features distribution.

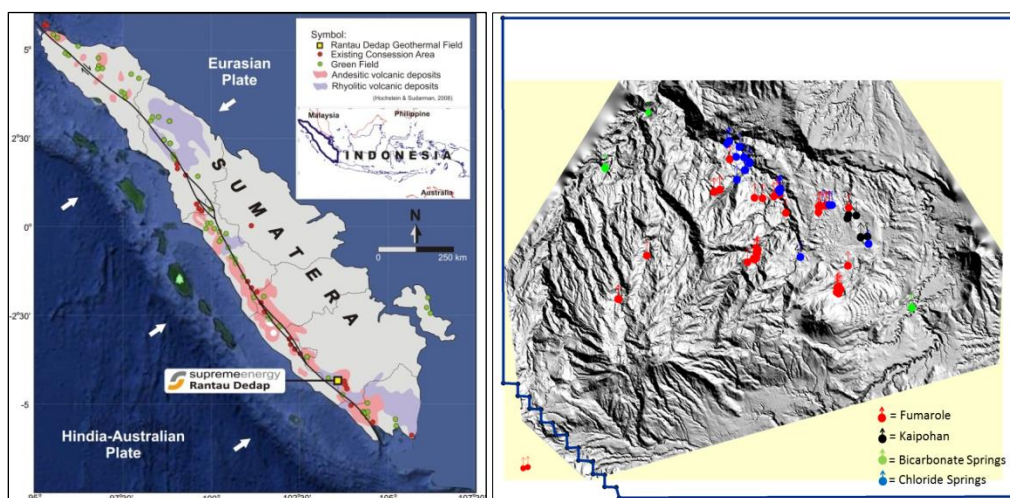


Figure 1: Rantau Dedap prospect location and surface features distribution

In 2014-2015 PT Supreme Energy Rantau Dedap (SERD) drilled six full diameter exploration wells in order to confirm the existence of geothermal system and to assess the field production capacity. During the course of exploration drilling comprehensive well testing surveys were executed, consisting of static formation temperature test (SFTT), completion test, heating-up test, production test, and interference test. The well testing programs were designed with an aim to provide a reliable and inclusive data that will be used as a basis to conduct resource assessment. Key parameters that the well testing intended to confirm include initial thermodynamic state of reservoir fluid, permeability structures, reservoir size, well output, and fluid chemistry. Moreover, some well testing surveys was also planned to provide technical justification on decision making during the sixth well drilling execution. In the subsequent paragraph the implementation of the well testing programs are presented.

2. STATIC FORMATION TEMPERATURE TEST (SFTT)

The main objective of this test is to estimate the undisturbed temperature at certain depth during drilling that can assist the drilling program in setting production casing shoe (PCS) at appropriate depth where the temperature is expected to be 220-230°C. This is normally done at exploration stage since no downhole measurement data available.

To determine PCS setting depth, SFTT has been conducted in the first three wells, providing undisturbed temperature estimate which supplement other information gathered from drilling records such as Methylene Blue (MeB), the appearance of high temperature

mineral (epidote), drilling breaks, and loss of circulation. Ideally the test should be conducted before loss of circulation to allow conductive heat flow only, so in practical when loss of circulation occurred close to the initially planned survey depth, drilling was stopped immediately and SFTT was performed 50 m above the bottom of the hole. The heating up duration was set to be longer than circulation time at specified survey depth.

Several methods were used to estimate undisturbed temperature such as Roux, Brennand, Ascencio and Horner Method. In RD-B2 well SFTT was conducted at a depth of 792 mMD at which the drilling records (i.e. MeB<10, appearance of epidote) indicated the temperature of rock being drilled is 200-220°C. Figure 2 (a) shows how the transient temperature recorded from SFTT being extrapolated using Ascencio Method, providing an estimate temperature of 205°C. Brennand Method provided 192°C while Horner Method provided more conservative number of 174°C. Eventually, pressure-temperature (PT) heating up measurements revealed the actual temperature of 207°C, concluding the Ascencio’s as the closest estimate.

Figure 2 (b) displays complete set of SFTT calculation results using the above methods compared to the actual stabilized temperature in the first three wells. Good agreement can be found in the RD-B2 where no partial losses occurred prior the test, giving deviation of less than 10°C using Ascencio Method. In general, estimated temperature is less than the actual one due to limited heating-up time (i.e. related with operation rig cost) and non-ideal conductive heat flow due to partial losses.

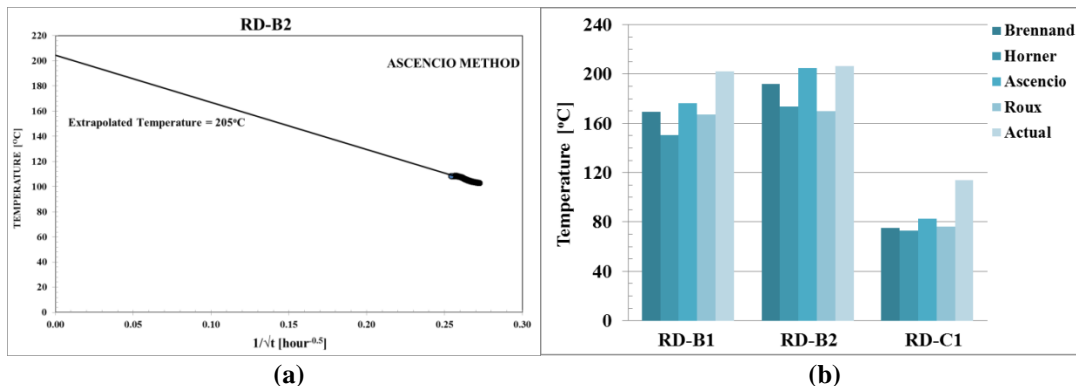


Figure 2: Calculated undisturbed temperature using different methods

3. COMPLETION TEST

Completion test was carried out immediately after drilling completed by utilizing the drilling rig equipment. The test consist of a series of surveys including dummy run, pressure-temperature-spinner (PTS) injection, multiple-rate injectivity test (II test) followed by fall-off test (FOT), run sequentially, spending approximately 27 hours rig time. The objective of these measurements is to acquire information regarding feed zone(s) depth, individual feed zone permeability, well injection capacity, permeability thickness, and near wellbore permeability. Surface Read-out (SRO) measurements were done to observe the measured data in real-time, which allowed faster data acquisition, thus minimizing rig time. A completion test program has been designed to provide reliable data with minimum rig time. In general the completion test program is described in Figure 3. The test was started with dummy run to assess wellbore conditions and to investigate the well maximum clear depth. Such information consequently provides aid to design the subsequent surveys.

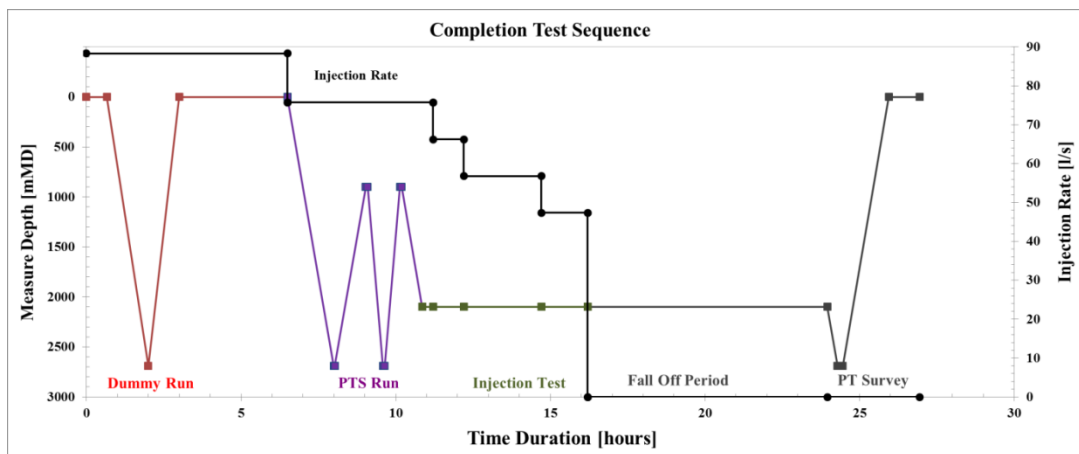


Figure 3: General completion test sequence

3.1 PTS Injection

PTS injection test was conducted to identify location of the permeable zones (feed zones) within the tested well. The data was furthermore analyzed to quantify mass loss to each identified zone. In some cases reservoir fluid may flow into the wellbore (interzonal

flow), requiring unconventional analysis to carry out. A comprehensive analysis involving spinner interpretation and mass and heat balance calculation was done to provide a detailed report of feedzones characteristics. Figure 4 demonstrates calculation workflow in RD-B1 where downflow was observed during the test.

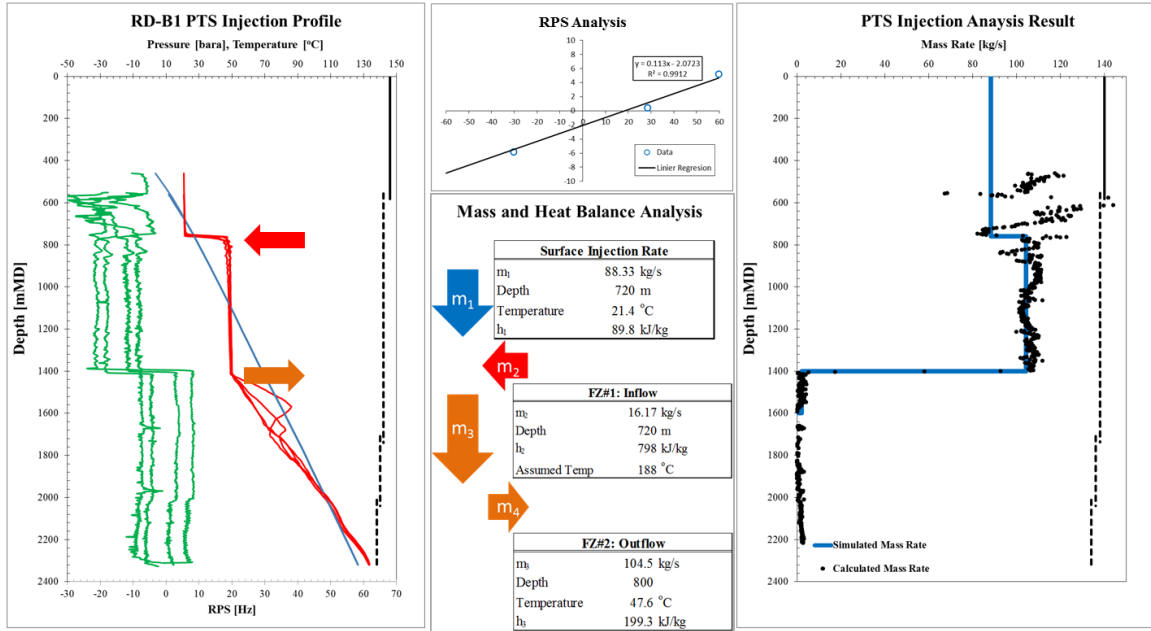


Figure 4: PTS injection calculations for a well with downflow

3.2 Multi-rate Injectivity Test

Multi-rate injection test is conducted to obtain well Injectivity Index (II) value from which the well injection capacity can be estimated. The II value is essential in providing a measure of well permeability and when combine with pressure and temperature data could provide a preliminary indication of the well production capacity. Step down isochronal multi rate injectivity test is selected to be performed in order to minimize rig time utilization. In this test, the well was injected with multiple injection rates while downhole pressure recorder was set close to pivot point which expected located adjacent to the identified major feed zone location from PTS Injection. SRO utilization during the test was very helpful in determining the corresponding pseudo steady state downhole pressure condition at each injection rate. Figure 5 provide an example of typical step down multi rate injectivity test applied in each exploration well.

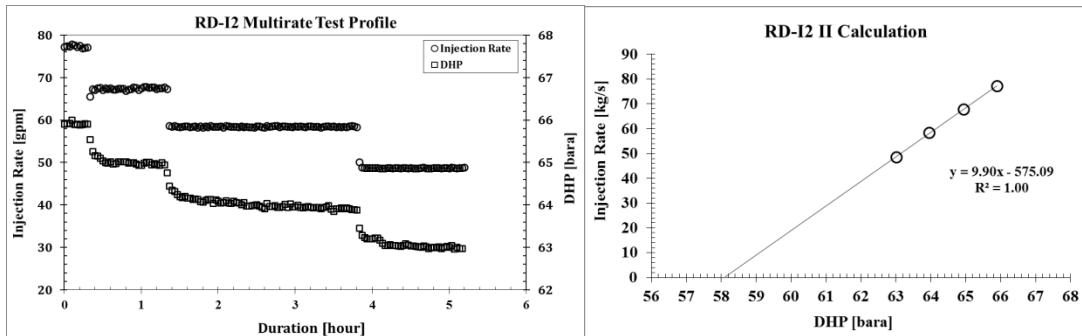


Figure 5: Injection test calculation

3.3 Fall-off Test (FOT)

Generally this test is performed right after II test completed by recording downhole pressure at particular depth after injection has stopped. The well pressure recovery data was analyzed using type curve matching to provide initial estimate of the rock transmissivity (kh) which translates well permeability, near wellbore condition and boundary condition.

Due to dynamic wellbore conditions such as interzonal flow, gas trap in the wellbore, steam rising, and temperature heat-up, the FOT test provided poor data quality, leading to noisy pressure derivative that would give unreliable interpretation. However, attempt to analysis fall-off data was made where unfavorable circumstances have less effect on data quality. Figure 6 illustrates fall-off data analysis in RD-B2. A good match of the pressure and its derivative was obtained by using a Dual Porosity model ($\Omega=0.05$, $\lambda=7E-8$) with no boundaries. The reservoir properties inferred to obtain this match are:

- Initial reservoir pressure (P_i) = 52.4 Bara (consistent with the Multi-rate Injectivity Test observation)
- Transmissivity (kh) = 25.8 Dm
- Skin (S) = -1.5

Using 350 m of reservoir pay thickness (from 870 to 520 masl), the reservoir permeability at macroscopic scale is evaluated to be around 75 mD.

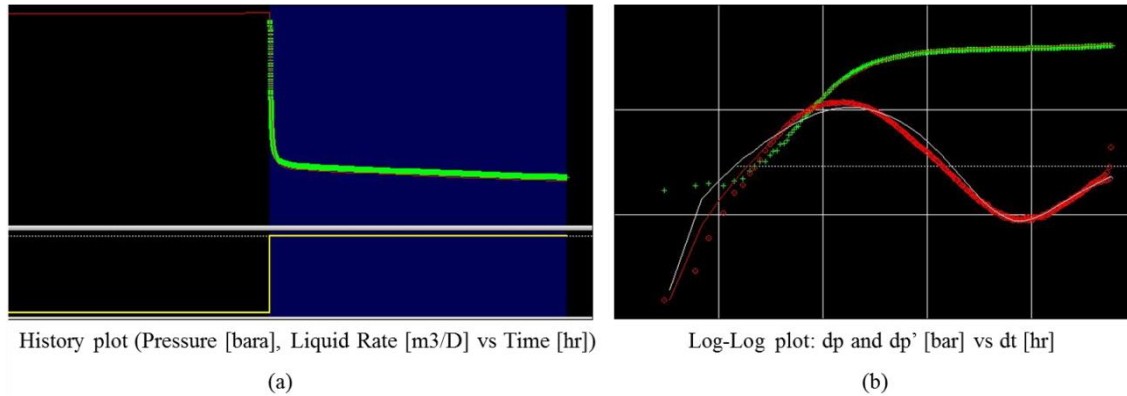


Figure 6: Fall-off data analysis in RD-B2. (a) Pressure match (data in green, model in red) and rate history (in yellow); (b) Match of the pressure (data in green, model in red) and its derivative (data in red, model in white)

4. HEAT-UP SURVEYS

After completion test completed, the well was put in shut-in to allow the reservoir temperature heats up. During this period, pressure-temperature (PT) surveys were conducted to monitor natural pressure and temperature recovery. As general rule of thumb in geothermal industry, at initial, PT heat-up surveys was planned to be conducted on day 1, 3, 7, 14, 25 and 45 after completion test with flexibility to be extended depending on the temperature recovery required. Such stabilized profiles consequently provide essential elements for initial state numerical model calibration. In addition the temperature profile from day 1, 3, and 7 were usually extrapolated to estimate undisturbed temperature profile, providing additional information for the next well drilling program.

4.1 Temperature

In the implementation most of the wells required longer time to fully heated-up, leading to more surveys conducted. The slow temperature recoveries observed in some wells is affected by huge amount of drilling fluid loses into the reservoir and natural state condition of the reservoir. Consequently air cap discharge stimulations were conducted in several wells in order to expedite temperature recovery.

Figure 7 illustrates heating-up process in RD-B1. Temperature extrapolation is drawn based on data on day 1, 7 and 14 which indicates good agreement with temperature after flowing (day 389) and initial temperature data. The extrapolation data was required to support decision on next drilling target.

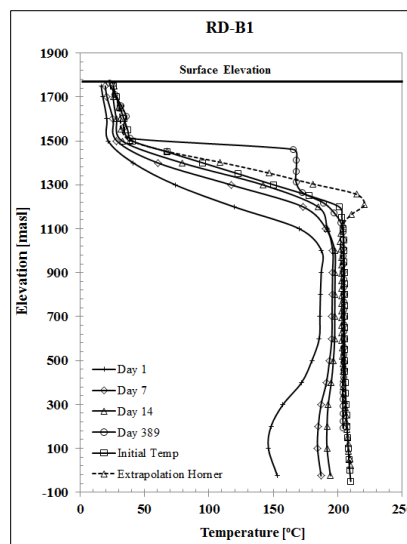


Figure 7: Heat-up temperature profiles in RD-B1

4.2 Pressure

As the well heats-up, the pressure in the wellbore is dynamically shifting due to hydrostatic gradient changes on liquid column. There is a pivot point located at depth where pressure remains stable. Normally, the pivot point corresponds to feed zone depth at single feed zone well. At multiple feed zones well, the pivot point located between feed zone depths weighted by their injectivity index and fluid enthalpy.

Figure 8 shows the initial reservoir pressure correlation constructed from the pivot point of all wells. It seems that the wells have been drilled into the same pressure regime with the gradient 0.08255 bar/m, corresponding to 230°C reservoir temperature. Exception is RD-I2 where the pivot point is lower than the pressure correlation. This probably indicates that RD-I2 drilled into the upflow of the system, which is consistent with the fact of being the hottest well in the field.

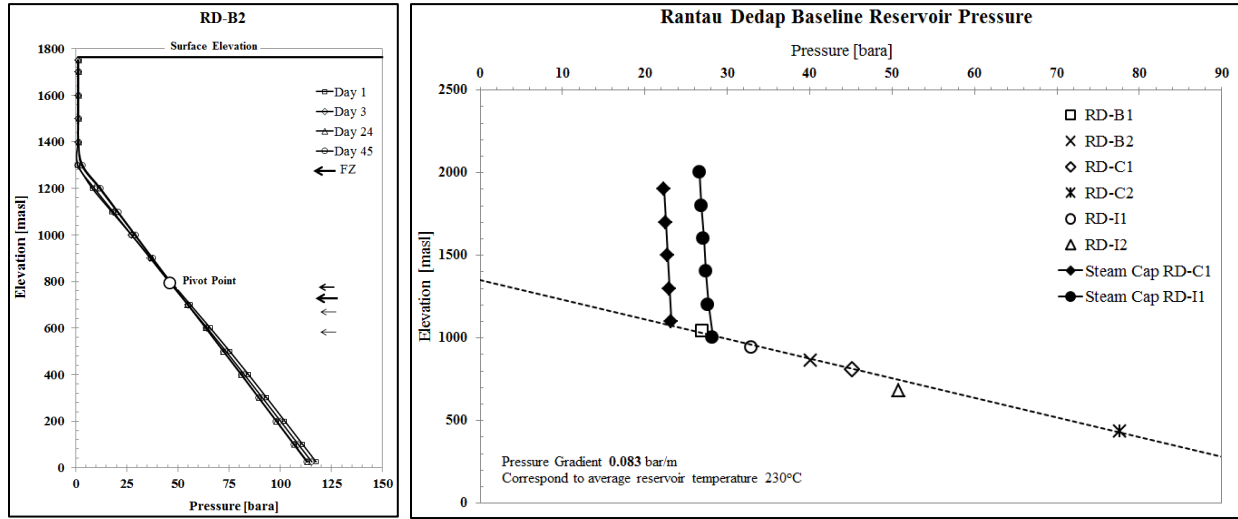


Figure 8: Pivot point identification and pressure distribution

4.3 Fluid State

Temperature and pressure in the wellbore will stabilize as heating-up period ends, providing initial temperature and pressure of the field. Such information provides fundamental elements for the construction of conceptual model and numerical model. Boiling curve with depth (BCWD) was also constructed to understand fluid state in the initial condition of reservoir, whether the fluid is compressed liquid, two-phase or dry steam.

As illustrated in Figure 9, initial temperature and pressure profile completed with BCWD suggested that the reservoir is liquid dominated with thin steam cap. It is also noticed that all wells have similar pressure near 1000 masl indicating good horizontal permeability on the field scale.

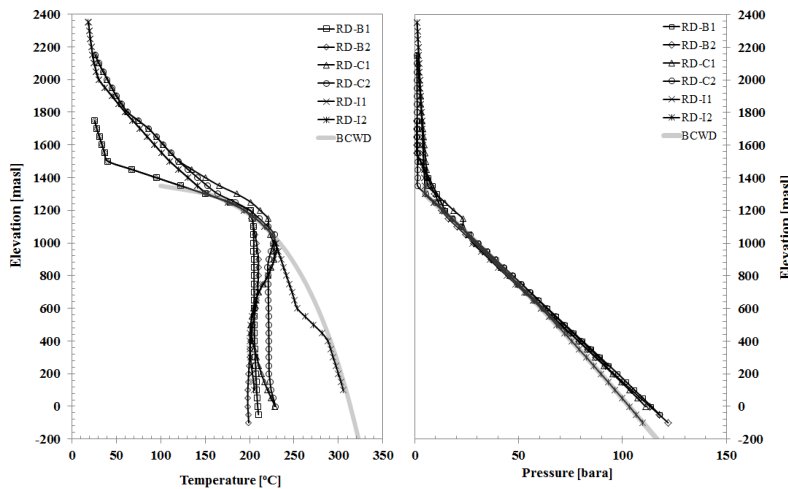


Figure 9: Initial reservoir temperature and pressure RD

5. PRODUCTION TESTING

5.1 Discharge Initiation

Normally discharge attempt is made once heating-up reached conditions ready to flow. Due to slow heating-up process, however, some wells needed stimulation to initiate discharge. It was expected that by allowing the well to flow will expedite the heating up process, allowing more key information to be gathered earlier (i.e. well production capacity, actual temperature profile). These key information is then used as important input to possibly revise the subsequent wells drilling program. Air lift and air cap/air compression have been conducted to stimulate flow.

Air lift method requires drill pipe as medium for the high-pressure air injected from air compressor up to 2300 scfm. This method can target specific depth yet operationally limited since the well need killed by re-injection cold fluid in order to pull the drill pipe out. In addition, the production parameters estimated such as total flow rate, steam and enthalpy did not reflect actual well performance. However, air lift method that had been applied in the first and the second well improved the chance of air cap stimulation by heating-up the upper cold section.

Air cap stimulation is the common stimulation method to initiate discharge by injecting high-pressure air through wing/side valves, compressing a liquid level down to production casing shoe/permeable formation. This allows the liquid to get heated up by higher downhole temperature. Once the liquid gets heated up to sufficient temperature and pressure decrease during opening the well, phase changing will occur and allowing lower density fluid travel up to the surface. In most of the wells, wellhead pressure after air injection can be up to 42 barg, depending on liquid level and PCS shoe depth. All stimulated wells are successfully discharged by this method.

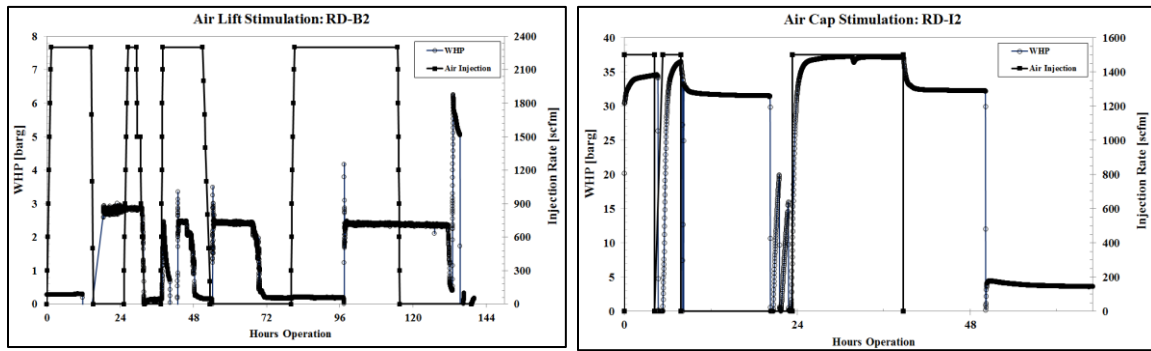


Figure 10: Typical airlift and air cap wellhead profiles and air injection rate.

5.2 Production Test

During production test, production parameters such as fluid enthalpy and total flow rate were continuously measured using James Lip Pressure method. In addition, Pressure-temperature-spinner (PTS) flowing is also taken to confirm productive feed zones location, measure their temperature, assess their individual contribution and calculate productivity index (PI). Furthermore, chemistry sampling and Tracer Flow Test (TFT) were conducted to identify fluid chemistry and validate James Lip Pressure measurements. Both short-term and long-term production test had been carried out for all exploratory well to allow evaluation of well production sustainability with time.

As initial plan for production wells, PTS flowing was planned to be conducted twice along with TFT survey. The PTS flowing is conducted at the early time of the well reaching stabilize flowing wellhead pressure condition and at the end of production test, which is usually parallel with Flow Performance Test (FPT). However, the actual number of the implemented PTS flowing surveys again is highly depend on well performance and downhole data requirement to support dynamic exploration program.

As an example, RD-I2 comprehensive surveys are provided here. The discharge was started on day 43. Calculation on production parameters with James lip method has been validated by PTS flowing and TFT result, leading to weirbox height calibration by adding +1.5 cm to the field data reading. The resulting discrepancy on calculated enthalpy is 5% and 6% on total mass flow. Comparison on discharge test parameters between TFT and James Lip (weir box readings corrected by 1.5 cm) is presented in Table 1 while summary of discharge parameters over the time and various flow control valve (FCV) is presented in Table 2.

Table 1: Comparison between TFT and James Lip Pressure method after calibration

WHP	3.8		5.6		10.7	
	James Lip	TFT	James Lip	TFT	James Lip	TFT
Enthalpy (kJ/kg)	972	909	1072	1013	1393	1351
Total Flow Rate (kg/s)	47.4	47.6	68.1	64.5	104.8	93.4
Steam Rate (kg/s)	7.8	7.1	12.9	11.2	31.7	27.9
Brine Rate (kg/s)	39.7	40.5	55.2	53.3	73.0	65.5

Table 2: RD-I2 discharge parameters summary (after calibration on weir box head)

Day after Completion	WHP	FCV	Enthalpy	Total Mass Flow Rate	Steam Rate
	(barg)	(%)	(kJ/kg)	(kg/s)	(kg/s)
46	3.47	100	933	46.4	7.0
77	5.75	100	1,065	71.0	13.0
107	7.95	100	1,130	92.3	17.9
138	10.57	100	1,407	101.4	31.5
162	13.75	10	1,313	66.4	16.2

Figure 11 shows calculated production parameters and flowing wellhead pressure monitoring. As shown in the figure, steady increase on flowing wellhead pressure was observed from day 43 to day 111 as the well heated-up. Sharp increase in RD-I2 flowing WHP was observed on day 111 – day 116 and gradually decreased afterwards. These flowing behaviors were evaluated by running PTS during steady increase of WHP (day 59 and day 68) and gradual decrease of WHP (day 156).

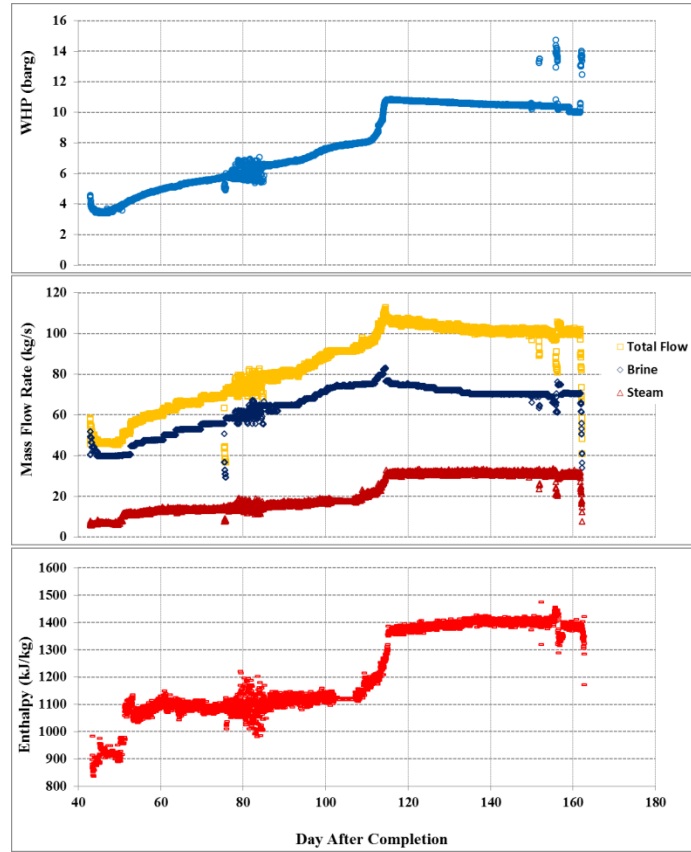


Figure 11: RD-I2 production parameters monitoring

The analysis of PTS flowing involves spinner interpretation and wellbore simulation. The method had provided confirmation of feed zone characteristics such as location, mass rate contribution and in-situ fluid enthalpy. Drift flux correlation was applied in wellbore simulation to match pressure and temperature measurements and interpreted velocity.

An example of PTS flowing analysis from measurement during high flowing wellhead pressure (after sharp increase) is illustrated in Figure 12. A good match of wellbore model with observed data obtained by assigning three feed zones, suggesting that the deepest feed zone was at boiling condition. Such boiling could explain the sharp increase of wellhead pressure recorded at the surface.

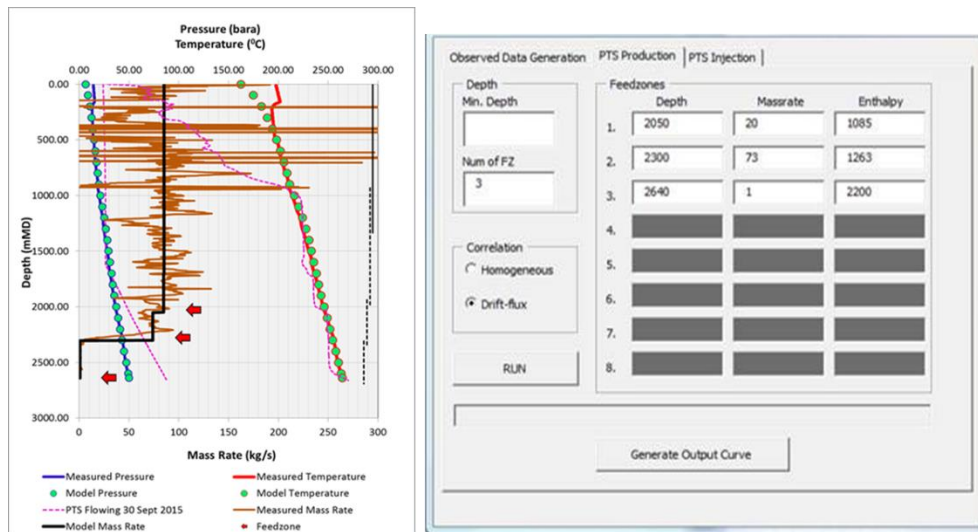


Figure 12: PTS flowing analysis using wellbore hydraulic model

5.3 Flow Performance Test

Just before shutting-in the well at the end of the long-term discharge test, a flow performance test (FPT) was performed. The objectives of this test are to construct well output curve and determine maximum pressure discharge (MPD). This test was accomplished by throttling the well at different openings of the Flow Control Valve and monitoring the production parameters over these different FCVs.

In RD-I2, the test was performed at FCV openings, consecutively 100, 50, 20, 15 and 10% after four months of flowing period. The MPD was reported at 14.8 Bara at 10% opening. Production parameters were calculated by calibrated James Lip Pressure method. Construction of output curve was accomplished by plotting these parameters against correspondence flowing wellhead pressure. Measured production parameters computed by TFT are also reported (empty dots). The changes of enthalpy with the different openings quite clearly indicate that the respective contribution of each feed zone changes as well (the higher the WHP, the lower the enthalpy and thus the lower the contribution of the deep boiling feed zones).

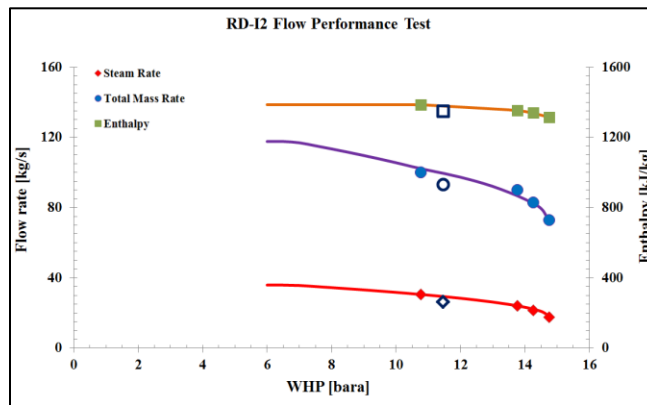


Figure 13: Output curve (James Lip Pressure method in solid dots, TFT in empty dots)

5.4 Chemistry Sampling

Comprehensive fluid chemistry sampling consisting of sampling analysis from brine, NCG, condensate and isotope was conducted during production test. The objectives are to characterize fluid origin and its features, reservoir process, scaling analysis and ultimately support conceptual and hydrology model.

Normally, sampling activity is performed along with TFT survey. In Rantau Dedap, chemistry sampling was planned to be conducted 4 (four) times during production test. This program was made based on assumption that the well needs sufficient time to reach stabilization, thus monitoring during developing phase and reach stabilization will allow the analysis thoroughly.

Throughout the extensive production test, fluid chemistry sampling was taken in 6 (six) exploration well. The fluid chemistry results suggest that the reservoir fluid is benign with neutral pH (range 7-8) and considered as chloride type fluid. The fluid have no tendency of corrosive and scaling also relatively low NCG content 0.07 – 0.8 wt% in steam. The geo-thermometer suggested that reservoir temperature in Rantau Dedap Geothermal field ranging from 220 to 280°C which is align with measured downhole reservoir temperature and calculated production parameters.

5. INTERFERENCE TEST

Interference test aims to reveal information regarding inter-well connectivity in a field scale, thus it involves minimum 3 wells acted as producer, injector and monitoring well. Well assignment is done after all data regarding estimate production or injection capacity; and stabilized pressure and temperature are obtained. The test was accomplished over 5 months duration by assigning all six wells; RD-B1, RD-C2, RD-I1 and RD-I2 as producer, RD-B2 as injector and RD-C1 and RD-I1 (later) as monitoring well. Figure 14 briefly demonstrates well location and its assignment.

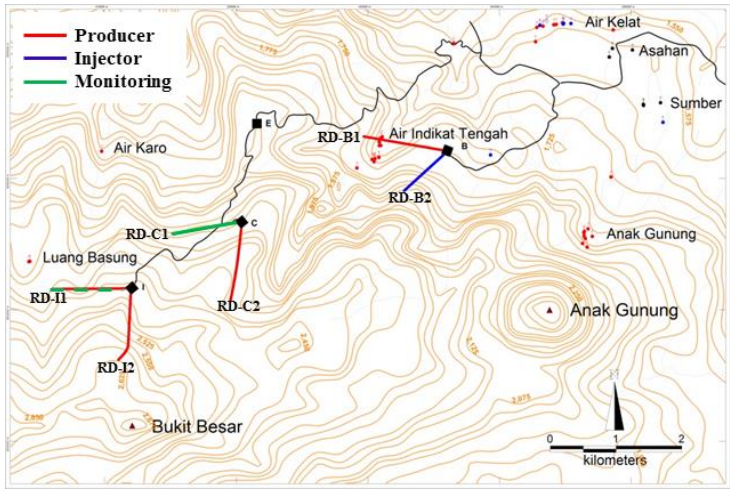


Figure 14: Well location and its assignment

Figure 15 shows the interference monitoring history during exploration stage. During the first month of monitoring, RD-C1 suggested no decline in pressures as only RD-I1 was being produced. As RD-I2 start to produce (gradually increasing in flow), RD-C1 began declining during the second month. Together with simultaneous production of RD-B1, RD-C2 and after the transition to high flow rates at RD-I2, RD-C1 reached a decline rate of about 0.5 bar/year. This decline is considered as relatively modest rate. After production, RD-I1 assigned as monitoring well. No measurable decline on the pressure trend over 2 months of monitoring. The low pressure decline rates in these wells could possibly explained by inducing boiling in upper permeable zones within the reservoir thus may buffer the pressure declines induced by production. Existence of steam cap zone in the natural state condition observed on RD-I1 and RD-C1 support the explanation of downhole pressure monitoring response.

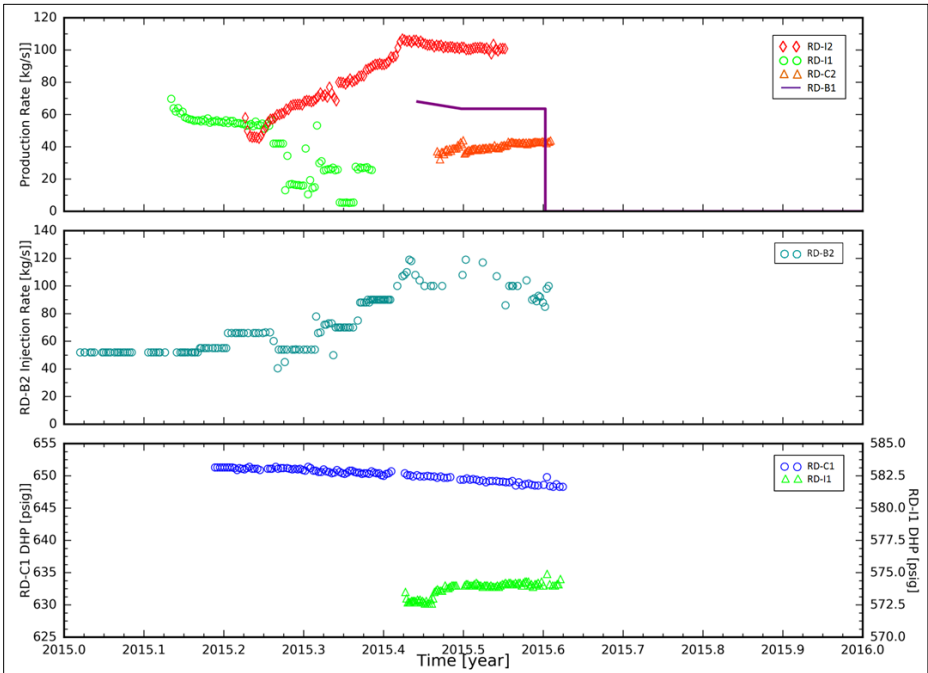


Figure 15: Rantau Dedap interference test history

6. CONCLUSION

The intensive well testing had been performed in Rantau Dedap geothermal field during exploration stage from year period of 2014 - 2015. The data sets obtained have provided adequate reliable information to perform complete individual well characterization process and thorough resource assessment for supporting Rantau Dedap development stage decision. Early well data obtained from SFTT, completion test and heat-up surveys evaluation had allowed necessary adjustment in the exploration program to achieve a successful geothermal exploration. In addition, implementation of both short-term and long-term production test period as well as fluid chemistry sampling for all exploratory wells had allowed prudent evaluation in well output sustainability with time and confirmation of benign fluid chemistry.

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REFERENCES

- Bacquet et al., Geothermal Wells Discharge Initiation Using Air Lift And Air Compression: Case Study With And Without Downflow In The Wellbore. *Proceedings 36th New Zealand Geothermal Workshop*, New Zealand, (2014).
- Bacquet et al., Inverse Numerical Modeling of Rantau Dedap Geothermal Field after Six Exploration Wells. *Proceedings, 41st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California*, (2016).
- Grant, M.A. and Bixley, P. F. *Geothermal Reservoir Engineering – Second Edition*. Elsevier.Inc, (2011).
- Martikno et al., Evaluation of Weirs Calculation to Estimate Well Capacity: A Numerical Study. *Proceedings, 13th Indonesia International Geothermal Convention & Exhibition*, Jakarta (2013).
- Sarmiento, Z. F. Application of Well Testing in Assessing Geothermal Resources. *UNU-GTP and LaGeo*, El Salvador, (2011).
- Situmorang, Jantiur. Pengembangan Program Komputer "PTS3" Untuk Karakterisasi Zona Permeabel dan Aliran Fluida dalam Sumur Panas Bumi Berdasarkan Survei PTS. Program Studi Magister Teknik Panas Bumi, Institut Teknologi Bandung, (2012).