Make-Up Well Selection for the Darajat Geothermal Field, West Java, Indonesia

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Keywords

Darajat, production wells, well planning, vapor-dominated

ABSTRACT

A make-up drilling campaign was implemented at the Darajat field in 2007-2008 in order to maintain full generation at 260 MWe until 2010. Decline analysis indicated that the make-up well needed to produce at least 160 kg/s steam. A preliminary analysis based on the average well production rate in 2006, which was 25 kg/s, indicated that up to eight wells would be required. In order to maximize the value of the drilling program, an attempt was made to achieve the most productive wells at the lowest drilling cost. A large portfolio of wells was developed that targeted wells from existing production locations. To determine an expected steam production rate for each well in the portfolio, correlations were established between well productivity and five targeting elements: hole angle, hole azimuth relative to open fracture orientation, lithology, entry elevation, and targeted production zone. A proxy for probability of success was developed from these targeting elements which could be correlated to expected well productivity. Eight wells were selected from the portfolio with an expected steam production of 231 kg/s. Seven of these wells were drilled, with one requiring a redrill, yielding an estimated total production of 266 kg/s steam. The drilling results demonstrate the success of this targeting and well selection approach.

Introduction

This paper describes an approach developed and applied by Chevron to choose the highest value make-up production wells to be drilled in 2007-2008 at the Darajat field in West Java, Indonesia. This is the first drilling campaign after the success of the development drilling in 1996-1998.

Darajat is a vapor-dominated system that began commercial operations in 1994 under a load of 55 MWe. Additional 95 MWe are generated from Power Plant Unit II, which came on line in 2000. With the start up of the 110 MWe Power Plant Unit III in July 2007, the field now supports generation of 260 MWe, making Darajat the second largest geothermal development in Indonesia.

Based on an analysis of expected steam decline rates following the start up of Power Plant Unit III, Chevron began an eight well make-up drilling campaign in 2007. Because of the success of the targeting and well selection approach, only seven wells had to be drilled to meet the steam requirements for the program. The seven wells were drilled on three locations (Figure 1). One well required a re-drill because of its failure to hit the drilling targets and because a fish was left in the hole. The successful completion of these wells raised the total number of production wells at Darajat to twenty-four. Another four wells are available for the injection of power plant condensate. Six slim holes were drilled around the margin of the field to better delineate the reservoir boundaries. The remaining three wells are either idle or abandoned.

Targeting Elements

The drilling program was designed to produce sufficient steam to sustain full production of 260 MWe until year 2010. The first step in the program was to establish the required steam production to offset the expected well decline following the start up of Power Plant Unit III. This analysis indicated that at least 160 kg/s total steam production has to be achieved from this drilling campaign. The existing wells had an average production of 25 kg/s, suggesting that 6-8 wells would be required to meet the steam requirements for the program, accounting for the uncertainty in well results and field decline rates. Nevertheless, the well planning team expected to exceed the production rates of the average well through better well targeting.

Well planning began in 2006 with the preparation of a comprehensive well portfolio which consisted entirely of wells that could be drilled from existing production locations. The portfolio included new wells in addition to candidates for redrills, deepenings, and multi-lateral completions. The resulting portfolio included a total of nineteen new wells and six recompletions. The portfolio was subdivided into wells supporting either Power Plant Unit I or Units II/III. Power Plant Unit I wells are operated at lower wellhead pressures because Power Plant Unit I utilizes a lower turbine inlet pressure.

For the 2007-2008 drilling campaign, wells were selected using the metric MW/$, favoring wells with the highest expected steam production rate and lowest drilling costs. Establishing an expected steam rate for the wells in the portfolio proved to be a challenge. In order to achieve high steam production rates, a well targeting approach was developed by analyzing factors that may impact well productivity. A study to determine the correlation between rock type, fracture characteristics, fracture / permeability distribution and how the wells intersect the fractures to steam production rate was performed.

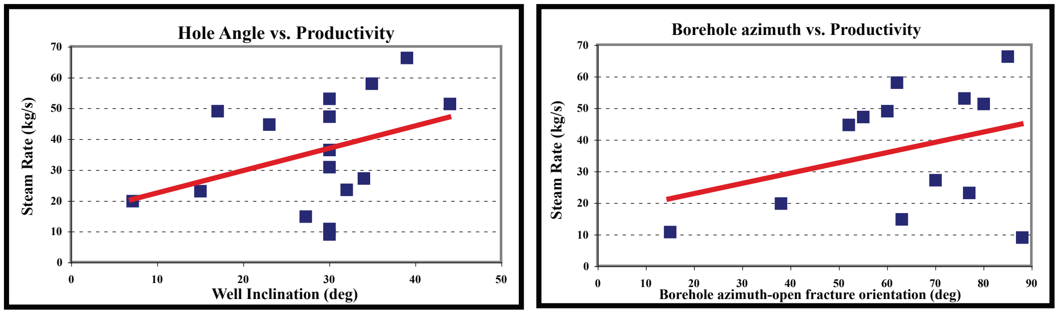

Figure 2. Relationships of hole angle and hole azimuth to well productivity. The azimuth represents the angle that the well course intersects the dominant fracture orientation. The regression line is based on wells drilled prior to 2007.

Using available data from 21 existing wells that penetrate the reservoir, correlations were identified between well productivity and the following five targeting elements:

- Well inclination / hole angle
- Angle between well direction and open fracture strike,
- Steam entry elevation,
- Lithology, and
- Targeted production sector.

Permeability distributions were analyzed from an integrated study of surface and subsurface data such as image logs, spinner logs, drilling information and micro-earthquake (MEQ) events. The subsurface fractures interpreted from 21 image logs as well as cores indicate that most fractures are steeply dipping with a dominantly northeast – southwest orientation, which is similar to the orientation of major geologic structures, such as the Kendang, Gagak, and Cibeureum faults (Figure 1). This orientation is consistent with the local stress regime as deduced from drilling induced fractures. Other fracture subsets have northwest - southeast and north-northwest – south-southeast orientations.

The relationships of well productivity to well inclination and angle between well azimuth to open fracture orientation are shown in Figure 2. In general, well productivity increases for higher angle wells and for wells that cross at high angle to the dominant open fracture orientation. Thus, high angle well that cross perpendicularly to the main fracture orientation encounter better permeability conditions.

Spinner logs indicate that the most prolific production zones occur between the elevations of 200-800 m above sea level. Below 200 m elevation the permeability of the wells declines with depth. Consequently, the depth where a well first intersects the top of the reservoir influences its productivity. The relationship of well productivity to entry elevation is shown in Figure 3.

The relationship of lithology to well productivity is shown in Figure 4. Subsurface data from 31 existing wells indicated that the Darajat reservoir is mainly composed of sub-volcanic intrusive complex consisting predominantly of microdiorite dikes and sills that have intruded into lavas with minor pyroclastic rocks (Figure 4). Draped over the intrusive complex is a sequence of andesitic pyroclastic rocks consisting primarily of lahars and tuffs with minor lavas. The frequency of entries is similar for both units, but the entries in the intrusive complex tend to be more productive (Figure 4).

The final and most important targeting element involves the assignment of the wells to a specific productivity region (Figure 5). Four regions have been identified at Darajat based on the production rates of the wells drilled into the region. The highly productive Region I was originally defined by well DRJ 21, the largest well in the field, and MEQ alignment recorded from the past surveys.

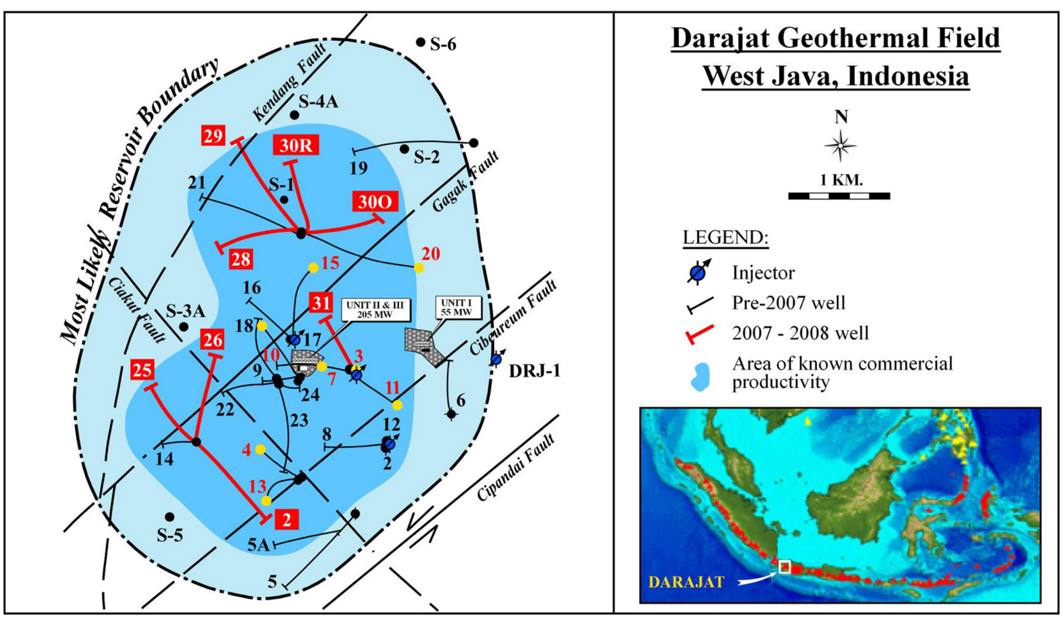

Figure 1. A well location map for the Darajat field highlighting wells drilled in 2007-2008. The most likely reservoir boundary, area of commercial production, power plant sites, and major geologic structures are also shown.

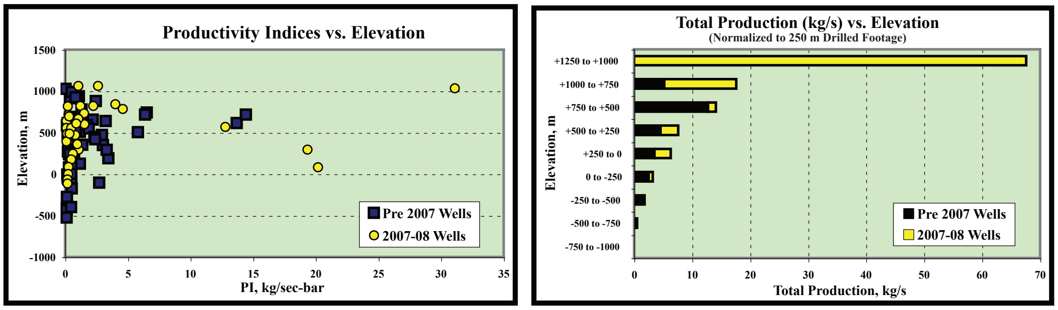

Figure 3. Well productivity as a function of entry elevation. The figures include the results of the 2007-2008 wells.

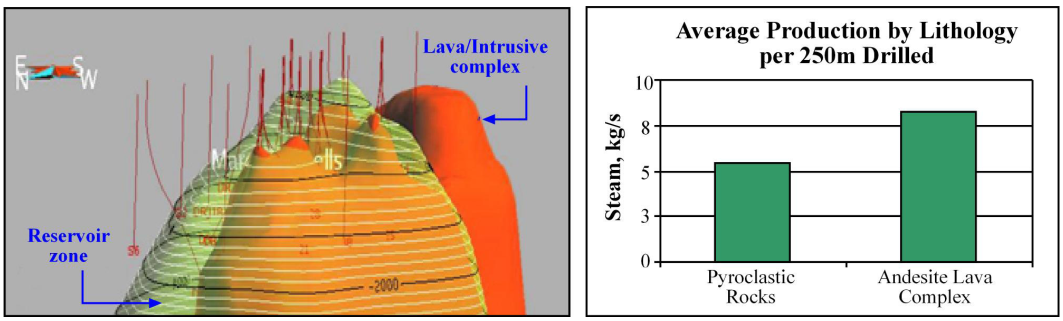

Figure 4. The distribution of the lava/intrusive complex and reservoir zone (contour lines are elevation in ft), and average steam production by lithology per 250 meter drilled.

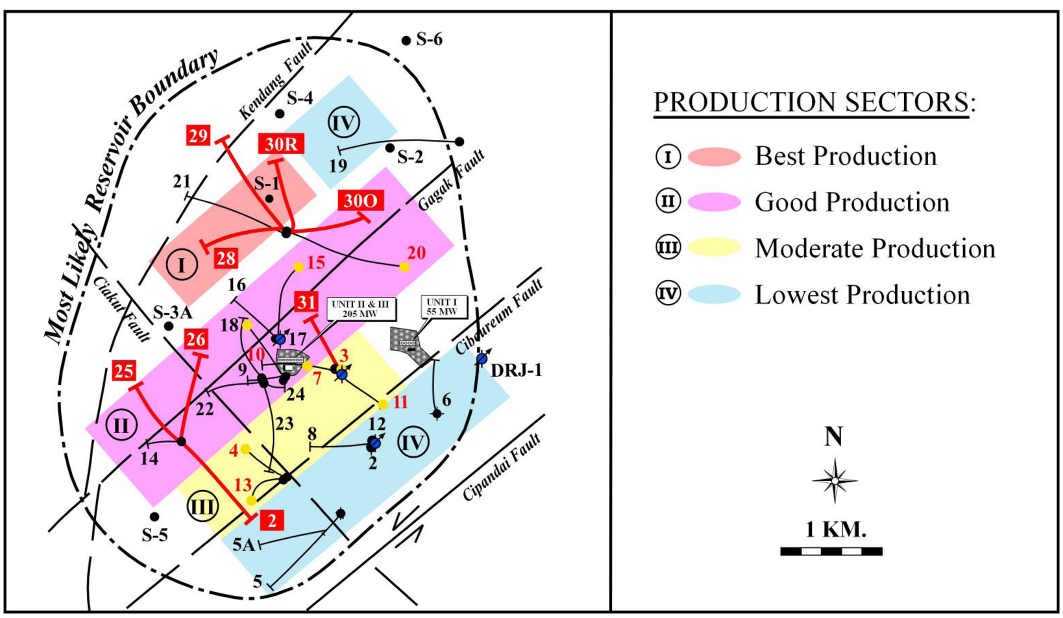

Figure 5. The location of different productivity region.

Region II, which is aligned along the Gagak Fault, is another region with enhanced permeability that has served as an important drilling target for many of the wells in the field. Region III, which lies between the Gagak and Cibeureum faults, has moderate permeability. Region IV to the south of the Cibeureum fault is characterized as a lower permeability region based on poorer well results. DRJ 19, a well with deep entries in the northern portion of the field, is also assigned to Region IV.

POS Score

The relationships of well productivity to the five targeting elements allows for the determination of a score which can represent the probability of success (POS) for a well to produce at a commercial production rate. For example, a high angle well drilled in a northwest orientation through the shallow reservoir within the intrusive complex should have a higher POS than a vertical well drilled through pyroclastic rocks on the margins of the reservoir. To test this relationship, each well was categorized according to the five targeting elements. A score is assigned to each zone in each targeting element proportionally to its contribution to the well productivity (Table 1, overleaf). Higher score is given to a zone that provides higher contribution to well deliverability. A POS score was then calculated for the well using the following equation:

POS score = (A x 1) + (B x 2) + (C x 3) + (D x 4) + (E x 5)

where 1, 2, 3, 4, 5 equal the scores for each of the targeting elements and A, B, C, D, E equal the weighting factors for each targeting element.

The weighting factors were determined through an iteration method by plotting the POS score versus well productivity. The weighting factors were adjusted until the best correlation between the POS score and productivity was attained through regression analysis. The results of this approach are shown in Figure 6, overleaf. The resulting weighting factors are the following:

Hole Angle (A) = 0.09
Angle between well direction to fracture orientation (B) = 0.25
Lithology (C) = 0.18
Reservoir Top (D) = 0.07
Production Sector (E) = 0.41

The production area and angle between well direction and open fracture strike exert the strongest influence on well success.

Table 1. Targeting elements, score and weighting factor used to determine the POS score. The weighting factors were determined from a trial and error regression analysis for all Darajat production wells.

Targeting Elements	Hole Angle		Angle to Fracture Orientation		Top of Reservoir		Lithology		Production Sector	
	Angle, °	Score	Angle, °	Score	Elev, m	Score	Rock	Score	Zone	Score
	<20	2	0-10	2	>1250	2	Lava/intrusive	10	1	10
	20-30	4	10-30	4	750-1250	8	Pyroclastics	4	2	8
	30-40	6	30-50	6	250-750	10	Tuff	2	3	6
	40-50	8	50-70	8	-250 - +250	6			4	4
	>50	10	>70	10	<-250	4				
Weighting Factor	**9%**		**25%**		**7%**		**18%**		**41%**	

The relationship shown in Figure 6 provides the means for estimating the expected steam production for any new well. All that is required is the calculation of the POS score for the wells in the portfolio. The POS score is also used to estimate the probability of obtaining a commercial well (POS%). The highest POS% is set at 85%, which is based on the success rate for all of the reservoir penetrations at Darajat. The lowest POS% is set at 50%, which represents the geologist's assessment of the chance of success for the lowest ranked well in the portfolio. Thus, the POS% score is distributed over the range of 50-85 %, as shown in Figure 6.

Ranking the Portfolio Wells

The next step in selecting wells for the drilling campaign is to rank the portfolio on a MW/$ basis. This is accomplished with the spreadsheet shown in Table 2. For new wells and re-drills, the expected steam is adjusted for interference effects that are dependent upon the well's proximity to the main production area in the field. Multilateral completions are further handicapped by the probability of having both legs producing after the well is completed and by an interference effect caused by two legs producing into the same wellbore. High deliverability wells experience more wellbore interference than low productivity wells, as do wells with smaller diameter completions. Finally, an estimate of the well costs needs to be assigned to each well and recompletion.

In addition to MW/$, other factors can influence the final choice of which wells to drill. For example, minimizing rig moves, modifications to the drilling locations, and pipeline capacity can also be important factors for consideration. In the case of Darajat, minimizing rig moves was used as an additional factor for developing the drilling schedule. Additionally, well DRJ 31 was specifically drilled for Unit I, even though it had a lower MW/$ ranking than the Unit II and III wells.

Table 2. The ranking spreadsheet as applied to the 2007-2008 portfolio wells. The well costs estimates were made in late 2006 for the purpose of ranking the wells and do not represent the actual costs of the wells. The shaded wells were selected for the 2007-2008 drilling program.

	Portfolio Well	POS Score	Expected Steam (kg/s)	Interf-erence (%)	Multi-lateral Inter-ference (%)	Net Steam (kg/s)	POS (%)	POS Drilling	Risked Expected Net Steam (kg/s)	Well Cost, $MM	MW/$
Unit I	DRJ 10 ML	7.64	29.7	15	15	21.5	72	75	11.6	2	3.22
	DRJ 10 Deepening	6.93	10	15		8.5	68	100	5.8	1	3.21
	DRJ 8 ML	7.17	24.8	10	10	20.1	69	75	10.4	2	2.89
	DRJ 2A	7.17	24.8	10		22.3	69		15.4	3.5	2.44
	DRJ 3B	7.08	23.9	15		20.3	69		14.0	3.5	2.22
	DRJ 4 ML	6.67	19.6	10	30	12.3	66	75	6.1	2	1.70
	DRJ 3A	6.32	15.9	10		14.3	64		9.2	3.5	1.45
	DRJ 5A ML	5.79	10.4	5	15	8.4	61	75	3.8	2	1.07
	DRJ 4A	5.86	11.1	5		10.5	61		6.4	3.65	0.98
	DRJ 5B	5.79	10.4	5		9.9	61		6.0	3.65	0.92
Unit II and III	DRJ 20B	9.45	48.7	5		46.3	84		38.9	3.9	5.54
	DRJ 24ML	7.67	30	15	10	23.0	73	75	17.2	2	4.78
	DRJ 20A	8.45	38.2	5		36.3	78		28.3	3.9	4.03
	DRJ 18A	8.14	35	15		29.8	76		22.6	3.65	3.44
	DRJ 14A	8.14	35	10		31.5	76		23.9	3.9	3.41
	DRJ 14B	8.14	35	15		29.8	76		22.6	3.8	3.31
	DRJ 14C	7.82	31.6	5		30.0	74		22.2	3.8	3.25
	DRJ 15A	7.64	29.7	10		26.7	72		19.2	3.8	2.81
	DRJ 18B	6.99	22.9	15		19.5	68		13.2	3.65	2.01
	DRJ 20V	6.46	17.4	5		16.5	65		10.7	3.5	1.71
	DRJ 14V	6.46	17.4	10		15.7	65		10.2	3.5	1.62
	DRJ 20C	6.58	18.6	10		16.7	66		11.1	3.9	1.57
	DRJ 14D	6.08	13.4	5		12.7	62		7.9	3.9	1.12
	DRJ 20D	6.08	13.4	5		12.7	62		7.9	3.9	1.12
	DRJ 14E	6.08	13.4	10		12.1	62		7.5	3.9	1.07

Results of the 2007-2008 Campaign

The first well in the 2007-2008 campaign, DRJ 25, was spudded on 8 April 2007 on the Darajat 14 location. DRJ-25 had surprisingly poor results for reasons that are not yet fully understood (Table 3). The subsequent six wells exceeded expectations; therefore, the eighth well in the program, which was intended to be a multi-lateral completion of well DRJ 8, was not undertaken. Despite the poor results of DRJ 25, the drilling campaign yielded 266 kg/s of additional steam

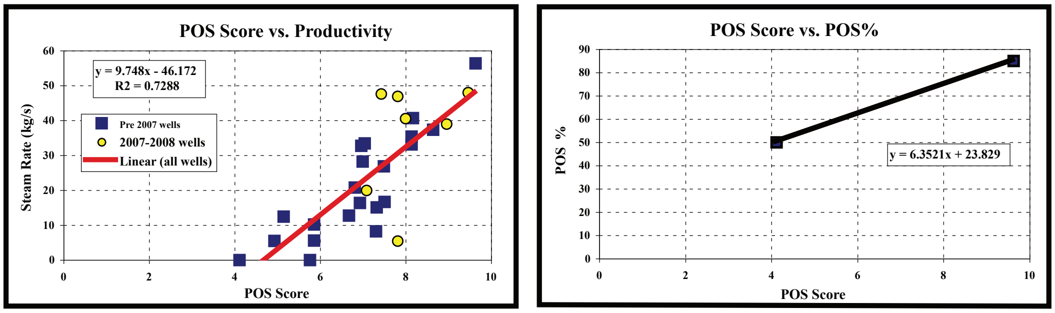

Figure 6. The relationship of the POS scores to the production rates of the wells, and the relationship of the POS score to the POS% (probability of a commercial production rate).

compared to an expected steam rate of 231 kg/s. This equates to an average of 38 kg/s for the seven successful penetrations. At a steam consumption of 1.67 kg/s per MW, the average make-up well has a production rate equivalent to 22.9 MW before taking into account interference effects.

Table 3. The actual versus expected results from the 2007-2008 drilling campaign. The production rates are normalized to a wellhead pressure of 17.5 bara as of 14 June 2007, which is prior to the start-up of Unit III, so that they can be compared to the rates from the existing wells at the same time period. The rate reported for DRJ 31 is based on an injection test because the well has yet to be flow tested.

Portfolio Well Name	Actual Well Name	Expected Steam, kg/s	Actual Steam, kg/s
DRJ 14A	DRJ 25	31.5	5.5
DRJ 14B	DRJ 26	29.8	41.3
DRJ 14C	DRJ 27	30	49.4
DRJ 20A	DRJ 28	36.3	51.6
DRJ 20B	DRJ 29	46.3	54.7
DRJ 20C	DRJ 30RD	16.7	43.2
DRJ 3B	DRJ 31	20.3	20
DRJ 8 ML	Not drilled	20.1	
Total Steam, kg/s		231	265.7

Conclusions

The use of subsurface data to analyze parameters that affect drilling success led to the increasing of probability of obtaining large, commercial wells. The 2007-2008 make-up drilling results proved that the targeting approach is applicable and can be used to select future drilling targets. The results favor portfolio wells at Darajat with the following characteristics: wells drilled in NE-SW orientation with greater than 30 degree inclination, targeting relatively shallow production in lava/intrusive rocks in regions of known high productivity. Development drilling at other fields could also benefit from this approach, although other targeting elements should also be considered.

Acknowledgments

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References

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