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Long term flow test of the MT-2 well, the Mataloko geothermal field, Ngada, Flores Island, Indonesia

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Abstract: The exploration well MT-2 with a total depth (TD) of 180.02 m was successfully tested using the orifice method with D and D/2 tappings from 22 April to 14 July 2001. The optimum capacity of the MT-2 well is about 16.0 t/h at a commercial well head pressure (WHP) of 5.5 barg, which is equivalent to a power potential of 1.48 MWe, assuming a turbine efficiency of 80 % and outlet pressure of 0.5 bar. At this WHP, the well discharges high enthalpy dry steam (2784.0 - 2785.3 kJ/kg) with temperatures greater than 163.0 ℃ (superheated by 20.28 - 21.28 ℃). The draw down analysis of the flow test data is being done to confirm the stable output from the well.

The P-T Kuster logging was done five times during bleeding, flowing and pressure buildup test and shows a higher range of temperature (182.40 - 192.30 ℃) at a depth of 130 - 175 m. Analysis of the pressure recovery data after shut in indicates that the feed zone has a relatively high flow capacity (14.43 darcy-meters). The high flow capacity seems to be generated during the steam flowing due to a negative skin factor value (-5.583).

The superheated steam produced from the well MT-2 has a very low content (0.18 - 0.59 vol% or 0.43 - 1.83 wt%) of non-condensible gases (NCG). Concentrations of H_2S, CO_2 and residual gas in NCG are about 0.41 - 0.89 ppm, 3.74 - 15.58 ppm and 0 - 0.07 ppm, respectively. Hence, the steam is unlikely to cause corrosion problems.

1. Introduction

In the five-year (1997 - 2002) cooperative research between Indonesia and Japan, the Directorate of Mineral Resources Inventory (DMRI) has completed a flow test of MT-2 from 15 April to 14 July 2001. The exploration well MT-2 (TD = 180.02 m) is situated at 8° 50' 09" S latitude and 121° 03' 45" E longitude (Fig. 1) at an elevation of 952.86 m asl. In the drilling program, the MT-2 well was planned to a total depth of 1000 m. However the drilling operation was stopped at the 180.02 m depth because some hole problems made it difficult to continue drilling. At the 162.35 m depth, the well was flow tested using the critical lip pressure method on 22-27 January 2001. The well discharged high enthalpy steam (2713.5 - 2727.3 kJ/kg) with a maximum flow rate of 16.34 t/h at a WHP of 3.63 barg. At the WHP of 5.79 - 5.88 barg, steam flow rates varied between 14.48 and 14.71 t/h at a temperature range of 135 - 140 ℃ (Sitorus *et al.*, 2001).

Even though the lip pressure data indicated that the well could be utilized commercially, a longer term production test was required to provide further information on the well characteristics such as optimum output, down-hole temperature and feed zone parameters. In March 2001, the cooperative research between Japan represented by the New Energy and Industrial Technology Development Organization (NEDO), Geological Survey of Japan (GSJ), Mitsubishi Materials Natural Resource Development Corp. (MRC) and West Japan Engineering Consultants Inc. (WESTJEC) and Indonesia (DMRI) decided a long period flow test of the well MT-2. In this paper, we describe the field work, flow test data, down-hole temperature, feed zone parameters and some discussions related to the MT-2 well.

2. Description of the flow test

Test equipment used for the flow test consisted of a typical setup required for use of the orifice plate method with D and D/2 tappings (British Standard Institution, 1964; Fig. 2). A 6 1/8" throttle valve

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Keywords: Word: Mataloko, flow test, P-T logging, pressure buildup test

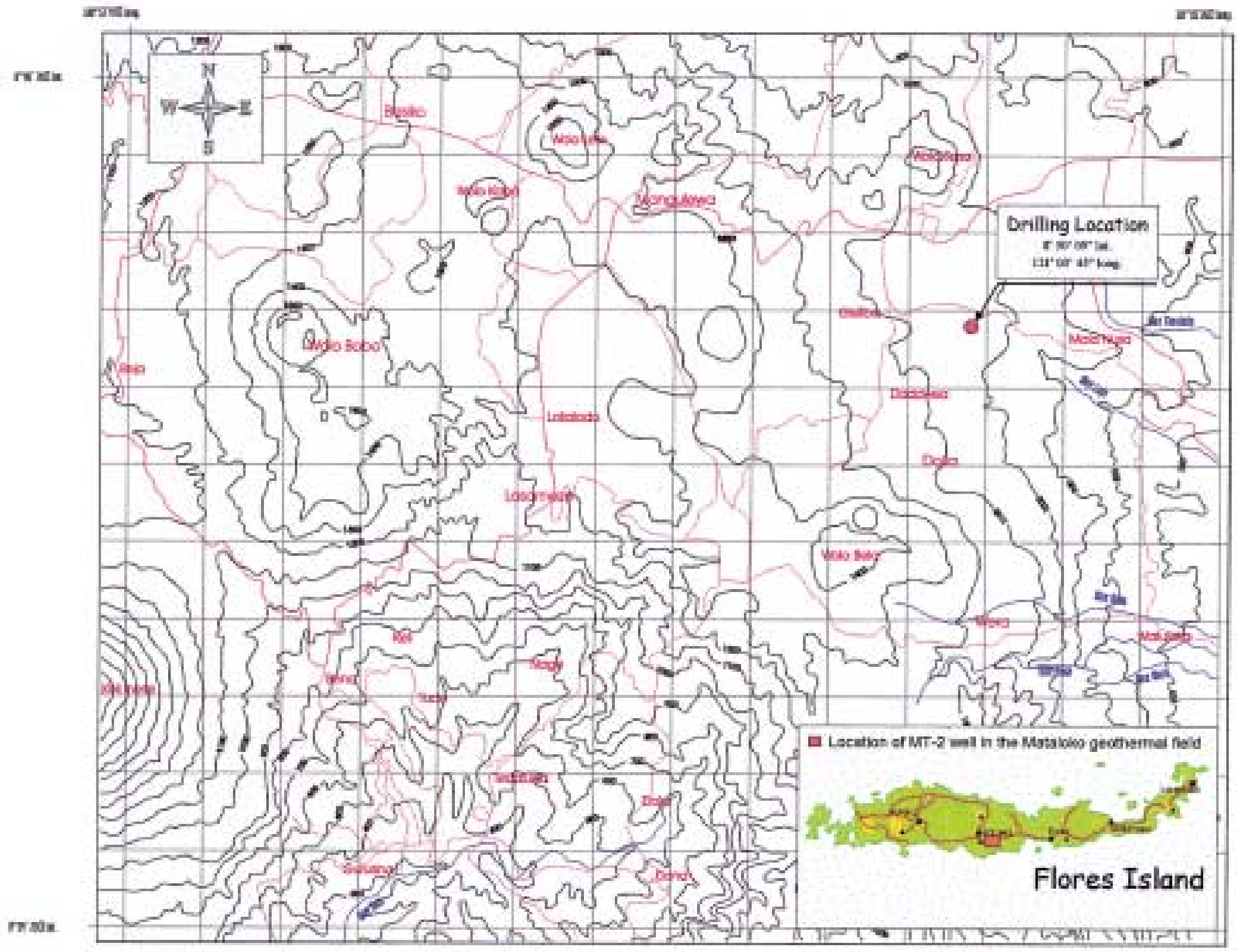

Fig. 1 Location of the geothermal well MT-2 in the Mataloko geothermal field.

connected the wellhead to the horizontal pipeline. The pipeline with an internal diameter of 152 mm was equipped with an orifice plate, a control valve and the flow pipe continued to the silencer at the end of the line. The differential pressure between the orifice upstream and downstream was recorded using a Barton gauge. The unit of pressure used in this paper is expressed as barg (bar-gauge), which is the pressure reading of the gauge installed at the wellhead or in the pipeline. Whereas, bar (or bar-absolute) is defined as a sum of barg and atmospheric pressure. The atmospheric pressure of 0.9 bar was measured at the Mataloko geothermal field. All of the equipment was installed during 7 days (15 - 22 April 2001). Figure 2 also shows the locations of the calorimeter, pressure and temperature measuring points, flow metering instrumentation and chemical sampling point.

A detailed test procedure including the monitoring of flow, chemical parameters and P-T Kuster logging was prepared by DMRI. Prior to the flow test, a P-T survey for a small bleeding was conducted on 15 April 2001. We found that the depth of the hole decreased by about 2 m to a depth of 178.0 m. The data provided base information on the hole conditions. The MT-2 well was ready to flow without using a separator.

Horizontal discharge started with a WHP of 5.0 barg on 22 April 2001 at 10:15. At the early discharge, some black water (about 50 l/min) flowed to the silencer. During the day, the well periodically throttled toward 100 % open. No water flowed to the silencer when the throttle was fully opened at 16:35 (WHP 0.4 barg). The flow test continued with upstream pressure (PU) of 3.0 barg, 5.0 barg and 7.5 barg and WHP in a range of 4.5 - 11.0 barg until 7 June (Fig. 3). Non-condensible gas (NCG) and steam-condensated (SC) samples were collected from the sampling point (upstream of the orifice) at different WHPs following the test program.

The long-term flow test was performed at a PU of 7.5 barg (WHP = 8.0 and 8.5 barg) and a PU of 5.0 barg (WHP = 6.0 and 7.0 barg) on 7 - 29 June 2001. Prior to the pressure buildup (PBU) test, the well flowed with fully opened (no resist) in 30 June - 3 July 2001 to provide parameters at a low WHP.

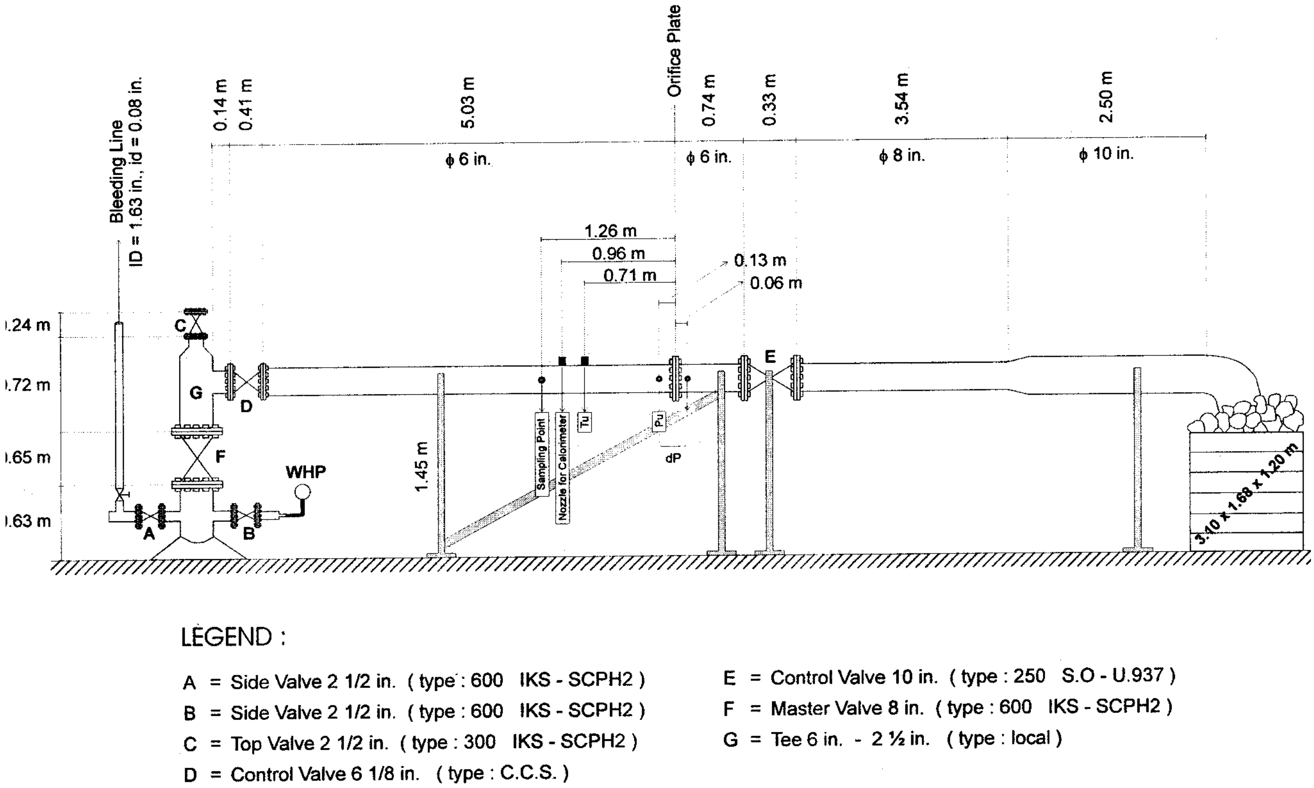

Fig. 2 Schematic installation for the flow test of the well MT-2 in the Mataloko geothermal field.

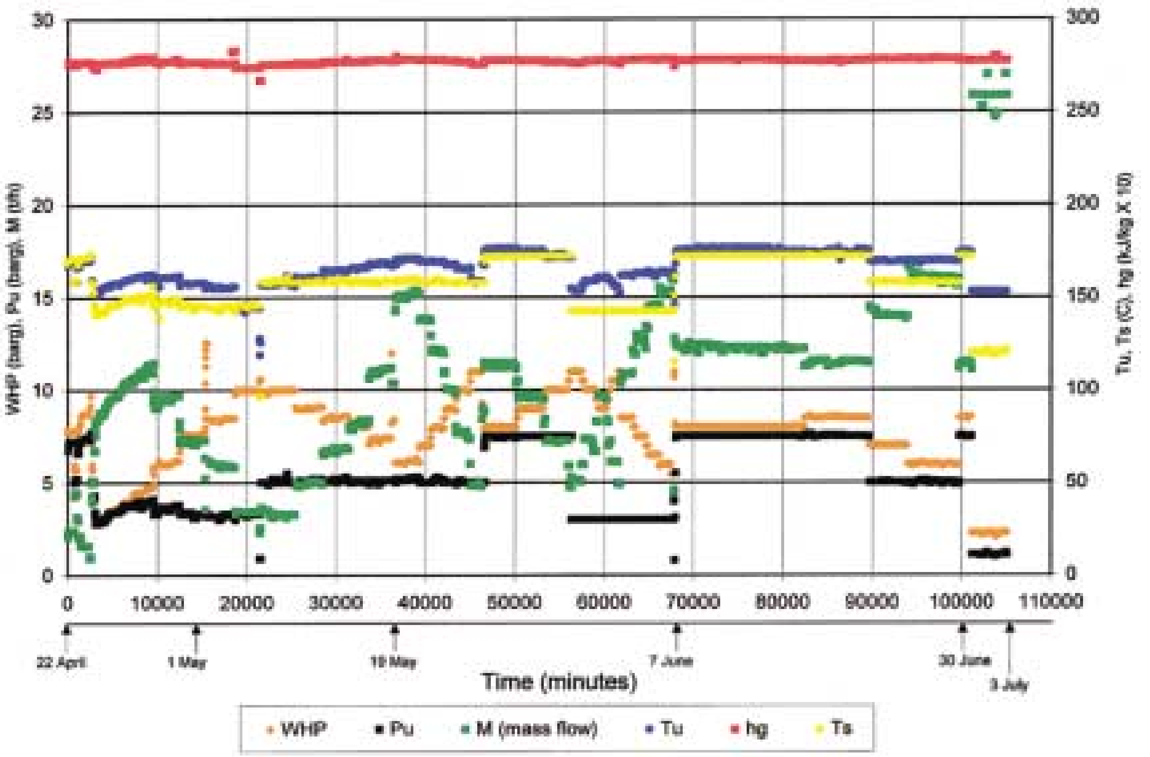

Fig. 3 Graph of WHP, Pu, Tu, Ts, hg, M versus time in the Mataloko geothermal field.

The P-T surveys during the flow on 24 April and 30 June 2001 provided down-hole conditions at different WHPs.

The PBU test in 3 - 14 July 2001 provided down-hole pressure data from 10:00 on 3 July to 09:00 on 14 July 2001. During the PBU test, the P-T Kuster survey was conducted on 5 and 8 July 2001.

3. Flow test result

The data collected during this flow test such as flow rate, flow line temperature (Tu), upstream pressure (PU) and differential pressure (dP) at different WHPs are plotted as graphs, which show relationships between the parameters versus WHP (or with time). All graphs, including the Kuster logging and PBU test, were used to evaluate the flow parameters of the well MT-2.

3.1 Flow parameters

Steam flow rates were calculated using the orifice method (British Standard Institution, 1964), and only selected data were presented in this report (Table 1). Attempts were made to measure enthalpy using a calorimeter but the results were sometimes too high compared with the discharge enthalpy from the steam table (Bain, 1964). It is possibly due to the superheated steam from the MT-2 well. There is a significant variation in steam flow rate during the first twenty-two days, indicating that the flow rates resulted from unstable conditions. This is the reason why some parameters were rechecked (Fig. 3).

The selected data on flow rate, flow line temperature, and enthalpy for the PUs of 3.0 barg, 5.0 barg and 7.5 barg are plotted with WHP (Fig. 4). The plot presents a parabolic curve of the average steam flow rate, i.e. $Y = -0.1446 X^2 + 0.3816 X + 18.35$, where Y is flow rates, and X is the WHP.

The increase in flow rate with decreasing WHP is a normal characteristic of a geothermal well. The steam flow rate at a WHP of 5.5 barg is about 16.0 t/h, which is consistent with the flow test data of 16.03 t/h at a PU of 3.0 barg (Table 1). Maximum ranges of flow rate at PU 5.0 barg and PU 7.5 barg are 14.24 - 15.14 t/h (WHP of 6.0 barg) and 11.17 - 11.50 t/h (WHP of 8.0 barg). Steam flow rates at a lower WHPs of 5.0, 2.5, 2.0 and 1.0 barg are calculated to be 16.64, 18.40, 18.53 and 18.59 t/h, respectively. In contrast, steam flow rates that resulted from WHPs of 11.0, 12.0 and 12.5 barg are 4.95, 2.11, 0.53 t/h, respectively. The MT-2 well will not be able to flow at the maximum discharge pressure of 12.6 barg (Fig. 4).

The changes in temperature with WHP are clearly shown by some data for PUs of 3.0, 5.0 and 7.5

Table 1 The selected flow test data of the MT-2 well (TD = 180.02 m) at upstream pressures (Pu) of 5.0 barg, 7.5 barg and 3.0 barg in the Mataloko geothermal field.

Pa (atmospheric pressure) = 0.9 bar
ID. ORIFICE (d) = 100, 110 and 120 mm
ID. PIPE LINE (D) = 152.0 mm

No.	DATE	START (h)	WHP Programme (barg)	WHP Actual (barg)	dP RANGE ksc	Tu RANGE °C	ENTHALPY RANGE (kJ/kg)	FLOW RATE RANGE (t/h)	FLOW RATE AVERAGE* (t/h)	Diameter Orifice (mm)	EXPLANATION
I.	Pu of 3.0 barg										
1.	30-31 May 2001	16:15	11.0	11.0	0.178-0.186	153.5-155.0	2761.2-2765.2	5.04-5.32	5.13	100.0	Superheated 10.48 - 12.28°C
2.	3 June 2001	07:00	11.0	11.0	0.167-0.172	151.9-153.5	2758.3-2761.8	4.89-4.96	4.89	100.0	Superheated 8.18 - 10.78°C
3.	31 May 2001	11:30	10.5	10.5	0.255-0.258	156.5-157.0	2768.6-2769.7	5.96-5.99	5.96	100.0	Superheated 13.78 - 14.28°C
4.	2-3 June 2001	17:00	10.5	10.5	0.268-0.274	153.5-155.7	2767.5-2774.2	6.11-6.13	6.13	100.0	Superheated 13.28 - 16.28°C
5.	31-1 June 2001	16:30	10.0	10.0	0.329-0.400	158.5-159.2	2773.1-2774.2	6.69-7.36	7.33	100.0	Superheated 15.78 - 16.48°C
6.	2 June 2001	13:30	10.0	10.0	0.363-0.386	159.0-160.0	2774.2-2776.5	7.01-7.24	7.24	100.0	Superheated 16.28 - 17.28°C
7.	1 June 2001	14:30	9.5	9.5	0.522-0.528	160.5-160.8	2777.6-2778.3	8.27-8.31	8.27	100.0	Superheated 17.78 - 18.08°C
8.	2 June 2001	10:00	9.5	9.5	0.520-0.541	160.2-160.8	2776.9-2778.5	8.26-8.41	8.31	100.0	Superheated 17.48 - 18.08°C
9.	1-2 June 2001	18:30	9.0	9.0	0.708-0.755	160.2-161.5	2777.6-2779.1	9.45-9.72	9.72	100.0	Superheated 17.78 - 18.78°C
10.	3-4 June 2001	11:00	8.5	8.5	0.500-0.567	161.4-162.2	2778.7-2781.3	10.32-10.92	10.87	110.0	Superheated 19.08 - 19.48°C
11.	4 June 2001	10:30	8.0	8.0	0.693-0.732	162.4-162.8	2781.6-2782.9	11.91-12.18	11.95	110.0	Superheated 19.68 - 20.48°C
12.	4-5 June 2001	17:00	7.5	7.49-7.5	0.410-0.468	162.6-163.2	2782.2-2783.7	12.23-12.98	12.88	120.0	Superheated 19.68 - 20.28°C
13.	5 June 2001	10:30	7.0	7.0	0.496-0.498	163.5-163.9	2784.2-2785.1	13.31-13.49	13.31	120.0	Superheated 20.78 - 21.28°C
14.	5-6 June 2001	15:00	6.5	6.5	0.593-0.609	161.5-164.0	2778.7-2785.3	14.39-14.61	14.53	120.0	Superheated 18.28 - 21.28°C
15.	6-7 June 2001	11:30	6.0	5.9-6.0	0.683-0.710	163.7-163.8	2784.0-2785.7	15.10-15.54	15.16	120.0	Superheated 20.98 - 21.08°C
16.	7 June 2001	10:00	5.5	5.5	0.755-0.770	163.0-164.0	2783.1-2785.3	15.94-16.06	16.03	120.0	Superheated 20.28 - 21.28°C
II.	Pu of 5.0 barg										
1.	17-19 May 2001	17:00	6.0	6.0-6.2	1.077-1.184	168.0-171.0	2779.2-2785.6	14.24-15.14	14.94	100.0	Superheated 9.18 - 12.18°C
2.	19-20 May 2001	14:45	7.0	6.9-7.0	0.969-0.981	169.5-170.0	2781.9-2784.0	13.74-13.87	13.85	100.0	Superheated 11.18 - 11.82°C
3.	20-21 May 2001	12:15	8.0	7.85-8.0	0.711-0.738	169.3-169.9	2781.1-2783.6	12.04-12.19	12.16	100.0	Superheated 9.58 - 11.72°C
4.	21 May 2001	13:15	8.5	8.45-8.5	0.575-0.577	168.5-169.0	2780.2-2780.9	10.9-11.02	11.02	100.0	Superheated 10.18 - 10.72°C
5.	21-22 May 2001	15:15	9.0	8.95-9.0	0.481-0.485	167.6-168.1	2779.1-2779.5	10.03-10.04	10.03	100.0	Superheated 7.18 - 8.48°C
6.	22 May 2001	11:10	9.5	9.5	0.312	168.0	2777.5	8.03	8.03	100.0	Superheated 8.48°C
7.	22-23 May 2001	13:00	10.0	9.8-10.0	0.279-0.288	166.0-167.0	2772.4-2775.0	7.67-7.75	7.68	100.0	Superheated 8.82 - 9.82°C
8.	23 May 2001	13:30	10.5	10.5	0.168	165.3	2772.6	6.02	6.02	100.0	Superheated 7.12°C
9.	23-24 May 2001	13:45	11.0	10.9-11.05	0.104-0.112	158.0-159.0	2758.9-2774.8	4.81-4.97	4.92	100.0	Superheated 0.12 - 2.82°C
III.	Pu of 7.5 barg										
1.	24-26 May 2001	15:15	8.0	7.9-8.0	0.414-0.480	174.8-176.8	2779.9-2782.4	11.17-11.50	11.35	100.0	Superheated 3.55 - 4.35°C
2.	26 May 2001	12:10	8.5	8.5	0.350-0.361	176.0	2777.4-2781.1	10.37-10.52	10.44	100.0	Superheated 3.55°C
3.	26-28 May 2001	15:15	9.0	8.9-9.0	0.166-0.174	175.0-175.8	2777.4-2779.5	9.48-9.78	9.54	100.0	Superheated 2.55 - 3.35°C
4.	28 May 2001	13:35	9.5	9.5-9.6	0.215-0.232	173.0-174.2	2772.4-2775.4	8.13-8.43	8.43	100.0	Superheated 0.55 - 1.75°C
5.	28-30 May 2001	16:35	10.0	10.0	0.165-0.167	171.5-173.5	2768.7-2773.7	7.17-7.34	7.25	100.0	Saturated-Superheated 0.55-1.05°C
6.	30 May 2001	10:30	10.5	10.5	0.112	171.5-172.0	2768.7-2770.0	5.91	5.91	100.0	Saturated steam
7.	30 May 2001	13:30	11.0	11.0	0.072	171.5	2760.7-2768.7	4.75	4.75	100.0	Saturated steam

*) Average value is recorded from the dominant value *(relatively stable parameters)*.

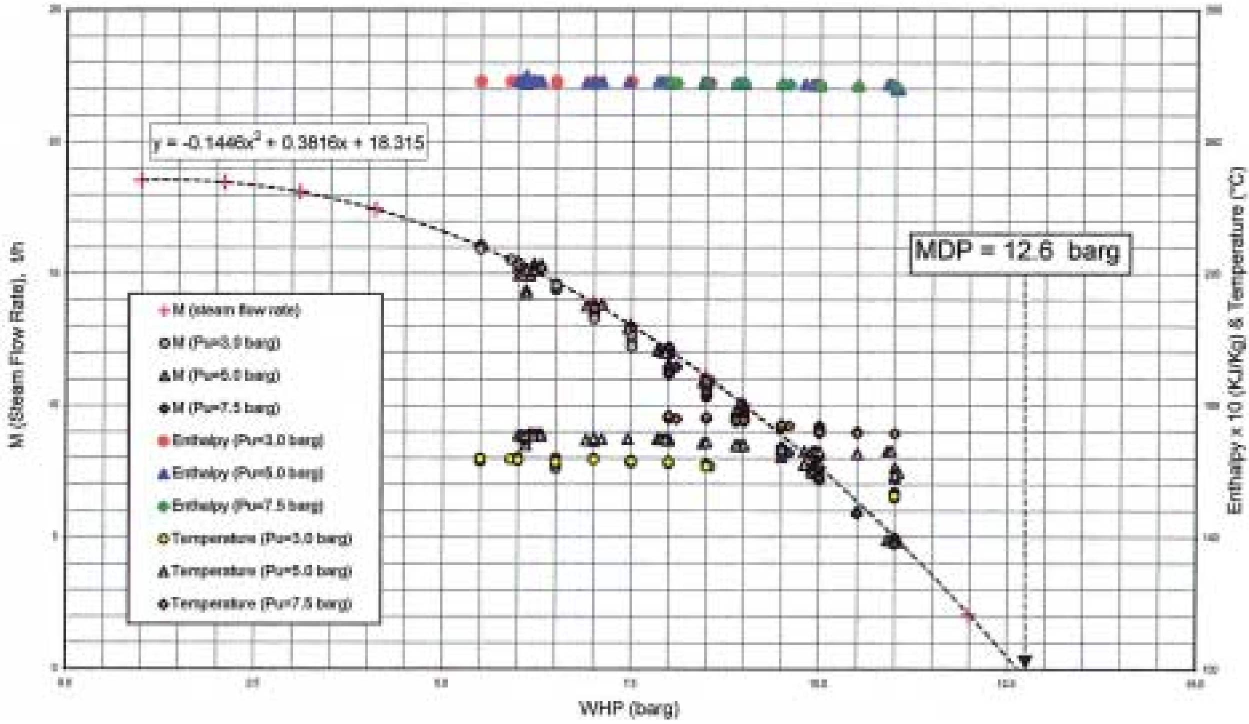

Fig. 4 Graph of steam flow rate, enthalpy and temperature versus WHP of the MT-2 well in the Mataloko geothermal field.

barg. A high temperature range of steam (171.5 - 176.8 ℃) is recorded at a PU of 7.5 barg, whereas temperatures at PUs of 5.0 and 3.0 barg are relatively low, i.e. 158.0 - 171.0 ℃ and 153.5 - 164.0 ℃, respectively. However, the flow line temperature during the test varies between 151.9 - 176.8 ℃. Most steam that flowed from the MT-2 well are characterized as superheated steam by 0.12 - 21.28 ℃, except the saturated steam that flowed at a PU of 7.5 barg and WHP of 10.5 - 11.0 barg (Table 1).

The reduction in the discharge enthalpy with increasing WHP is also a common characteristic of geothermal wells. This change is clearly shown by the data from PUs of 3.0, 5.0 and 7.5 barg. When the PU was 7.5 barg, the enthalpy range of 2760.7 - 2768.7 kJ/kg and 2779.9 - 2782.4 kJ/kg were observed at WHPs of 11.0 barg and 8.0 barg, respectively (Table 1). A high enthalpy steam (2758.3 - 2785.7 kJ/kg) was obtained when the PU was 3.0 barg.

3.2 P-T logging

The Kuster P-T logging was run in the hole five times at the bleeding, flowing and static conditions. Both temperature and pressure are increased with increasing depth (Table 2). The highest temperature (182.40 - 192.30 ℃) at a depth range of 130.0 - 175.0 m was observed during the first run on 15 April 2001. The maximum interval of down-hole pressure (12.84 - 13.86 barg) was measured under a static condition on 8 July 2001. The temperature range of 178.79 - 180.44 ℃ measured on 30 June 2001 in a flowing condition was relatively higher than the saturated temperature (Table 2). There was a dry steam column (superheated by 0.06 - 0.65 ℃) at depths of 130.0 - 175.0 m. Therefore, the interval depth of 130.0 - 180.0 m indicates the feed zone in the well MT-2.

3.3 Pressure buildup test

The PBU test started at 10:00 on 3 July 2001, showing a WHP of 2.1 barg and increased to 10.70 barg an hour later. At 09:00 on 14 July 2001, the WHP was 13.25 barg. The WHP data at the time of one hour are plotted on a Horner semi-log plot and appear to reach a semi-log straight line over a range of Horner time {(t + dt) / dt} from 1 to 1000000 (Fig. 5). The slope (m) of the line is equal to 20 bar^2/cycle. Based on the semi-log straight line and 50-m feed zone thickness, the transmissivity or permeability thickness (kh) and skin factor (s) are calculated as 14.43 darcy-meters and -5.583, respectively. These values are typical for a fracture-type geothermal system.

3.4 Analysis of steam and gas chemistry

At each WHP of the flow test, NCG and SC samples were taken from a mini-separator installed in the pipeline. The H_2S, CO_2 and residual gases from a syringe bottle were directly analyzed in the field. The 63 NCG samples analyzed in the field show that the superheated steam from the well MT-2 has a very low content of NCG (0.18 - 0.59 vol% or 0.43 - 1.83 wt%). Concentrations of H_2S, CO_2 and residual

Table 2 Temperature and pressure Kuster logging of the MT-2 well in the Mataloko geothermal field.

DEPTH	PRESSURE					LOGGING (T-LOG) AND SATURATED TEMPERATURES (T-SAT) - °C									
	Run-1	Run-2	Run-3	Run-4	Run-5	Run-1		Run-2		Run-3		Run-4		Run-5	
(m)	(barg)	(barg)	(barg)	(barg)	(barg)	T-LOG.	T-SAT.	T-LOG.	T-SAT.	T-LOG.	T-SAT.	T-LOG.	T-SAT.	T-LOG.	T-SAT.
0.0	5.96	-	-	12.26	12.84	155.90	164.14	-	-	-	-	179.56	192.17	93.91	194.17
10.0	-	-	8.52	-	-	-	-	-	-	173.26	177.30	-	-	-	-
25.0	6.15	8.56	8.56	12.37	-	164.10	165.25	173.39	177.57	174.00	177.48	183.63	192.55	-	-
50.0	7.47	8.63	8.62	12.50	13.14	**168.00**	*167.04*	175.70	177.80	175.25	177.76	183.84	193.00	184.04	195.17
75.0	8.88	8.66	8.67	12.62	-	**170.50**	*169.26*	176.53	178.03	176.50	177.98	183.91	193.41	-	-
100.0	9.73	8.71	8.71	12.75	13.43	176.70	182.55	176.54	178.16	177.24	178.16	183.92	193.86	186.15	196.13
110.0	10.30	8.73	8.77	12.79	13.49	177.70	184.86	176.61	178.25	177.38	178.43	184.13	194.00	186.07	196.33
120.0	10.87	8.77	8.81	12.84	13.54	178.40	187.06	176.64	178.43	177.96	178.61	183.92	194.17	186.17	196.49
130.0	11.14	8.81	8.85	12.87	13.60	182.40	188.11	176.65	178.61	**178.79**	*178.79*	184.06	194.27	185.94	196.69
140.0	11.71	8.84	8.90	12.91	13.66	183.70	190.21	176.68	178.74	**179.07**	*179.01*	187.01	194.40	185.75	196.88
150.0	12.18	8.88	8.94	12.95	13.72	187.00	191.88	176.82	178.89	**179.56**	*179.18*	188.40	194.54	186.08	197.07
160.0	12.75	8.90	8.99	13.00	13.77	189.50	193.86	177.24	179.01	**179.80**	*179.40*	188.26	194.71	189.31	197.23
170.0	13.32	8.94	9.05	13.04	13.83	191.70	195.77	177.76	179.18	**180.20**	*179.66*	186.38	194.84	189.14	197.43
175.0	13.60	8.98	9.08	13.06	13.86	**192.30**	196.36	179.07	179.30	**180.44**	*179.79*	186.38	194.91	188.35	197.52

	Run-1	Run-2	Run-3	Run-4	Run-5
DATE	15-04-2001	24-04-2001	30-06-2001	05-07-2001	08-07-2001
MEASUREMENT					
STARTED (h)	20:40	09:50	10:30	10:15	09:55
TILL (h)	22:57	12:30	13:25	13:15	12:30
WELL CONDITION	*Bleeding*	*Flowing*	*Flowing*	*Static (?)* (Leaking)	*Static (?)* (Leaking)
WHP (barg)	5.85	8.7	8.5	12.30	12.96
Tu (°C)	-	175.0	173.1	-	110.0
Pu (barg)	-	7.5	7.5	-	-
Flow Rate (t/h)	-	1.4	11.43	-	-

EXPLANATION :

Actual depth of the MT-2 well = 178.0 m

Atmospheric pressure in the Mataloko geothermal field = 0.9 bar

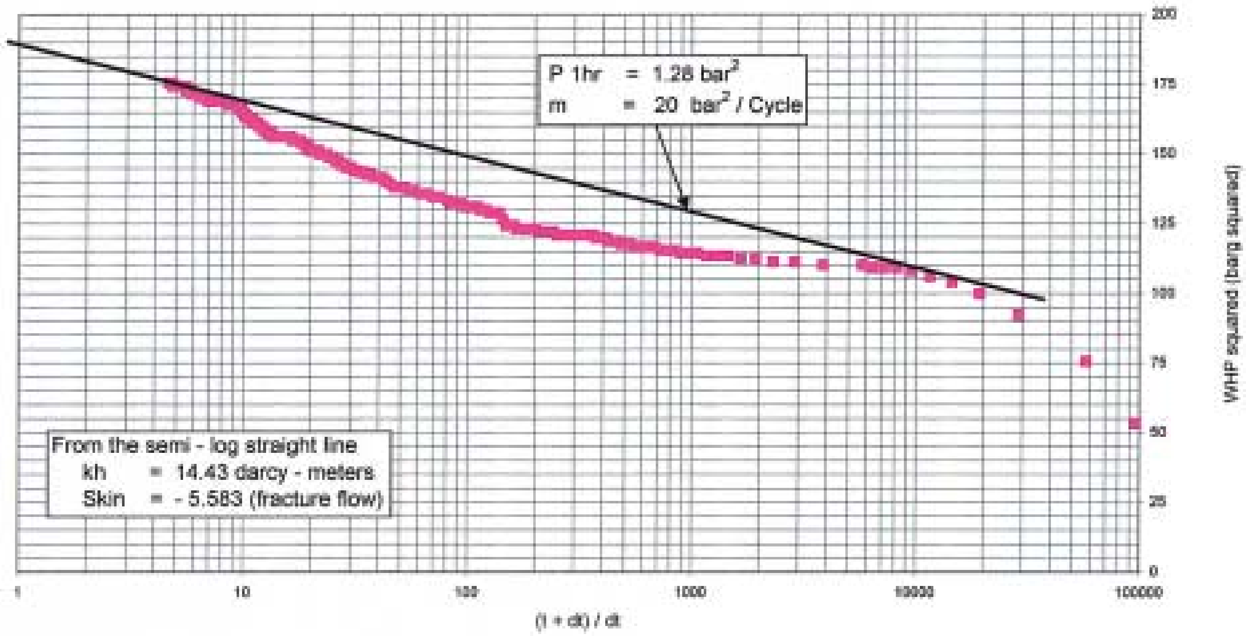

Fig. 5 Pressure buildup data (Horner semi log plot) from the MT-2 well in the Mataloko geothermal field.

gas in NCG are 0.41 - 0.89 ppm, 3.74 - 15.58 ppm and 0 - 0.07 ppm, respectively (Directorate of Mineral Resources Inventory, 2001). The low gas content in the superheated steam from the MT-2 well indicates that the steam is not corrosive. Fourteen samples of NCG are collected in vacuum bottles. These samples are being analyzed in the VSI Laboratory in Yogyakarta.

4. Discussion

The changes in power output with regard to WHP are calculated by assuming a turbine efficiency of 80 % and outlet pressure of 0.5 bar (Table 3). The results show that the optimum output of the well is 1.48 MWe. This requires a steam flow rate of about 16.0 t/h at a WHP of 5.5 barg (Fig. 6). This initial result indicates that the MT-2 well can be utilized commercially. However, stable output analysis is required to provide information for a geothermal power plant with long-term production. A stable output can be estimated with draw down analysis, which was successfully done in the KMJ-14, KMJ-17 and KMJ-18 wells of the Kamojang geothermal field, West Java, Indonesia (Rumi, per. comm.). This method principally estimates a deduction of the output curve for 1, 6, 12, 24, 60 and 300 months of production. This analysis is still being done to the output curve of the MT-2 well.

Before the flow test of the MT-2 well, a sinker-bar was run in the hole to the bottom on 15 April 2001, but it was stopped at a depth of 178 m. We tried to run the sinker-bar deeper several times, but did not successful. Since the final drilling on 5 February 2001 (TD = 180.02 m), the total depth has decreased by 2 m in 68 days. From the subsurface geological data, swelling clay (40 - 60 % of the total rock) was present at depths of 136.0 - 180.02 m. It is a serious problem because the rocks will cave in if they interact with water. Prior to the flow test, the MT-2 well was vertically bleed with a 2" pipeline (inner diameter is 1.63") at a WHP of 3.82 barg. The steam discharges were periodically followed by an outburst of hot water for 5 - 7 seconds. It is consistent with the Kuster survey data on 15 April 2001 that the down-hole temperatures are relatively low compared with the saturated temperatures (Table 2). In this case, the hole is characterized by a steam column contains a water fraction. To minimize water fraction in the hole, the well should be maintained at a high temperature. Therefore, the P-T Kuster tool should be run at least once every six months or when the well declines in WHP.

The feed zone of the well MT-2, about 50 m thick (130.0 -180.0 m depth), is characterized by a relatively high flow capacity (14.43 darcy-meters). This fact seems to be inconsistent with the drilling parameters because no losses were recorded during the drilling to a total depth of 180.02 m. The only data showing a partial loss (static loss of 42.0 l/min) was measured after a short flow test (TD = 162.35 m) with the lip pressure method on 22 - 27 January 2001. In the early stage of the flow test of the well MT-2 (22 April - 17 May 2001), flow rate, temperature and enthalpy were increased with increasing time. Flow parameters were changed to a stable

Table 3 Estimation of the optimum output of the MT-2 well in the Mataloko geothermal field.

Asumption :
- Outlet P. of turbine = 0.5 bar
- Turbine Efficiency = 80 %
- Pressure loss is ignored

WHP		at well head		P. Outlet	at outlet of turbine				X	h	dh	n	M	Output
barg	bar.abs	hg J/g	Sg J/g	Turbine bar	hf	hfg	Sf	Sfg					t/h	MWe
2.1	3.0	2725.4	6.992	0.5	340.56	2304.9	1.0912	6.502	0.908	2432.3	293.1	0.8	18.48	1.20
3.1	4.0	2738.6	6.897	0.5	340.56	2304.9	1.0912	6.502	0.893	2398.7	339.9	0.8	18.11	1.37
4.1	5.0	2748.7	6.822	0.5	340.56	2304.9	1.0912	6.502	0.881	2372.1	376.6	0.8	17.45	1.46
5.5	6.4	2759.7	6.739	0.5	340.56	2304.9	1.0912	6.502	0.869	2342.7	417.0	0.8	16.08	1.49
6.0	6.9	2762.9	6.713	0.5	340.56	2304.9	1.0912	6.502	0.865	2333.4	429.5	0.8	15.38	1.47
7.0	7.9	2768.5	6.667	0.5	340.56	2304.9	1.0912	6.502	0.858	2317.1	451.4	0.8	13.88	1.39
7.5	8.4	2771.1	6.647	0.5	340.56	2304.9	1.0912	6.502	0.854	2310.0	461.1	0.8	12.95	1.33
8.0	8.9	2772.5	6.627	0.5	340.56	2304.9	1.0912	6.502	0.851	2303.0	469.5	0.8	12.23	1.28
8.5	9.4	2775.6	6.608	0.5	340.56	2304.9	1.0912	6.502	0.848	2296.2	479.4	0.8	11.02	1.17
9.0	9.9	2777.5	6.590	0.5	340.56	2304.9	1.0912	6.502	0.846	2289.8	487.7	0.8	10.05	1.09
10.0	10.9	2781.3	6.557	0.5	340.56	2304.9	1.0912	6.502	0.841	2278.1	503.2	0.8	7.78	0.87
11.0	11.9	2784.3	6.526	0.5	340.56	2304.9	1.0912	6.502	0.836	2267.1	517.2	0.8	4.95	0.57

X = (Sg - Sf) / Sfg
h = hf + (X x hfg)
dh = hg - h
Output (Potency) = dh.M.n / 3600

From the graphic of flow rates against WHP, it is estimated :
- Optimum WHP = 5.5 barg
- M (Steam Flow Rate) - optimum = 16 t/h
- Optimum Output = 1.48 MWe

hg : specific enthalpy of steam at well head (inlet of turbine)
Sg : specific entropy of steam at well head (inlet of turbine)
hf : specific enthalpy of saturated liquid at outlet of turbine
Sf : specific entropy of saturated liquid at outlet of turbine
Sfg : specific entropy of evaporation (liquid and stem) at outlet of turbine.

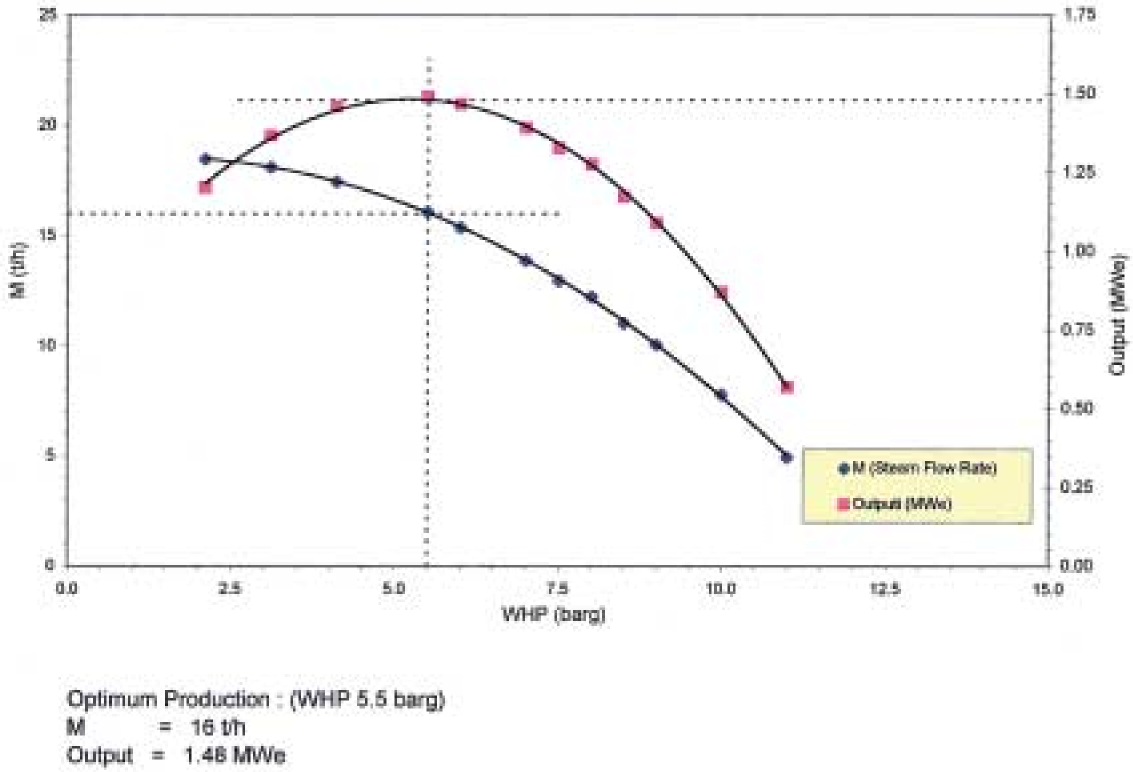

Fig. 6 Steam flow rate and output versus WHP of the MT-2 well in the Mataloko geothermal field.

condition in the middle and final stages of the test. A smaller diameter orifice in the early test can not be used in the middle test because differential pressure was not lower than 20 % of the PU as one criterion for the use of the orifice plate method with D and D/2 tappings. The data suggest that a high flow capacity is most possibly developed during the flow test of the well MT-2, which is consistent with the negative skin factor value, -5.583, as a fracture-type geothermal system.

5. Conclusion and suggestion

From the earlier discussion, the following several conclusions and suggestions can be made.

1) The MT-2 well is able to discharge high enthalpy (2758.3 - 2785.7 kJ/kg) dry steam (superheated by 0.12 - 21.28 ℃) at a temperature range of 151.9 - 176.8 ℃.
2) Maximum ranges of flow rate at Pus of 3.0 barg, 5.0 barg and 7.5 barg are 15.94 - 16.08 t/h at a WHP of 5.5 barg, 14.24 - 15.14 t/h at a WHP of 6.0 barg and 11.17 - 11.50 t/h at a WHP of 8.0 barg.
3) An optimum output of the MT-2 well is 1.48 MWe with a steam flow rate of 16.0 t/h at a WHP of 5.5 barg. This initial result requires a draw down analysis for the final evaluation of stable output. The MT-2 well will not flow at a maximum discharge pressure of 12.6 barg.
4) The feed zone of the well MT-2 (at depths of 130.0 - 150.0 m) is characterized by a relatively high flow capacity (14.43 darcy-meters) with a temperature range of 182.40 - 192.30 ℃. The high flow capacity was most possibly developed during the flow test and is consistent with a negative value of the skin factor (-5.583) as a typical fracture-type geothermal system.
5) Steam from the well MT-2 has a very low content of NCG (0.18 - 0.59 vol% or 0.43 - 1.83 wt%). The H_2S, CO_2 and residual gas in NCG varies between 0.41 - 0.89 ppm, 3.74 - 15.58 ppm and 0 - 0.07 ppm, respectively. A low gas content indicates that the steam is not corrosive.
6) A stable output for 1, 6, 12, 24, 60 and 300 months of production can be estimated with a draw down analysis. The analysis also provided information for the life time of the MT-2 well.
7) The hole has decreased in depth by 2 m 68 days after the completion of the drilling. The MT-2 well is unstable and should be maintained to a high temperature using a P-T Kuster tool at least every six months or when the well declines in WHP.

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インドネシア，フローレス島ンガダ郡マタロコ地熱地域MT-2井の長期噴出

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要　旨

調査井 MT-2（全長 180.02 m）は，2001 年 4 月 22 日から 7 月 14 日までの長期にわたる D および D/2 タッピングによるオリフィス法坑井試験を成功裏に終えた．MT-2 井の最適生産量は，商業的坑口圧 5.5 barg の条件下で約 16.0 t/h であり，これはタービン効率を 80 %，出口圧を 0.5 bar とした場合の発電量で 1.48 Mwe に相当する．この坑口圧では，生産蒸気は 163.0 ℃以上（20.28～21.28 ℃の過熱状態）の高エンタルピー流体または乾き蒸気（2784.0～2785.3 kJ/kg）となる．坑井からの安定的生産を確認するため，噴出試験データのドローダウン解析が行われた．

5 回にわたる噴出中の P-T クスター検層，および噴出／密閉圧力ビルドアップテストの結果は，深度 130～175 mでの温度がさらに高い（182.40～192.30 ℃）ことを示した．密閉後の圧力回復データ解析によれば，生産ゾーンの流量は比較的高い（14.43 darcy-meters）．この高い流量は，蒸気流動中のスキンファクターが負（-5.583）であることに起因するようである．

坑井 MT-2 から生産される過熱蒸気は，非凝縮ガスが極めて少ない（0.18～0.59 vol% または 0.43～1.83 wt%）．H_2S，CO_2 および他の非凝縮ガス濃度はそれぞれ約 0.41～0.89 ppm， 3.74～15.58 ppm，0～0.07 ppm である．従って，この蒸気は腐食を起こしにくいものである．

（要旨翻訳：水垣桂子（地圏資源環境研究部門））