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Projecting the Performance of Nasuji-Sogongon Production Wells with the Additional 20 MWE Power Plant in the Palinpinon-2 Area, Southern Negros Geothermal Production Field, Philippines

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Keywords

Decline curve analysis, volumetric stored heat estimate, pressure-mass flow-enthalpy correlations, Palinpinon-2, Philippines

ABSTRACT

An additional 20 MWe modular power plant will be constructed in the Nasuji area, Palinpinon-2 of the Southern Negros Geothermal Production Field, Philippines and will begin operation by early 2006. An assessment using lump parameter model (decline curve analysis) and volumetric stored heat estimate, demonstrated that the field could support the additional capacity with minimal drawdown of ~1 MPa. Correlation of the pressure, mass flow and enthalpy trends were also made to establish the corresponding changes with pressure drawdown. The projected well outputs at any time during production were then calculated. The results of the correlation clearly distinguished the effects of reinjection returns and wellbore blockages on the outputs of the wells that otherwise, would give misleading or erroneous approximations. In the absence of an arduous simulation work, this simple and straightforward method has yielded reasonable steam and brine flow projections for the 25-year economic life of the plant.

Introduction

The Southern Negros Geothermal Production Field (SNGPF) is located in Negros Island, central Philippines. Also known as the Palinpinon Geothermal Field, SNGPF is subdivided into two geographical areas, namely and currently, the operating fields of Palinpinon 1 (Paln-1) and Palinpinon 2 (Paln-2) as shown in Figure 1. The commercial production of electricity from the field began when the National Power Corporation (NPC) commissioned its 112.5 MWe Paln-1 geothermal power plant in the Puhagan area in June 1983. Generation from Paln-2 commenced about 10 years after when 1x20 MWe Nasuji, 1x20 MWe Balasbalas and 2x20 MWe modular plants, also owned by NPC, were commissioned between December 1993 and January 1995. Geothermal power from SNGPF is being supplied to the whole island of Negros and to the neighboring islands of Panay and Cebu via submarine power cables.

The NPC Visayas Monthly Generation and Energy Sales Forecast for 2003 to 2005 indicated an increase of 56.3 MWe/year or approximately 9.8% annual load increase. It is expected that the generation capability of NPC will be insufficient to meet the load demand of the Cebu-Negros-Panay grid by January 2005.

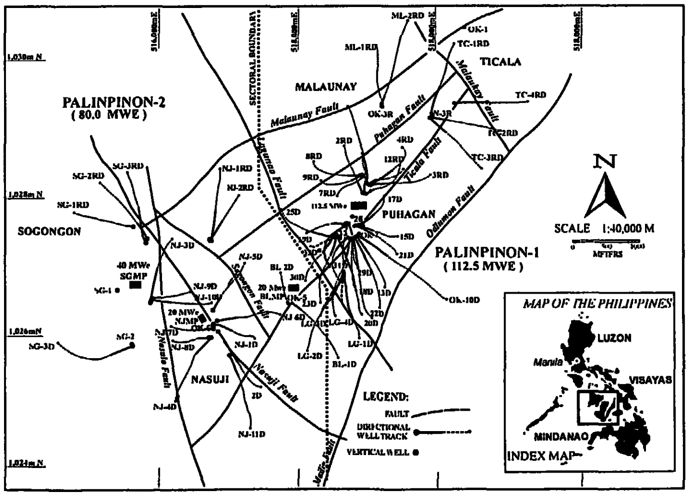

Figure 1. Location map of the Southern Negros Geothermal Production Field. (Courtesy of Geoscientific Department-SNGPF, PNOC-EDC).

Based on this demand forecast, PNOC-EDC has programmed to put up an additional 20 MWe modular plant in the Nasuji area to be commissioned in early 2006. A reservoir assessment using lump parameter model and volumetric stored heat estimates indicated that the field could support the additional capacity with minimal drawdown of pressure. The prediction of the resulting production and reinjection well performance would be a difficult task in the absence of a reservoir simulation work. However, a simple and straightforward method was used to assess the reservoir pressure response to an additional 20 MWe capacity in the area. In addition to the pressure decline curve analysis, pressure-mass flow and pressure-enthalpy plots of the production wells were evaluated to predict trends with pressure. Steam and brine flows within the 25-year economic life of the power plants were then projected.

Field Assessment

The lumped parameter model and the volumetric stored heat methods used by Amistoso, et. al. (2002) had demonstrated that the Paln-2 reservoir could still support an additional 20 MWe modular power plant for a commercial operation of 25 years as shown on Figures 2 and 3. The additional potential of the field could even be as high as 40 MWe based on the decline curve analysis. The resulting pressure drawdown was estimated to be only within 1 MPa and is not expected to have significant effect on the output of the wells considering that the current reservoir pressure in Paln-2 of ~6 MPag is still 1.0 MPa higher than ~5 MPag of Paln-1. The drawdown will expand the two-phase zone and will result to more steam and less brine production.

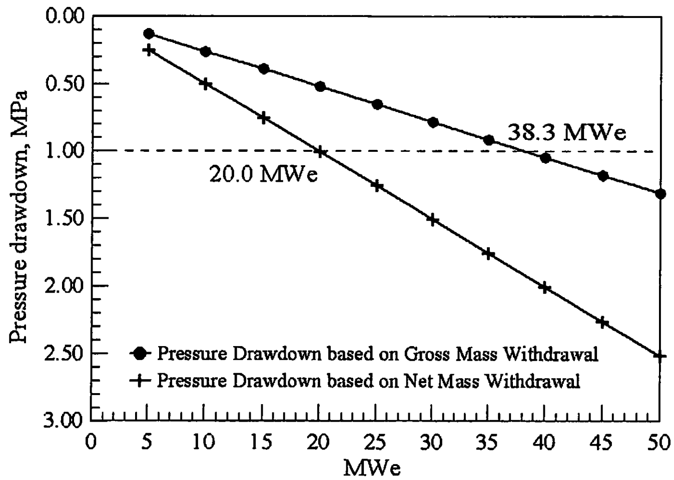

Figure 2. Paln-2 pressure drawdown per MWe (based on pressure decline curve analysis).

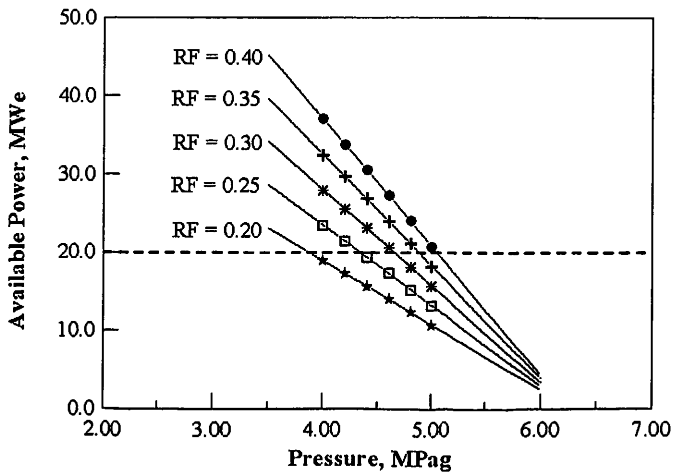

Figure 3. Available power versus reservoir pressure at 1000 m below sea level (based on pressure decline curve analysis).

The current steam supply in the Paln-2 area is presently in excess (Table 1) and could be utilized for the additional 20 MWe power plant. However, only the excess steam supply from the Nasuji sector (7 MWe) is to be utilized for the conventional flash plant since the interconnection of Balasbalas and Sogongon sectors to Nasuji would involve huge piping cost. The other sources of steam would be from the work-overs of Nasuji production wells with mineral blockages (8.3 MWe) and the drilling of an additional production well (~7.1 MWe output estimated based on the existing wells). Table 2 shows the expected output recoveries of the wells to be worked-over. The available capacity from the Nasuji and Sogongon injection wells of 123.4-146.1 kg/s is sufficient to meet the injection requirements (estimated at ~95 kg/s) for the additional 20 MWe module at start-up. However, additional injection wells may have to be drilled later because of the possible injection returns to the production area coming from the utilization of the Sogongon injection wells. Targets for the additional wells to be drilled have already been identified.

Table 1. Paln-2 steam availability.

SECTOR	AVAILABLE STEAM		PLANT REQUIREMENT		EXCESS	
	TPH	MWe	TPH	MWe	TPH	MWe
BALASBALAS	225.3	29.8	152.3	20	73	9.8
NASUJI	220.8	27.0	160.7	20	60.1	7.0
SOGONGON	360.3	44.0	232.9	40	36.4	4.0

Table 2. Nasuji-Sogongon wells for work-over and expected output recoveries.

WELL	BLOCKAGE DEPTH (mMD)	OUTPUT (MWe)		
		PRE-BLOCKAGE	CURRENT	RECOVERABLE
Nasuji Sector				
OK-6	1352/1818	7.3	5.4	1.9
NJ-4D	1298-2000	7.8	5.9	1.9
NJ-5D	1449	8.5	7.1	1.4
NJ-7D	1755	6.8	3.3	3.5
			Subtotal	*8.7*
Sogongon Sector				
SG-2	1448	15.6	11.1	4.5
SG-3D	1984	13.5	10.6	2.9
			Subtotal	*7.4*
			Total	**16.1**

Pressure Drawdown

The pressure drawdown at any time during production can be computed using the decline curve analysis (Sanyal and Stefanson, 1986). It is given by

$$P_o - P_l = \frac{W_l}{\alpha_r}\left(1 - e^{-t/T}\right) \qquad (1)$$

Where P_o-P_l = pressure drawdown (MPa), P_o = initial pressure (MPag), P_l = pressure at any time (MPag), W1 = mass withdrawal rate (kg/s), α_r = recharge coefficient (kg/s-MPa), t = any time during production (sec) and T = pressure relaxation time (sec).

Figure 4a and 4b show the pressure trend in the Paln-1 and Paln-2 area at 1000 m below sea level, respectively. The reservoir pressure in Paln-2 was ~8 MPag at the start of the commissioning of the modular plants and declined to ~6 MPag as production continued. The pressures were observed to stabilize at this level beginning in 2001. Based on the historical pressure data and average mass flow requirement of 133 kg/s for the additional 20 MWe plant, the pressure relaxation time and the recharge coefficient were estimated to be 4 years and 2.5331×10^2 kg/s-MPa, respectively. The projected pressures shown on Figure 4b were calculated using equation (1).

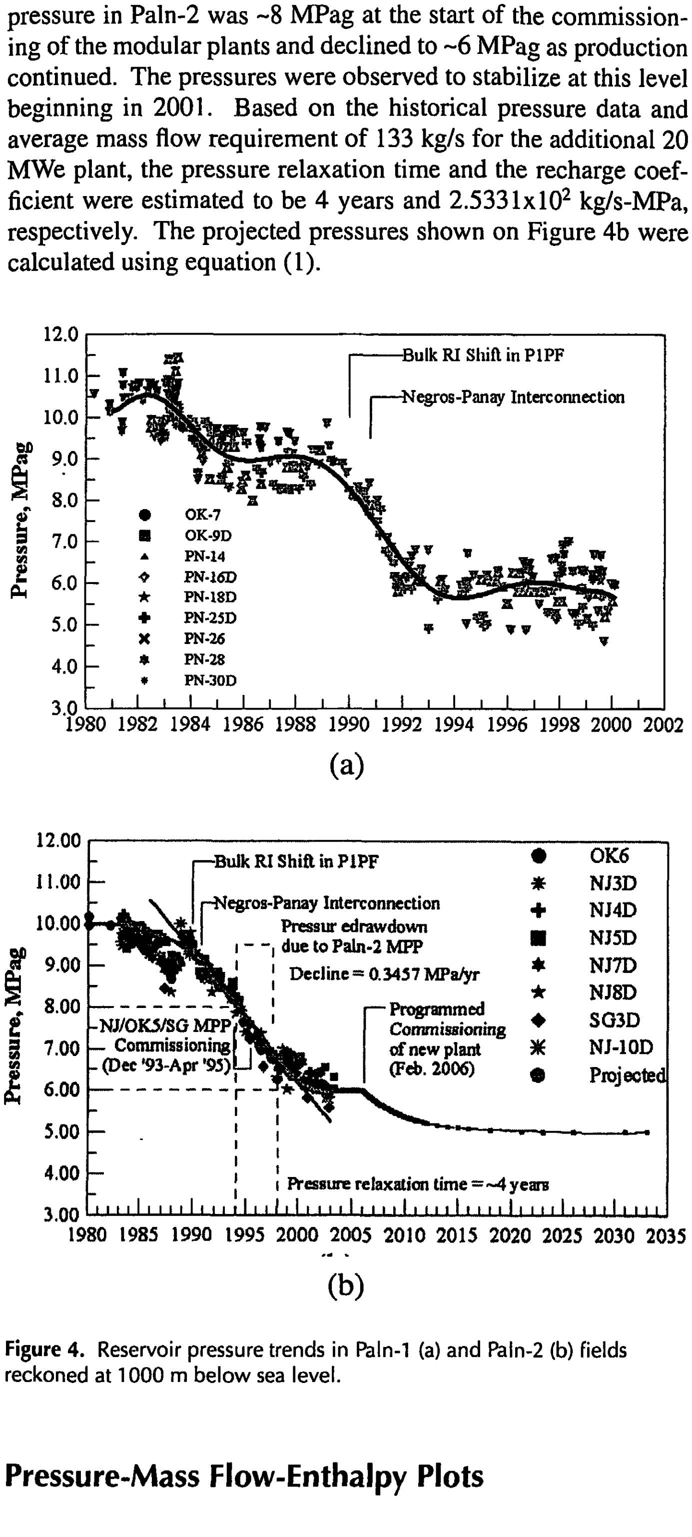

Figure 4. Reservoir pressure trends in Paln-1 (a) and Paln-2 (b) fields reckoned at 1000 m below sea level.

Pressure-Mass Flow-Enthalpy Plots

The enthalpy and mass flow of individual wells were correlated against reservoir pressure at 1000 m sea level. The resulting pressure-mass flow-enthalpy correlations yielded linear trends with pressure, from which, slopes corresponding to enthalpy increase and mass flow decline per MPa were obtained. The pressure-mass flow-enthalpy plots of selected wells are shown on Figure 5. The slopes of the best-fit lines of all Nasuji-Sogongon wells are summarized on Table 3.

Generally, the initial discharge data for the pressure-mass flow (p-MF) plots were excluded in obtaining the best-fit line. Data used were only those corresponding to the period when the reservoir pressure dropped from 8 MPag (1994) to 6 MPag (2001) during exploitation as they were representative of the actual field response to the production in Paln-2. The high initial mass flows in OK-6 and NJ-7D were pre-exploitation data in the early 80's during which, the reservoir pressure was still 10 MPag; hence, they do not fit with the linear trend corresponding to the period during exploitation.

On the other hand, the best-fit lines for the pressure-enthalpy (p-H) plots include pre-exploitation data since the enthalpy is more dependent on temperature rather than on pressure. Hence, early enthalpy data can be considered stable. Upon exploitation, the enthalpy is indirectly dependent on pressure drawdown due to boiling in the reservoir. Enthalpy data starting 1996 are already influenced by fluid recharge, likely injection fluids returning to the production sector.

The effects of fluid recharge, likely injection returns, and wellbore blockage became very distinguishable on the pressure-mass flow-enthalpy plots. Wells with blockages show persistent drop in mass flow with very minimal change in pressure. This was reflected as an almost vertical line on the p-MF plots in wells OK-6, NJ-4D, NJ-5D and NJ-7D that have confirmed obstructions in their wellbores. This trend is very pronounced in NJ-7D where there was substantial increase in enthalpy as the blockage suppressed the single-phase liquid feed from the bottom zone and caused two-phase feed from the upper zone to dominate discharge. Mass flow declines due to blockages should be excluded in determining the best-fit line of p-MF plots.

Boiling is the immediate and direct effect of reservoir pressure drawdown. This was observed in all the Nasuji wells and manifested as enthalpy increases as the pressures declined from 10 to 8 MPag. Although the data between 1980 and 1994 were scarce, the pressure-enthalpy relationship appeared to be linear and can be clearly observed in NJ-4D and SG-1. Furthermore, this linear trend was also observed in P1PF where substantial amount of data have been plotted (Figure 5f).

The effects of injection returns are clearly seen on the p-H plots of the wells affected, such as OK-6, NJ-4D and SG-1. The increasing enthalpy trends in these wells were arrested when the reservoir pressure reached 7 MPag, which corresponded to around year 1996 when chemical and mass fronts of the injection fluid have intruded the Nasuji production area. Since then, the enthalpy ceased to increase and assumed a stable, in some cases, a declining trend as in NJ-5D. This indicated that further boiling in the reservoir was prevented by the breakthrough of the injected brine into the production sector. A more pronounced effect of injection returns can be seen in NJ-5D. The enthalpy reversed to a declining trend as injection fluids continued to intrude the well. The injection breakthrough effects were also highlighted by some increases in mass flow as shown on the plot. Another manifestation of injected fluid returns in wells affected is the relatively low mass flow rate decline with pressure drawdown. This is observed in NJ-5D, as well as in the similarly affected NJ-3D. Injection fluids intruding these wells have acted as additional recharge. Data manifesting injection returns were excluded in obtaining the best-fit line for the p-H plots.

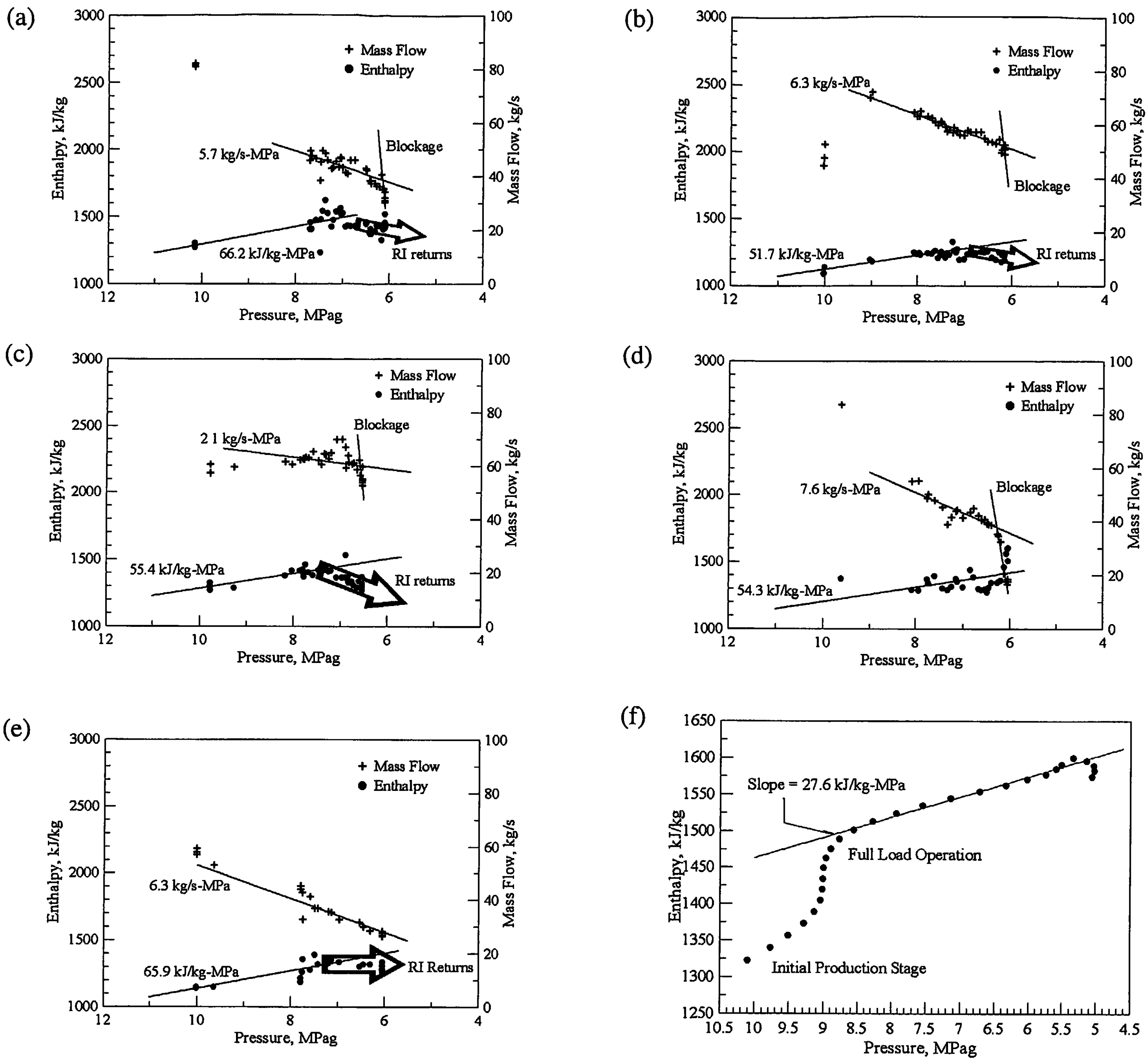

Figure 5. Pressure-mass flow-enthalpy plots of (a) OK-6, (b) NJ-4D, (c) NJ-5D, (d) NJ-7D, (e) SG-1 and (f) Paln-1 field.

Steam and Brine Flow Projections

Having now obtained the expected enthalpy and mass flow responses per MPa drawdown, the enthalpy H and mass flow MF at any time during production are computed using equations 2 and 3 below.

$$H = H_o + (P_o - P_1) \times dH \qquad (2)$$

$$MF = MF_o - (P_o - P_1) \times dMF \qquad (3)$$

Where H_o = initial enthalpy (kJ/kg), dH = p-H slope (kJ/kg-MPa) from Table 3, MF_o = initial mass flow (kg/s) and dMF = p-MF slope (kg/s-MPa) from Table 3.

The corresponding steam and brine flows were then calculated using mass-energy balance and plant parameters similar to the existing 20 MWe Nasuji module (i.e. separator pressure=0.63 MPaa, steam rate=2.273 kg/s-MWe). The comparison of the individual well outputs after the pressure had declined by 1 MPa is shown on Table 4. It is worthy to note that the outputs presented for wells with wellbore blockages (marked with * on the table) were estimated values after the work-over. These wells are already programmed for a mechanical work-over. NJ-11D output and the expected changes after 1 MPa drawdown are basically the average of the existing wells. Table 5 summarizes the annual total steam and brine flows for the first 10 years, on the 15th, 20th and 25th year of operation. Plots are shown on Figure 6.

Table 3. Slopes of the best-fit lines from the pressure-mass flow-enthalpy correlations.

SECTOR/ WELL	p-H PLOTS (kJ/kg-MPa)	p-MF PLOTS (kg/s-MPa)
NASUJI		
OK-6	66.2	5.7
NJ-4D	51.7	6.3
NJ-5D	55.4	2.1
NJ-7D	54.3	7.6
NJ-8D	64.4	3.9
SOGONGON		
SG-1	65.9	6.3
SG-2	94.1	8.2
SG-3D	244	7.2
NJ-3D	23.5	1.5
NJ-9D	149.3	2.8
NJ-10D	158.2	7.6

Table 4. Comparison of outputs of Nasuji-Sogongon wells after 1 MPa pressure drawdown. Calculations were based on separation pressure of 0.63 MPaa and steam rate of 2.273 kg/s-MWe.

SECTOR/	CURRENT OUTPUTS					AFTER 1 MPa DRAWDOWN				
WELL	H	MF	WF	SF	MWe	H	MF	WF	SF	MWe
NASUJI										
OK-6*	1430	46.0	29.4	16.6	7.3	1496	40.3	24.5	15.8	7.0
NJ-4D*	1280	58.0	41.2	16.8	7.4	1332	51.7	35.5	16.2	7.1
NJ-5D*	1340	61.0	41.6	19.4	8.5	1395	58.9	38.6	20.3	8.9
NJ-7D*	1390	45.0	29.6	15.4	6.8	1444	37.4	23.6	13.8	6.1
NJ-8D	1296	39.8	28.0	11.8	5.2	1360	35.9	24.1	11.8	5.2
NJ-11D	1347	50.0	33.9	16.1	7.1	1406	44.8	29.2	15.7	6.9
Sub-total		*299.8*	*203.8*	96.0	*42.2*		*269.0*	*175.5*	*93.5*	*41.2*
SOGONGON										
SG-1	1330	26.7	18.3	8.4	3.7	1396	20.4	13.4	7.0	3.1
SG-2*	2570	48.6	4.4	44.2	19.4	2664	40.4	1.8	38.6	17.0
SG-3D	1962	39.2	15.0	24.2	10.6	2206	32.0	8.5	23.5	10.3
NJ-3D	1273	64.6	46.1	18.5	8.1	1297	63.1	44.4	18.7	8.2
NJ-9D	1932	9.3	3.7	5.6	2.5	2081	6.5	2.1	4.4	1.9
NJ-10D	2021	33.9	12.0	21.9	9.6	2179	26.3	7.3	19.0	8.3
Sub-total		*222.3*	*99.7*	*122.6*	*54.0*		188.7	*77.5*	*111.2*	*48.9*
TOTAL		**522.1**	**303.4**	**218.7**	**96.2**		**457.7**	**253.0**	**204.7**	**90.1**

Table 5. Tabulated projected steam and brine flows in Nasuji-Sogongon area.

YEAR	STEAM (MWe)			BRINE (kg/s)		
	NJ	SG	TOTAL	NJ	SG	TOTAL
2006	42.2	54.0	96.2	203.8	99.7	303.5
2007	42.1	53.0	95.1	197.0	94.1	291.1
2008	41.9	52.2	94.1	192.2	90.2	282.4
2009	41.8	51.5	93.3	188.5	87.3	275.8
2010	41.6	51.0	92.6	185.6	85.0	270.6
2011	41.5	50.6	92.1	183.5	83.4	266.9
2012	41.5	50.2	91.7	181.7	82.1	263.8
2013	41.4	49.9	91.3	180.3	81.0	261.3
2014	41.3	49.7	91.0	179.2	80.2	259.5
2015	41.3	49.5	90.8	178.4	79.6	258.0
2016	41.3	49.4	90.7	177.7	79.1	256.9
2021	41.2	49.0	90.2	176.1	77.9	254.0
2026	41.2	48.9	90.1	175.6	77.6	253.2
2031	41.2	48.9	90.0	175.5	77.5	253.0

Conclusion

The decline curve analysis and the pressure-mass flow-enthalpy correlations have been of great aid in projecting the individual outputs of the Nasuji-Sogongon wells after the field pressure had declined by 1 MPa following the operation of the additional 20 MWe plant in the area. Aside from being simple and straightforward, the correlations were found to be very useful in distinguishing the effects of wellbore blockage and reinjection fluid returns. Thus, providing an easy method to eliminate their misleading effects in obtaining representative mass flow and enthalpy changes with pressure drawdown.

Calculation results indicated that the drawdown of 1 MPa would cause the Nasuji sector total steam capability to drop from 42.2 MWe to 41.2 MWe and the brine flow from 204 kg/s to about 176 kg/s. Similarly, the Sogongon sector capability would decline from 54.0 to 48.9 MWe and the brine flow from 99.7 to 77.5 kg/s. The relatively minimal decline in the field steam capability in Nasuji is due to the compensating effect of enthalpy increase on the decline in mass flow. Again, it must be noted that the output changes obtained eliminated wellbore blockage effects. Should obstructions recur in the production wells, likely as mineral depositions, inhibition systems may be installed.

(a)

(b)

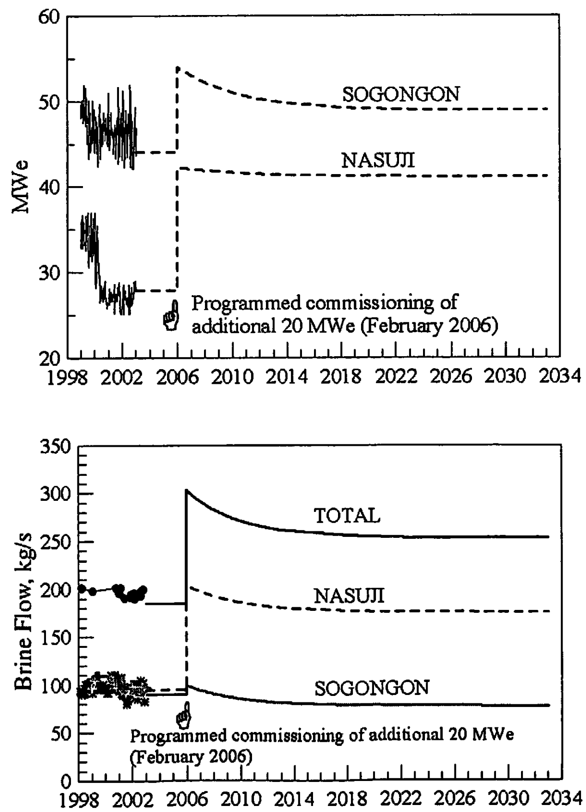

Figure 6. Plots of projected steam (a) and brine (b) flows in Nasuji-Sogongon area.

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