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DEVELOPMENT AND PERFORMANCE OF THE BULALO GEOTHERMAL FIELD

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ABSTRACT

The Bulalo Geothermal Field has generated electricity from geothermal steam since 1979. The wells produce two phase fluid from a 260-316 deg C benign, low gas, liquid dominated reservoir which is made up of fractured and intensely altered inter-layered volcanics. Separated steam from six satellite stations, flows to NPC's six 55 MW power plants while the residual brine is reinjected back into the reservoir on the periphery of the production area. Through 1988, the reservoir's performance has been excellent. The maximum field-wide steam supply decline rate observed thus far is approximately four percent per year. The power plants, through mid-year 1988, have generated a cumulative total of 15,375 GWh of electricity. The plants are now generating 14 percent of NPC's Luzon grid energy and are currently the top performing plants in the Philippines.

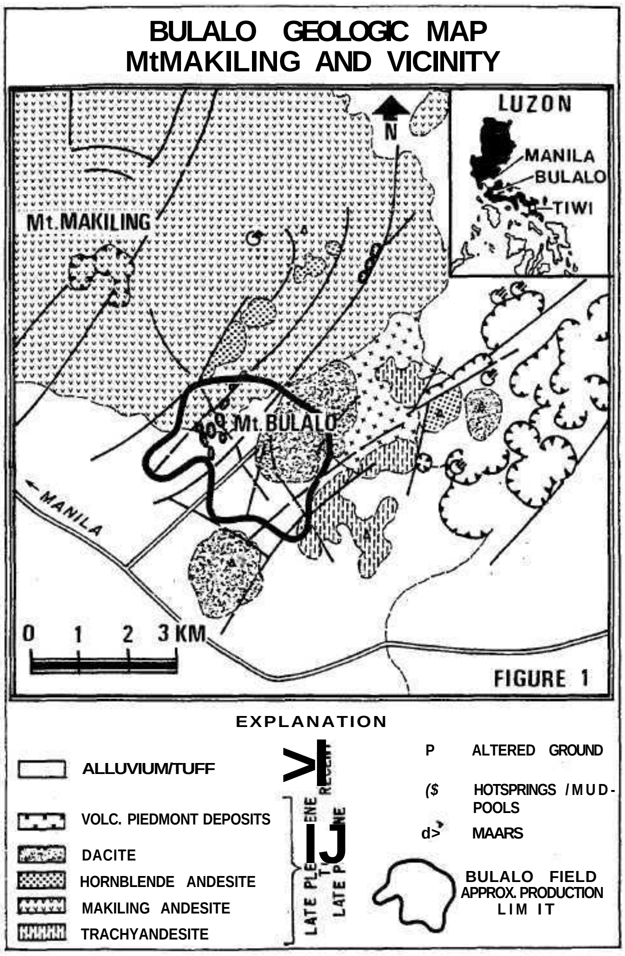
INTRODUCTION

The Bulalo Geothermal Field (hereafter called Bulalo) is located approximately 70 km south of Manila and has been commercially operating since April 1979. Bulalo is one of two geothermal projects developed by the National Power Corporation (NPC) of the Philippine Government and Philippine Geothermal, Inc. (PGI), a wholly owned subsidiary of Union Oil Company of California. After the 1973 signing of a service contract that includes the Bulalo area, exploration work began. The first production test, Bul-1 was drilled in late 1974 and completed as a discovery to 5722' (1744 m) T.D. In a 1975 flow test, the well produced a total mass rate of 467 kph (thousand lbs per hour) (211.8 T/h). Since then, 72 wells have been drilled and completed. These wells provide the steam and reinjection capacity required to operate NPC's six 55 MW Mitsubishi direct contact condensing turbine generators.

This paper briefly summarizes Bulalo's development, reservoir and generation performance through mid-year 1988. Extensive technical work has been carried out by both NPC and PGI on Bulalo. The results of selected studies will be presented in this paper.

GEOLOGICAL SETTING

Bulalo is located on the southeast flank of Mt. Makiling, an 800 m high extinct and partially eroded andesitic stratovolcano (Figure 1). The field is directly associated with the Mt. Bulalo dacite dome after which it is named. This parasitic dome was formed 500,000 years ago on the southeast flank of Mt. Makiling. Bulalo's main production area as delineated by development and exploratory drilling is approximately 7 to 8 square kilometers.



Several southwest-northeast trending regional and Makiling ring faults cross the field. These are normal faults downthrown towards Mt. Makiling. These faults have been intersected by northwest-southeast trending normal faults downthrown toward the south. Surface areas of acid sulfate steaming ground are located along the traces and at inter-sections of these fault systems. These thermal features reflect the venting of steam and gases from a two phase zone that overlies Bulalo's deep reservoir brine. The first well, Bul-1, was drilled within a low resistivity anomaly that is associated with these thermal features.

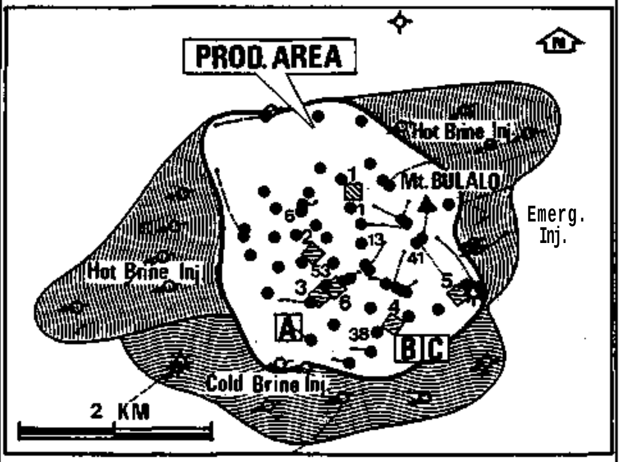
DEVELOPMENT

Bulalo's geothermal development continued over a span of 14 years. In late 1974 exploratory drilling started and continued through 1976. After the initial drilling results were evaluated, development drilling commenced and continued until 1983.

The first two 55 MW power plants Units 1 & 2 (Plant A) were completed in late 1979, followed by Units 3 & 4 (Plant B) in 1980. After extensive testing and analysis of production withdrawal associated with Units 1-4 operations, PGI notified NPC that Bulalo's reservoir could support another two 55 MW power plants. As a result, Units 5 & 6 (Plant C) were constructed and generation started in late 1984.

With each development phase the steam gathering and waste brine injection facilities were modified to accomodate increased reservoir mass withdrawal and power plant steam line piping flexibility. These modifications included facility changes to improve well testing capability, steam quality, waste brine injection capability and production-generation efficiency.

Figure 2 : BULALO FIELD



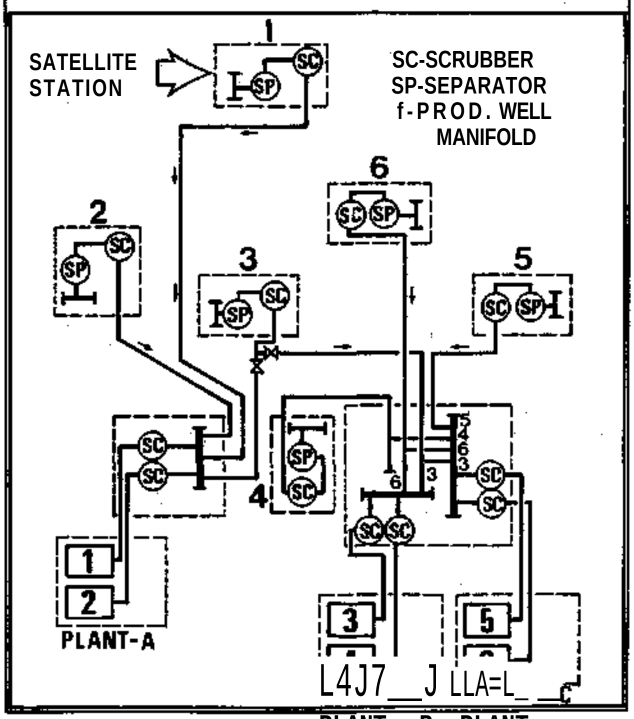
The generalized layout of Bulalo production and injection areas is shown in Figure 2. The field is subdivided into the following:

- Prod. Area – Includes all production wells
- Hot Brine Inj. - Separated brine injection area 175 deg C, single flash
- Cold Brine Inj.- NPC blowdown, brine flashed to atmosphere
- Emergency Inj. - Emergency injection wells

The producing area includes 55 production wells. The average steam and total mass flowrates of these wells are approximately 125 kph (56.7 T/h) and 220 kph (99.8 T/h) respectively. The hot brine injection area includes eight wells that can take up to 6000 kph (2721.6 T/h) while the cold brine area includes three active injection wells for the NPC coldwell blowdown and PGI's sump water. These cold brine injection wells handle approximately 1000 kph (453.6 T/h) of brine.

Three additional wells located within the production area are available for reihjection during injection wellbore or pipeline system problems. These wells are either non commercial or marginal producing wells. They provide the field with injection system redundancy and flexibility.

Figure 3 : STEAM PIPING SCHEMATIC



Steam Gathering System

Bulalo's steam gathering system is a satellite station type. There are six satellite stations at strategic locations within the field's production area. Each station consists of a primary separator, scrubber and a pumping station (Figure 3). Six to eight wells per satellite station, at an average flowing WHP of 180 psig (12.7 kg/sq.cm) produce fluids into the production well manifold which feeds into the main separator (Figure 3).

The production area has different characteristics of enthalpy, brine and steam fraction, non-condensible gas (NCG) and brine concentration depending on the well location. The southeast quarter (near satellite station no. 5) is characterized by higher Cl-SiO2 and NCG concentrations. This is attributed to close proximity to the reservoir upflow zone. Table 1 shows these characteristics for six typical wells from the satellite stations.

SAT. STATION	1	2	3	4	5	6
PLANT	A	A	B	C	C	B
NELL NO.	1	6	53	38	41	13
Month/Xr.	04/87	04/87	08/87	03/87	07/87	03-87
WHP (PSD	251	215'	200	188	241	200
SEP (PSD	183	150	145	152	162	160
STEAM (%)	64.6	28.8	47.1	81.7	51.4	88.3
ENTH. (BTO/LB)	900	586	741	1040	783	1097
IMF (KPH)	387.7	558.7	327.2	221.8	434.2	273.5
NA	1606	1554	1238	2085	2010	1581
K	305	267	326	509	508	281
CA	26	34	16	28	28	26
Mg	0.12	0.09	0.06	0.09	0.24	0.02
a	2808	2648	2112	3739	3498	2657
HOD,3	19	32	19	26	26	13
SO_4	14	13	13	16	13	18
B	69	41	41	118	105	88
SiO_2	486	551	593	643	650	546
STM NO3 Wt %	0.18	0.23	0.34	1.37	1.54	0.29
CD2 mole %		92.04	92.06	95.81	94.02	81.84
H_2 mole %		1.88	0.95	0.57	0.24	2.57
CH_4 mole. %		0.10	1.08	0.09	0.06	0.12
N_2 mole %		1.90	0.98	0.60	0.51	5.47
NH_3 ppn		0.7	0.90	0.6	1.10	0.5
H_2S ppm		170.0	160.0	200.0	270.0	350.0

Table 1. Bulalo Field 1987 geochemical and enthalpy data for selected satellite station sector wells. The analysis is corrected for steam flash. For the well location, see Figure 2.

The throughput of each satellite station is approximately 1100 kph (498.9 T/h) of steam which meets the requirements of one 55 MW unit. The field-wide design specific steam consumption rates for the NPC power plants vary between 18,050 and 19,050 lb/MW (8.19-8.64 T/h) depending on whether the steam ejectors or gas compressors are operating. Steam flows from the satellite at 135 psig (9.5 kg/sq.cm) and through 36 inch steam lines into secondary scrubbers at approximately 105 psig (7.4 kg/sq.cm) prior to entering the turbine. These scrubbers remove both condensate and any residual brine carry-over from the satellite station. The steam enters the turbine at an inlet pressure of 80 psig (5.6 kg/sq.cm) and with chloride and silica concentrations less than 1 ppm. At maximum loading steam gathering system pressure drop from the wells to the turbine inlet is approximately 100 psig (7.0 kg/sq.cm).

After attaining operating experience with Bulalo's steam gathering system some modifications were introduced. These focused on improving the steam gathering system capability for testing wells and reducing the amount of atmospheric stacked steam. These modifications have improved Bulalo's overall resource management plan.

From 1974 through 1985, welltesting was frequently completed with skid mounted test separators. This work was cumbersome and required steam to be vented to the atmosphere during, the test. In 1985 permanent test separators were installed in all the satellite stations. With this arrangement, the wells are tested at pressures higher than the system pressure while producing to the power plants. Well testing is important to characterize the reservoir conditions and to update steam supply forecasts. Two to three tests per well for three day periods are completed every year.

Atmospheric steam venting due to power plant upset conditions and excess hydropower curtailments was a problem until 1987. Wellsite two phase throttling valves have been installed which have helped reduce atmospheric stacked steam. The current system is designed to throttle wells to save steam, equivalent to an 80 MW curtailment. Planned improvements will expand and automate the two phase throttling system. By mid-year 1989, the system will provide curtailment of steam production equivalent to 140 MW.

Brine Injection Systems

Two brine injection systems have been installed in Bulalo: 1) Hot brine and 2) Cold brine. These two systems are mandatory because Bulalo is a landlocked geothermal system.

The hot brine system provides for reinjecting separated reservoir brine. From the satellite stations 175 deg C brine is pumped by 400-440 HP motor and steam driven pumps to injection wells through an interconnected network of 18 inch pipelines. The normal operating pressure for the system is 300 psig (21.1 kg/sq.cm), with a tripping discharge pressure of 365 psig (25.6 kg/sq.cm). The combined injection capacity of the eight injection wells at normal pressures is about 6000 kph (2721.6 T/h). Problems with this system have been minimal and include scaling in strainers, pumps and pipelines.

A second injection system operates in order to reinject excess NPC blowdown and PGI sump water. This system has many problems that are related to corrosion associated with the cooling tower blowdown. The blowdown is characterized by either low pH and/or high concentrations of disssolved oxygen. Pump casings, pipelines and wellbore failures have occurred due to the corrosive blowdown. Two wellbore failures which required well abandonment have occurred due to corroded casing. Future plans are to reinject excess blowdown directly from the NPC hotwell pump condenser discharge line for Units 1-4. This will greatly reduce the level of dissolved oxygen, and has already been completed for Units 5 & 6.

RESERVOIR

Physical Description

Extensive production testing, reservoir and geoscientific studies have been completed to evaluate and develop a conceptual model of Bulalo's reservoir. The results indicate that the reservoir is driven by a strong thermal upflow that rises beneath the south western edge of Mt. Bulalo from depths greater than 3,000 meters subsea to as shallow as sea level (Figure 4).

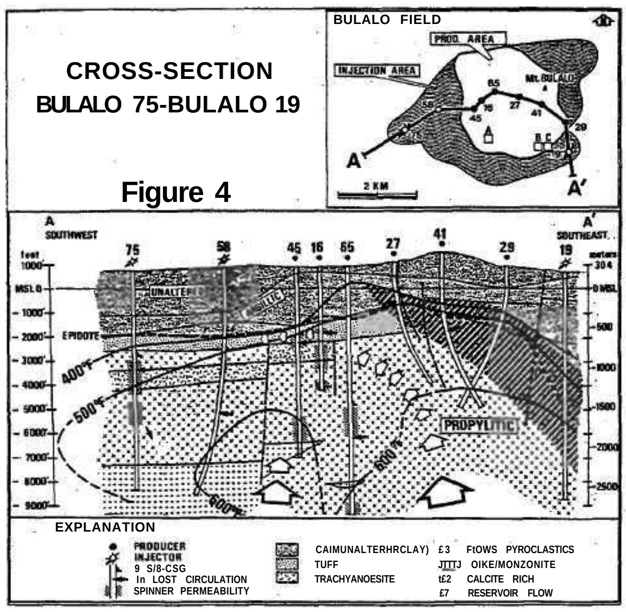


Figure 4

The upflow migrates through intensely altered fractured andesitic flows, tuffs and volcaniclastics along multiple near vertical permeable fault zones. The rising geothermal fluids encounter lower pressures, boil and form a two phase zone above the reservoir brine.

The more porous and permeable formations adjacent to the upflow planes such as tuffs and volcaniclastics become charged with the ascending geothermal fluids. These formations are primary reservoir aquifers which are characterized by intense propylitic alter ation, lost circulation during drilling and production influx zones during well flowing. The geothermal fluids flow laterally through these aquifers to the west and north. Flow to the east and south appears to be limited based on observed low well productivity and which may be related to abundant secondary mineralization (calcite). The thick calcite rich zone is related to the boiling of reservoir fluids as they ascend. This zone appears to be a lateral permeability boundary in the southeast part of the field.

The reservoir volume is very large, it expands in size and increases in temperature with depth. Approximately 70 percent of the reservoir volume exists below 1500 meters subsea. The cores and drillcuttings analyzed below this depth are all intensely altered with the reservoir propylytic mineralogical assemblage. Below this depth there are no significant mineralogical or temperature gradient reversals and approximately 60 percent of the estimated reservoir volume is at temperatures exceeding 288 deg C. The cores from this part of the reservoir have mean porosities of 11.4 percent.

Geochemistry

Table 1 gives the geochemical composition of separate brine (corrected for flash) and NCG for characteristic wells of Satellite Stations 1 to 6 . The data shows that Bulalo's reservoir fluids are a neutral chloride brine with.low salinities and low gas content. In order to characterize and compare fluid geochemistry with reservoir processes, the following classification of the fluids based on chloride enthalpy and chloride-boron relationships is utilized. This geochemical discussion is based on a pre-exploitation model.

Wells located in the central upflow zone such as Bul-41, are distinguished by high concentrations of chloride and NCG and high temperatures. The high concentrations result from reservoir boiling where steam and NCG is released. The NCG accumulates near the reservoir top and the well produces high concentrations of NCG. These wells are called transient flow wells. Some wells completed above this zone typically produce from steam caps and contain moderate to high NCG, high boron, low chloride and lower temperatures.

The lowest NCG wells are located in the western part of the field. These wells are distinguished by their moderate chloride concentrations, low geochemical temperatures, low NCG and high chloride/boron ratios. The boron fluids are thought to be modified brine which originated in the upflow zone. During upflow, the fluid boiled, losing NCG and boron to the steam, becoming cooler. The fluids are stored in lithologic aquifers which act as the primary outflow zones for fluids from the upflow regions.

The edge wells are further classified into two categories. Those along the western margin of the field have low NCG contents which indicate mixing of dilute ground waters with the brine stored in the reservoir acquifers. Those along the northern and southern margins of the field have moderately high gas concentrations which may indicate mixing of dilute ground waters with the upflowing thermal brine.

Exploitation Effects

Initially the Bulalo reservoir was a liquid dominated system with a two phase zone present at depths above 600 meters subsea. Exploitation reduced the pressure which has caused the steam-brine interface to drop from 600 m to 1070-1220 m subsea. Both vapor and reservoir brine pressure decline rates were high up to l'984. After late 1984, the vapor pressure has stabilized and the brine pressure decline rate has slowed down.

The stabilized vapor pressure supports the presence of near vertical fractures which act as conduits for recharging vapor zones from deeper boiling fluids. The slowing down of the brine pressure decline rate appears to be related to deep reservoir influx of either natural recharge or injection fluids. Thermal breakthrough of the injection fluids has been minimal.

Figure 5 '• BULALO 79-88 PRODUCTION

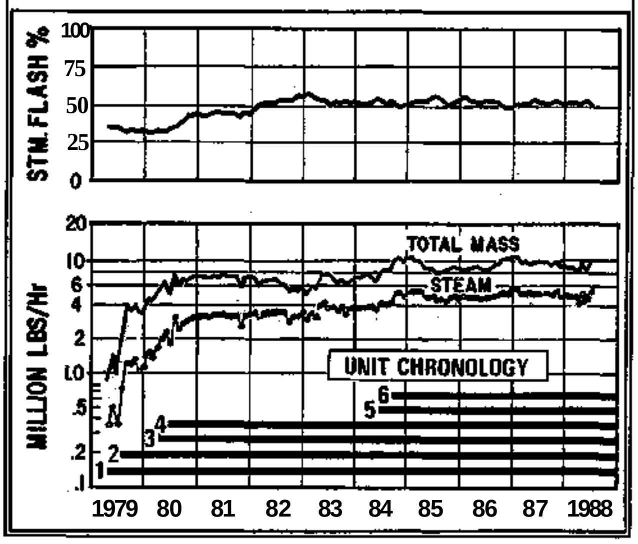
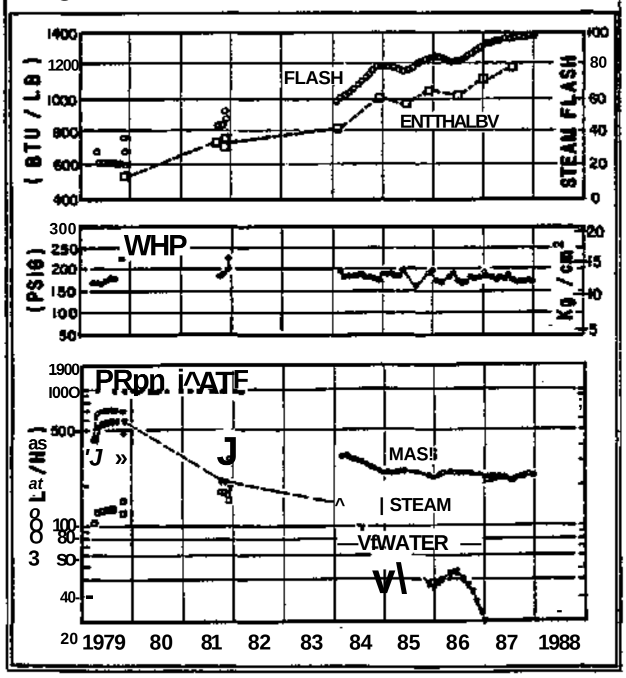


Figure 5 shows Unit chronologies steam quality, and monthly flow rates for steam and mass during the development period up to August 1988. Presently the yearly average withdrawal from the reservoir is approximately 5000 kph (2268.0 T/h) of steam and 4000 kph (1814.4 T/h) of brine. All the brine has been reinjected back into the reservoir. The average steam quality has risen from below 25 percent to approximately 55 percent. Some of the wells are still drying up and these exhibit little or no total mass decline rate An example is Bul-3A as shown in Figure 6.

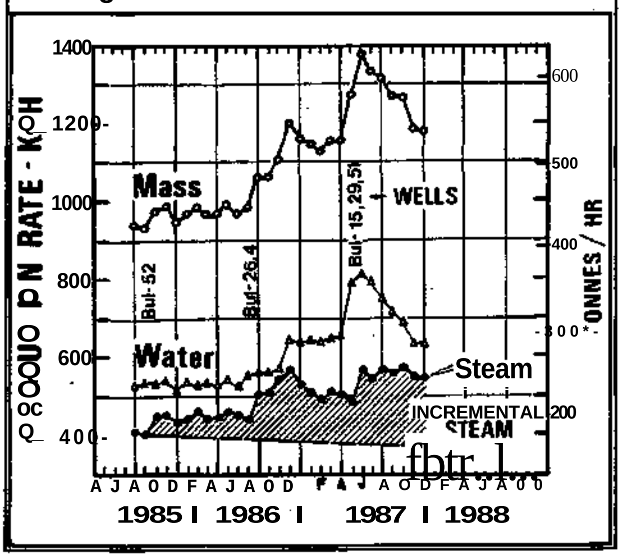
Figure 6 : WELL BUL 3A PRODUCTION



Currently the largest well in the field is Bul-1, the 1974 discovery well. This well is now producing 250 kph (113.4 T/h) of steam as compared to it's 1975 steam flowrate of 150 kph (68.0 T/h). This improvement is partly due to a 30 percent increase in enthalpy.

Since 1983, make-up steam supply optimization has been ongoing. The last production well, Bul-66 was drilled 5-1/2 years ago. Additional steam supply has been obtained by converting idle injectors into producers, reducing pipeline pressure losses, and acidizing wells. Figure 7 shows the results of acidizing six producers with hydrochloric and hydrofluoric acids. Through 1988 all these efforts combined with the reservoir's high porosity and excellent vertical communication have resulted in a low total field steam decline rate of approximately four percent per year.

Figure 7: BULALO STIMULATION

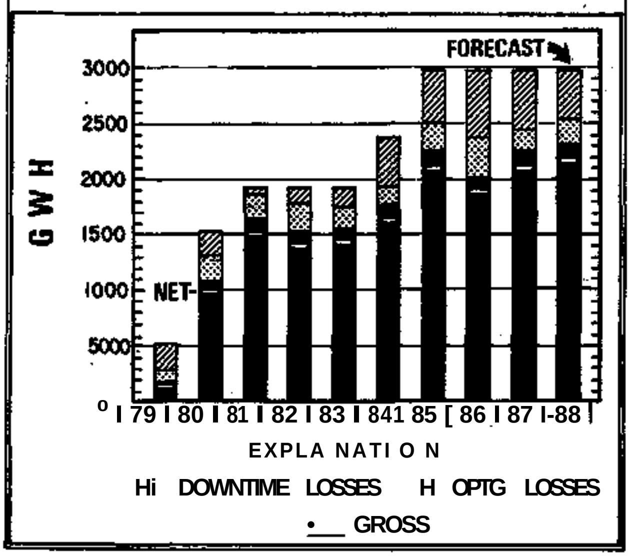


GENERATION PERFORMANCE

Generation

For the past nine years, Mak-Ban has been one the best performing power plant cycles in the Philippines. Figure 8 shows yearly generation bar graphs from 1979 to 1988.

Figure 8: 1979-1988 GENERATION PERFORMANCE



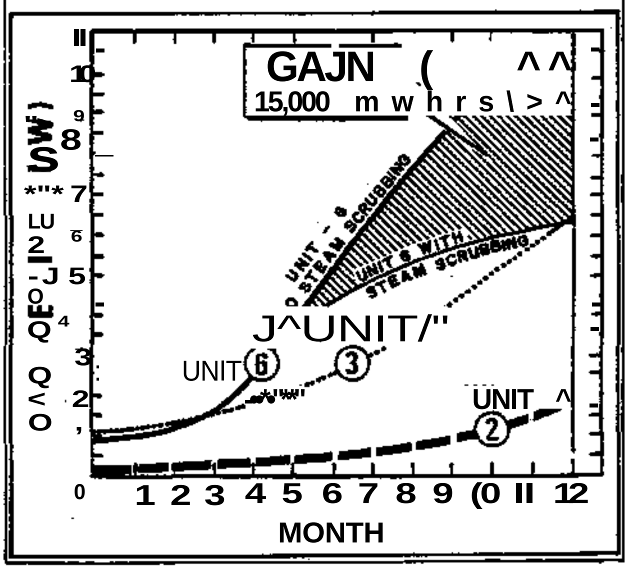
The field's generation output has increased every year with the exception of 1982, 83 and 86. This increasing trend will hold true in 1988, assuming there are no major forced outage incidents during the remaining part of the year. Table 2 shows the generation performance indicators for the last three years up to August 1988. The theoretical output load from the power plants minus annual scheduled maintenance and overhaul downtime is 290.2 MW. The past three year

PERFORMANCE INDICATORS	1985	1986	1987	1988 AUG.	AVERAGE
FACTORS (%, MW)					
Avail.	86.7	81.8	84.4	85.7	84.7
Capacity	77.7	69.8	77.7	77.1	75.6
Pd. Ld. Ave.	256.6	230.4	254.1	254.1	249.4
EQUIV. LOAD (MW)					
Optg. Losses	29.6	39.8	22.1	28.4	30.0
Excess DT	4.0	20.1	11.6	7.4	10.8
TOTAL (MW)	33.6	59.9	33.7	35.8	40.8
THEORETICAL (%)	11.6	20.6	11.6	12.3	14.1

Table 2. Mak-Ban 1985 thru 1988 August generation performance indicators. By meeting the downtime schedule of 6336 hours per year, (Per Unit: 1-35 day/overhaul and 3-3 day quarterly maintenance shutdowns) the maximum availability and capacity factors are both 87.9% or 290.2 MW ("0" operating or excess downtime losses). The total under equivalent load is the potential gain per year in load if both operating and excess downtime losses are eliminated, pd - Period.

average of 249.4 MW is 86 percent of this theoretical amount. The 14 percent deficiency is attributed to both extended overhaul/maintenance periods and operating generation losses. NPC is addressing this deficiency and is implementing programs to reduce the losses. One successful program has been turbine steam scrubbing. Unit 6 has had steep load declines due to turbine scale build-up, on the first stage nozzles since initial startup (Figure 9). A successful steam scrubbing experiment has been ongoing since February 1988, reducing turbine scale-induced generation losses by approximately 15,000 MWh This has reduced the unit's average load decline from 1.3 MW/month to 0.3 MW/month (Figure 9). NPC and PGI are currently designing a permanent steam scrubbing system for Units 3, 4, 5 & 6. Once operational, the steam scrubbing program is expected to increase the annual generation levels by 120 to 140 GWh.

Figure 9: LOAD DECLINE



In order to maximize unit availability, NPC plans are underway to eliminate excess downtime losses. These improvements are needed in order to optimize the performance of Bulalo's reservoir capacity. At this time, Bulalo's available reservoir steam is 10 to 20 percent higher than the operating capacity of the power plants.

Specific Steam Consumption

Bulalo's overall production generation efficiency is indicated by the specific steam consumption ratio. This ratio represents the following:

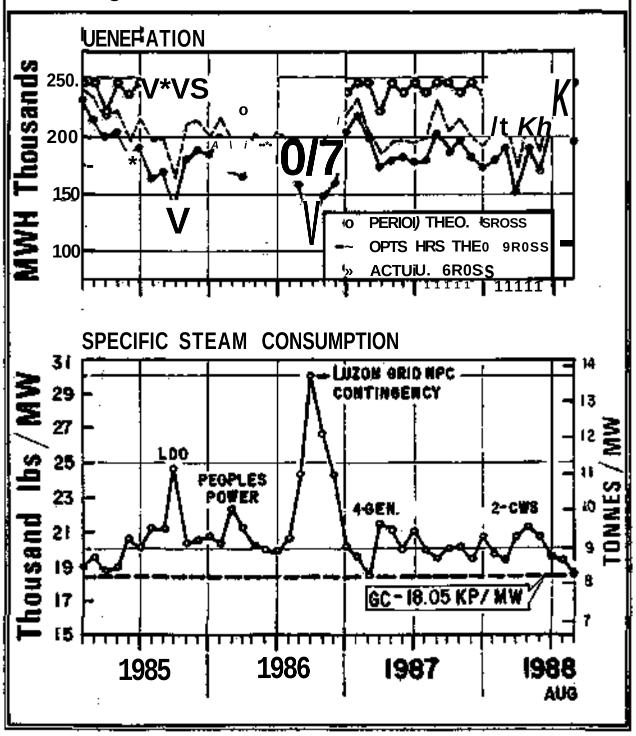
CONSUMER STEAM (lb)		STACKED STEAM (lb)
NPC - Turbine NPC - Steam Ejector NPC - Gland Seal Ejector PGI - Turbine Pumps PGI - Scrubber Drains	+	LDO NPC Upset NPC Maintenance PGI Upset Cont. Venting

= lb/MW

Metered Gross Generation (MW)

This ratio together with monthly generation numbers are shown in Figure 10. The ratio is plotted against the field design rate of 18,050 lb/MW (8.19 T/MW) (using gas compressors - G.C.). This design rate includes all steam consumers listed above. There are some high ratios in 1985 and 1986 that are attributed to LDO (excess hydro power), Peoples Power and Luzon grid contingency plans. In all cases, excess stacked steam occurred as a result of load curtailments. The years 1987 and 1988 have been the best years for production generation efficiency. In 1988, the field average specific steam consumption ratio through August is 19,850 lb/MW (9.00 T/MW). With the planned expansion and automation of the two phase throttling system, it is expected that this number will become lower in the future.

Figure 10: PROD/GEN EFFICIENCY



CONCLUSIONS

The Bulalo geothermal power plant cycle is reliable due to the presence of a very large and efficient reservoir, dependable steam gathering and waste brine injection systems and well-designed power plants. For the last eight years, Bulalo has been the top performing power plant cycle in the Philippines. NPC and PGI are introducing additional design improvements that will improve Bulalo's performance. NPC and PGI are currently studying the feasibility of adding more capacity to the field in the form of several small units.

ACKNOWLEDGEMENTS

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