Proceedings World Geothermal Congress 2005
Antalya, Turkey, 24-29 April 2005

Optimization of Palinpinon-1 Production Field Based on Exergy Analysis – The Southern Negros Geothermal Field, Philippines

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Keywords: exergy, specific exergy, utilization efficiency

ABSTRACT

This paper discusses the exergy assessment of Palinpinon 1 production field, and presents a sensitivity evaluation on the viability of a double flash, low pressure turbine system with respect to silica saturation.

Optimization of the Palinpinon 1 production field has become an urgent requirement with the increasing power demand of the Visayas Grid in Central Philippines. Projected short-fall may reach >100 MW at the end of Y2005. Add to this, the current steam production of the field has declined over the past twenty years of continuous exploitation barely meeting the requirement of the 112.5 MW power plant due to pressure drawdown, injection returns and wellbore blockages. Shifting the brine injection farther away from the production sector and well workovers in conjunction with acid stimulation have been successful in controlling the consequent adverse effects but recurrence of these problems only keeps the steam supply at a manageable level. Make-up and replacement wells could boost steam production but these are highly susceptible to the same problems encountered at present.

The recent exergy assessment of the Palinpinon 1 production field implies that the current power generation can still be increased significantly with the existing steam production. The Utilization Efficiency, η_u indicated that less than 40% of the maximum energy at the wellhead has been converted to electrical power. Exergy calculations from the wellhead down to the power plant showed that significant potential energy of the brine can still be harnessed to produce additional power for the plant before returning it back to earth. Thus, more power for the same fluid extraction. Moreover, the specific exergy of individual well provides a practical guide for optimum operation.

1. INTRODUCTION

The Palinpinon 1 sector of the Southern Negros Geothermal Production Field (SNGPF) located in Central Philippines (Figure 1 attached) was commissioned in mid 1983 supplying steam to the 112.5 MW power plant.

In over two decades of continuous exploitation, steam production has been affected by two major reservoir processes namely, pressure drawdown and injection returns. Moreover, the formation of mineral blockage in some wells also affected steam supply.

Steam availability, Figure 2 attached, declined from a pre-exploitation value of ~1400 tons per hour, tph *(~130MW)* to about 1000 tph *(~105 MW)* in 1990 due to effects of injection returns. Injection brine from the Puhagan RI sector, induced by 2 MPa pressure drawdown, was channeled into the production sector through a system of structural faults.

Shifting of brine injection farther towards the Ticala and Malaunay injection sectors restored the steam flow to the 1300 tph level but the subsequent decline in the average reservoir pressure by another 2 MPa and the resurgence of injection returns along the Ticala fault further reduced the steam supply to 1000 tph. Since then, steam supply remained within this level despite eliminating the injection load in the Ticala sector in 1996.

Formation of mineral deposits within the wellbore and immediate feed zones also reduced the steam generating capacity of some producing wells in Palinpinon 1. With calcite and anhydrite scaling affecting most of the producing wells, at least 46 tph of steam equivalent to 5 MW was lost. Recent mechanical workover jobs in conjunction with acid treatment have been successful in removing these mineral blockages but the susceptibility of recurrence has kept the steam supply at a status quo.

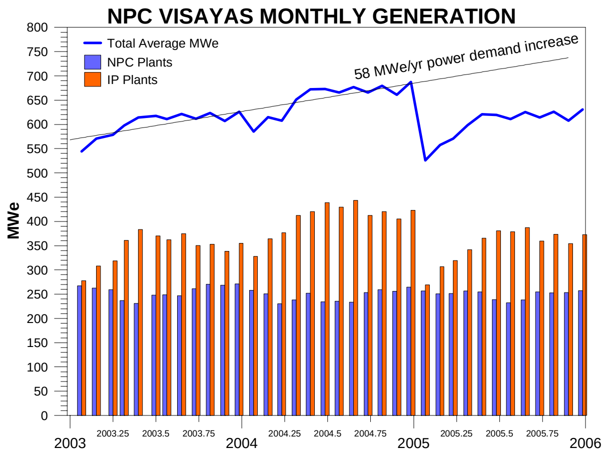

Figure 3: Projected Power Demand

The increasing power demand in Central Visayas and the shutdown of some independent power producers urgently requires the optimization of Palinpinon 1 production field. Based on the updated Y2003 power demand forecast of the Cebu-Negros-Panay power grid (CNP), a shortfall of over 140 MW is evitable by the end of Y2005 (Figure 3). The ongoing construction of the 20 MW optimization plant in Palipinon 2 and the 40 MW geothermal plant in Northern Negros, which is expected to be put on stream by 2005 and 2006, respectively will only partially address this power shortfall.

The current extraction and injection management strategies in Palinpinon are able to sustain the steam supply to the plant, while the workover-acidizing jobs have been successful in restoring the outputs of wells blocked by mineral deposits. However, these are not enough to optimize the operation of the Palinpinon 1 production field.

One optimization option calls for the assessment of the field-wide and individual well exergy intended to improve the over-all Utilization Efficiency, η_u and increase the plant capacity for the same fluid extraction. Moreover, a sensitivity study is hereby presented to verify the viability of combining a double flash, low pressure turbine system with respect to the silica saturation of waste brine.

2. PALINPINON – 1 EXERGY ANALYSIS

2.1 Basic Concept

Exergy is defined as the measure of the quality of energy. In a geothermal resource, the exergy measures how much useful work can be done by the geothermal fluid within a given ambient condition with pressure, p_o and temperature, T_o while considering the thermodynamic imperfections involved in the process. An exergy balance of the different phases of the geothermal plant identifies the areas of energy degradation or loss arising from irreversible heat dissipation in the form of friction and heat transfer, throttling, turbulence and fluid separation.

The ultimate work or exergy of any system operating on a steady state can be obtained by combining the First and Second Laws of Thermodynamics. The First Law can be written as follows (Freeston, 1991):

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) + 1/2\left(v_2^2 - v_1^2\right) + g\left(z_2 - z_1\right) \quad (1)$$

where Q = heat flow rate

W = rate of work

m = mass flow rate

h = enthalpy

v = velocity

z = vertical position

neglecting the changes in kinetic and potential energy,

$$\dot{Q} - \dot{W} = \dot{m}(h_2 - h_1) \quad (2)$$

The Second Law for the system states that,

$$\dot{\theta} = \dot{m}(s_2 - s_1) - \dot{Q}/T_0 \quad (3)$$

where $\dot{\theta}$ is the entropy production, s is the entropy and T_0 is the absolute temperature of the surrounding in °*K*. For a reversible operation, $\dot{\theta}$ approaches zero,

$$\dot{Q} = \dot{m}T_0\left(s_2 - s_1\right) \quad (4)$$

This ideal operation represents the upper limit in the performance of a plant for a given initial and final states of the geothermal fluid. Combining Equations (2) and (4) gives the expression for the maximum thermodynamic work as follows,

$$\dot{W}_{\max} = \dot{m}\left[(h_2 - h_1) - T_0\left(s_2 - s_1\right)\right] \quad (5)$$

For a geothermal plant where the final state of the fluid is identical with the ambient surroundings, the maximum possible work extracted from the geothermal fluid for a given initial state is defined by Equation (6) below, which is also known as Exergy.

$$\varepsilon = \dot{m}\left[(h_i - h_o) - T_0\left(s_i - s_o\right)\right] \quad (6)$$

The Specific Exergy, $e = \varepsilon/m$, thus Equation (6) becomes,

$$e = \left(h_i - h_o\right) - T_0\left(s_i - s_o\right) \quad (7)$$

Additionally, the need to classify Palinpinon 1 wells by exergy, individually and per sector, for operational exigency requires the evaluation of the Specific Exergy Index (SEI) and the mapping of the results in the H-s diagram. The concept of SEI (K.C. Lee, 1996) classifies a geothermal resource into high, medium and low exergy resource zone when plotted in the Mollier Diagram (H-s plot). The SEI is normalized to the maximum exergy of saturated steam at 90 bars abs and the triple point sink condition of saturated water where the entropy and enthalpy values equal to zero. Thus, the SEI is governed by the following equation,

$$SEI = \left(h - 273.16s\right)/(1192) \quad (8)$$

Equation (6) is used to compute for the exergy of the geothermal fluid at the different phases of the geothermal plant needed to facilitate the field exergy balance, while Equation (8) is used to evaluate the individual well and sectoral Specific Exergy Index.

2.2 Field Exergy Analysis

For this study, the Palinpinon 1 field exergy analysis compares the net power of the geothermal power plant with the wellhead exergy of all producing wells. The rate of exergy extracted from the reservoir would have given the maximum useful work of the geothermal fluid but with the primary objective of improving the system's utilization efficiency, analysis of the surface exergy would be a realistic and practical approach. Nevertheless, the reservoir management strategies being implemented would partially address the sub-surface exergy imperfections.

The analysis takes into account the exergy at the different phases of the geothermal fluid-steam conversion process where exergy degradation and imperfections are expected to occur. Consequently, the major components of the Palinpinon 1 Fluid Collection and Reinjection system (FCRS) e.g. common header, separator station among others are identified and exergetically assessed. In addition, exergy at the power plant is also assessed to determine the current efficiency of the plant in converting steam into electrical power.

Sectoral as well as individual well analysis was also made to establish the corresponding sectoral and well exergy that will help optimize production well utilization to suit power plant operational demands. The consequent specific exergy index *(SEI)* was also computed to facilitate plotting of the Palinpinon-1 wells in the h-s diagram

All exergy calculations are referred to the first quarter of 2003 when the plant was still operating on three turbine units. Ambient condition was taken at 25°C while the designed separator pressure of 0.68 MPaa was used. To compute for the exergy at the different areas of the FCRS, i.e. two-phase header, separator station, blow-off valve, interconnection header and turbine inlet, the system pressure in these areas were measured. Actual turbine inlet and outlet pressures of 0.63 MPaa and 0.0153 MPaa, respectively were used

2.3 Exergy Assessment Results

2.3.1 Exergy Balance

A schematic diagram of the Palinpinon 1 geothermal field, Figure-4 as shown, was undertaken to facilitate the analysis.

Wellhead exergy *(point 1)* totals ~232 MW from 21 out of 23 commercially producing wells. Energy degradation along the pipe lines, i.e. two-phase and steam lines, from the wellhead to the power plant amounted to 8.3 MW, with 90% lost along the two-phase lines. Exergy calculations at the separator station *(point 2)* indicated that only ~185.6 MW of steam is conveyed to the plant while about 38.1 MW is injected back to earth in the form of waste brine. The 3-turbine power plant *(point 5)* generates an equivalent of 92.8 MW of actual electrical power. Exergy of the fluid entering the condenser amounted to 43.0 MW while exergy loss across the turbines reached 24.5 MW. The over-all Utilization efficiency, η_u is 39.9%.

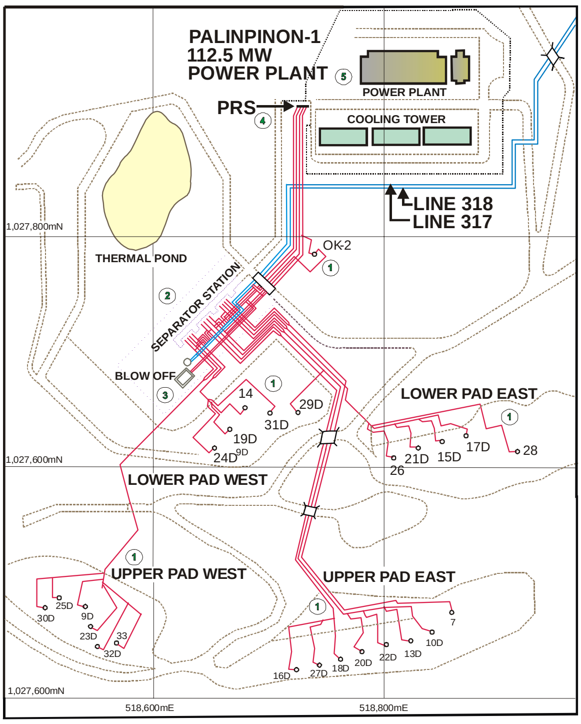

Figure 4: Palinpinon-1 Field and Plant Layout

The corresponding exergy balance, Figure-5 indicated that relatively high exergy loss occurs at the separator and condenser while significant loss is being incurred along the pipeline and at the turbine. Heat rejected in the form of brine at the separator accounted for about 17% while that in the condenser is 18.5%. Heat rejection along the pipelines and at the steam gas ejectors (SGEs) added almost 10% to the energy degradation.

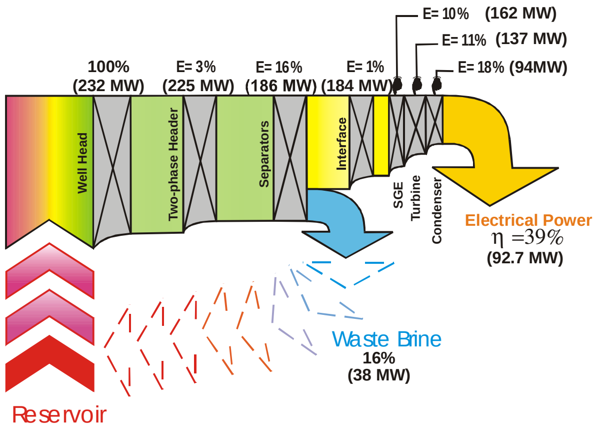

Figure 5: Palinpinon-1 Exergy Balance

The exergy loss at the turbine of about 25 MW or 11% of the total wellhead exergy is attributable to the no-load-steam necessary to start up the turbines amounting to 37.5 kg/s and inefficiency of the turbine units. Heat rejected in the condenser amounted to 18.5% equivalent to 43 MW of exergy. However, this could have been lower had the design condenser vacuum of 600 mmHg has been maintained.

Waste brine still has potential useful work when re-injected back to earth. A significant fraction of this could still be recovered to improve the utilization efficiency.

2.3.2 Specific Exergy Index

The SEI plot on the h-s diagram, Figure-6 indicated that all Palinpinon 1 production wells lies within the high medium *(above SEI=0.2)* and high exergy zones *(above SEI=0.5)*. Wells tapping the steam cap at shallow depths i.e. PN=33, OK-2 and those feeding on highly two-phase zones, i.e. PN-25D, PN-15D as well as the Lagunao wells consistently plot above the high exergy zone. In contrast, liquid-dominated wells like PN-18D, PN-16D, PN-29D plot close to the medium high SEI line. Moreover, high specific exergy are associated to wells with high enthalpy discharge.

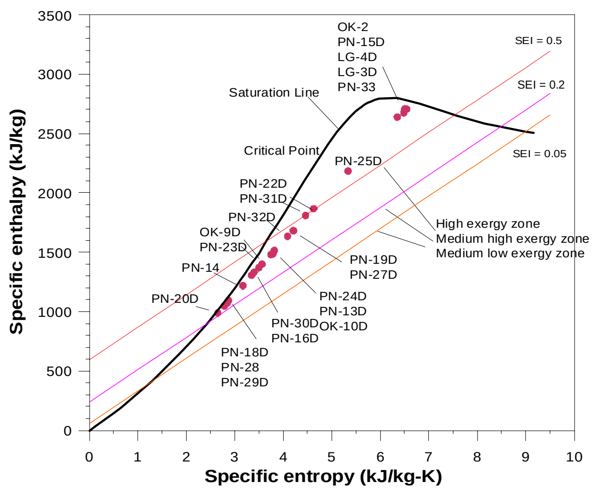

Figure 6: Classification of Palinpinon-1 Production Wells

3. PALINPINON-1 OPTIMIZATION OPTIONS

Based on the exergy analysis, a significant fraction of the potential useful work from the waste brine can still be recovered to augment the output capacity of the plant. Separated brine at 160°C could still be introduced to a second flash separator to a temperature as low as 90°C *(Ormat Second Flash system)* to produce additional steam prior to its disposal back to earth. Geo-chemical simulations, however, showed that flashing of Palinpinon brine is practical at 120°C both in terms of silica control and RI effect management[1]. Flashing of brine lower than this temperature is still possible on condition that mitigating measures are undertaken to control silica saturation and effects of cold brine injection. A sensitivity test was conducted to establish the potential additional output of the plant vis-à-vis the silica saturation index and over-all plant utilization efficiency at the different flash temperatures.

Outputs at the different flash temperature were based on a turbine and generator efficiency of 77.7 % and 98.5%, respectively.

The corresponding silica saturation index of the Palinpinon 1 brine at the different flash temperature was also computed as the weighted average between the SSI values taken from two injection lines, RIL 317 and RIL 318 that conveys the brine from the separation plant to the RI wells.

Two optimization options of the Palinpinon 1 power plant operation are presented. The first option hooks up all producing wells to the existing turbine-generators *(main plant)* and utilizes all the separated brine for the second flash separator. The second option, a modification of the first, requires the identification of low pressure production wells and hooks these to the second flash, low pressure turbine *(secondary plant)* together with the separated brine from the high pressure side.

3.1 First Optimization Option Results

With all producing wells hooked to the existing turbo-generators (Figure 7), separated brine amounts to about 362.8 kg/s with an equivalent power potential of about 38.1 MW. The maximum generator output of the main plant reached 92.8 MW. This option has the economical advantage over the other as no major change in the existing pipeline configuration is necessary.

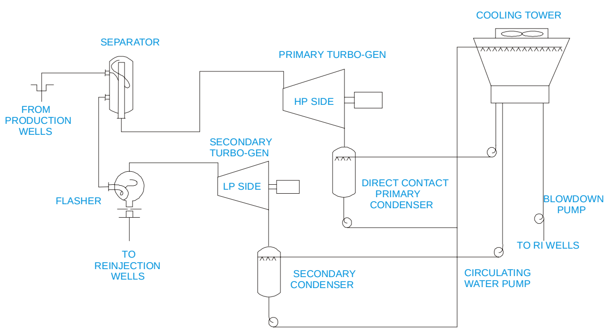

Figure 7: Option 1 Schematic Diagram

Exergy calculation at the second flash, low pressure turbine *(secondary plant)* at different flash temperature between 155°C and 90°C indicated a 10.3 MW additional power output at the optimum flash temperature of 105°C increasing the total plant capacity to 103 MW. Likewise, the over-all utilization efficiency increased to 44.4% from the existing 39.9% (Figure 8). The corresponding silica saturation index also indicated an increasing trend with a value of 1.88 at the optimum temperature.

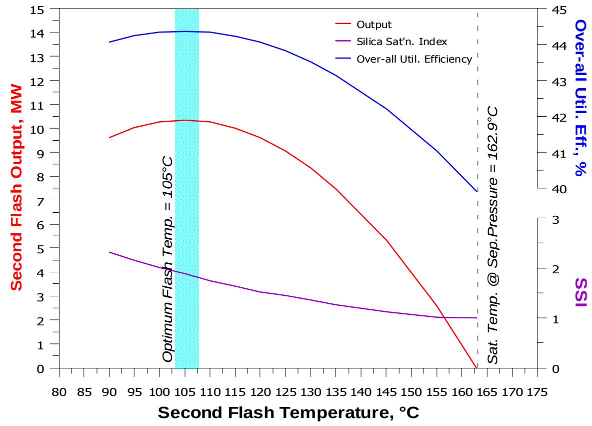

Figure 8: Sensitivity Test Results for Option 1

3.2 Second Optimization Option Result

Some of the Palinpinon-1 production wells, i.e. PN-14, PN-29D, PN-25D and PN-13D are already operating marginally with respect to the separator pressure due to drawdown. A number of these wells exhibit cyclic discharge lasting a few days to a week when connected to the FCRS, limiting the capability of the steam field to continuously supply steam to the plant.

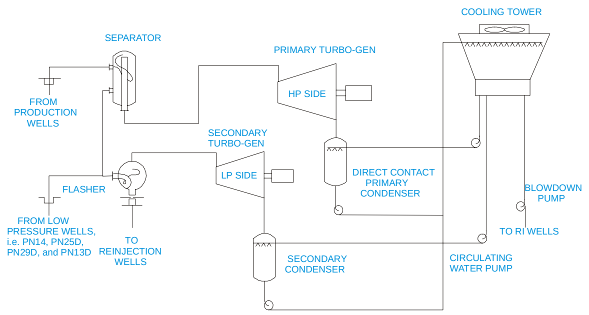

Figure 9: Option 2 Schematic Diagram

To optimize utilization, these wells will be hooked to the second flash, low pressure turbine together with the brine produced from the main plant (Figure 9). As such, the operation of these low pressure production wells would be sustained, ensuring maximum steam supply to the plant.

Similar exergy calculations indicated an optimum output at the secondary plant of 17.6 MW at a flash temperature of 115°C increasing the over-all plant output to about 106 MW. The corresponding over-all plant utilization efficiency increased to 45.6% (Figure 10.)

[1] Geo-scientific Internal Report, 2003

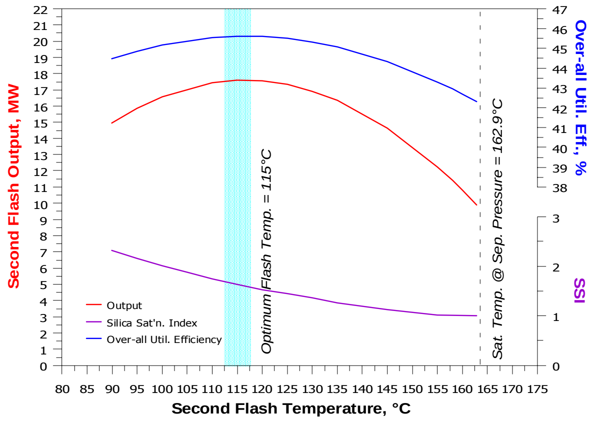

Figure 10: Sensitivity Test Results for Option 2

The total fluid flow *(low pressure mass flow and waste brine from the main plant)* entering the second flash system increases to around 420 kg/s. Consequently, the shifting of the aforementioned production wells from the main plant to the second flash, low pressure turbine decreases the power output of the main plant to 88.4 MW.

Even without the waste brine from the main plant, the secondary plant still generates power from the low pressure production wells directly hooked to the second flash, low pressure turbine, increasing the total plant output to 98.3 MW and the utilization efficiency to 42.3%

The sensitivity tests suggest that Option 2 is the better optimization option to pursue for the following reasons:

1. Higher secondary plant output, about 17.6 MW compared with only 10 MW for Option 1, increasing the total actual plant capacity to 106 MW.

2. Optimum output occurs at higher flash temperature of 115°C compared to the 105°C for Option 1; hence lower SSI value.

3. The lower SSI value of 1.64 as against 1.88 for Option 1 translates to lower silica inhibition cost.

4. Higher utilization efficiency, η_u of 45.6% compared with 44.4% for Option 1.

5. Higher output of low pressure production wells at the secondary plant of as much as 9.9 MW compared to 4.4 MW when hooked to the main plant. In addition, continuous steam supply to the plant is ensured with the maximum utilization of these low pressure wells.

Moreover, the results of the sensitivity test proved that flashing of brine below 105°C is no longer viable as the potential output and hence, the over-all plant utilization efficiency starts to decline below this temperature. The major downside of this option however, is the necessity to revise the piping configuration to convey the low pressure two phase fluids directly from the wellhead to the second flash equipment.

For both options, the main area of concern is the expected effects of the much cooler waste brine *(<165°C)* from the second flash separator on the production sector. Simulations made by M.B. Esberto of the Reservoir Engineering Department on the effects of cold waste brine injected at 120°C could adversely affect the productivity of the neighboring production well within 1 kilometer radius from the injection well.[2] Increasing the injection distance farther away from the production sector would only prolong the time for the injection fluid to reach the production sector. To ascertain the extent of the injection effects of the above optimization options, similar simulations could be done.

One option to minimize the effects of injection returns is to inject the cold waste brine into the Malaunay sector where no direct connection to the production sector has been known so far. Limited injection could be done in the Ticala and Puhagan injection sectors so as to maintain the pressure support into the south, west and southeast production sectors.

4. CONCLUSION AND RECOMMENDATION

Optimization of the Palinpinon-1 geothermal plant becomes an urgent requirement due to the increasing power demand of Central Visayas Power grid and declining steam supply due to effects of injection returns, pressure drawdown and mineral blockage.

Mechanical workovers in conjunction with acid stimulation where mineral blockage is present, do not present a long term solution to sustaining steam supply to the plant. Drilling of make-up and replacement wells, aside from the uncertainty of the output, are highly susceptible to the reservoir prevailing reservoir processes affecting the production sector.

Harnessing the remaining useful work of the separated brine presents a better alternative to optimize the operation of the geothermal plant as this is less susceptible to the effects of the prevailing reservoir processes.

Results of the exergy analysis and sensitivity tests indicated that of the two options presented, the second option, where production wells with low well head pressure are directly connected to the secondary plant together with the waste brine from the main plant, is the better optimization option for the Palinpinon 1 geothermal plant. The secondary plant would yield 17.6 MW increasing the total plant capacity to about 106 MW. The over-all utilization efficiency, η_u will likewise increase from a current ~40% to 45.6%. The results further showed that maximum improvement occurs at flash temperature of 105°C for Option 1 and 115°C for Option 2. Flashing of brine below these optimum temperatures yields lower outputs, hence the 90°C minimum flash temperature of the Ormat System is not practical.

The corresponding increase in the SSI value at the optimum flash temperature can be mitigated by silica inhibition system to control the formation of silica deposits along the RI lines as well as within the injection wellbore.

The classification of Palinpinon 1 production wells with reference to the individual Specific Exergy Index *(SEI)*, could provide a practical guide in setting up of a production well compliment that would suit operational demands.

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[2] Simulation results presented during the 3Jun04 SNGP Site Technical meeting.

Aside from the recoverable useful work from the waste brine generated at the main plant, exergy degradation along the two-phase line from the well head to the separator vessels presents another area for improvement. Based on the exergy analysis, 7.5 MW is being lost due to irreversible heat loss, friction and exergy loss due to the mixing of geothermal fluids at the interconnection header.

In view of this, the following recommendations are hereby presented for evaluation to further optimize the operation of the Palinpinon 1 geothermal plant.

1. Assess the effectiveness of the existing pipe insulation of the two phase lines and improve where necessary.

2. Conduct regular de-scaling of the two phase pipelines to minimize effect of friction.

3. Investigate the feasibility of hooking production wells to the separator by order of their enthalpy values. This is intended to reduce exergy degradation as a result of mixing high enthalpy wells with low enthalpy wells. Nevertheless, it is proposed to retain the interconnection headers to maintain operational flexibility during preventive maintenance of the turbo-generators and emergency shutdowns.

Finally, it is recommended to evaluate the viability of using mechanical gas extractors over the existing steam-gas ejectors *(SGEs)* to maintain condenser vacuum. The SGEs, which use about 30 kg/s of steam to remove the non-condensible gases, are no longer effective in maintaining the set vacuum at present. Improved vacuum condition would increase significantly the turbine work. Moreover, steam intended for the SGE would now be utilized to generate additional turbine output.

5. ACKNOWLEDGEMENT

The authors would like to thank first of all Dr. R.C.M. Malate, Reservoir Engineering Department manager for reviewing the draft and for the comments that helped enhance the content of the paper. Thanks to O.O. Maturgo and D.R. Sanchez of the Geo-services section for the chemistry data and other information relevant to this study. Thanks also to C.M.R. Borromeo of the Production group for the valuable inputs related to this study. Finally, the authors greatly appreciate the technical support of the Reservoir Engineering, Geo-services and Production Department staff given during the making of this paper.

REFERENCES

Dunstall, M.C. and Lee, K.C. (1996), "Geothermal Engineering Lecture Notes", Geothermal Institute, The University of Auckland, Auckland, New Zealand. pp. 3-17 – 1-24.

Lee, K.C. (1996), "Classification of Geothermal Resources – An Engineering Approach", Proceedings, 21st Workshop on Geothermal Reservoir Engineering, Stanford University, Stanford, California, 22-24January,1996. pp. 85-92

Keenan, J.H. et. al (1978), "STEAM TABLES Thermodynamic Properties of Water Including Vapor, Liquid and Solid Phases (SI Units)", John Wiley & Sons, Inc., New York.

Kent, W. (1950), "Kent's Mechanical Engineers' Handbook", 12th ed, power volume, John Wiley and Sons, Inc. New York. pp.8-64.

Orizonte, R.G., Amistoso, A.E. and Aqui, A.R. (2000), "Reservoir Management During 15 Years of Exploitation: Southern Negros Geothermal Production Field", Proceedings, World Geothermal Congress, Kyushu – Tohoku, Japan, 28May-10June, 2000. pp. 2773 – 2778.

Quijano, Julio (2000), "Exergy Analysis for the Ahuachapan and Berlin Geothermal Fields", Proceedings, World Geothermal Congress, – Tohoku, Japan, 28May-10June, 2000. pp. 861 – 866.

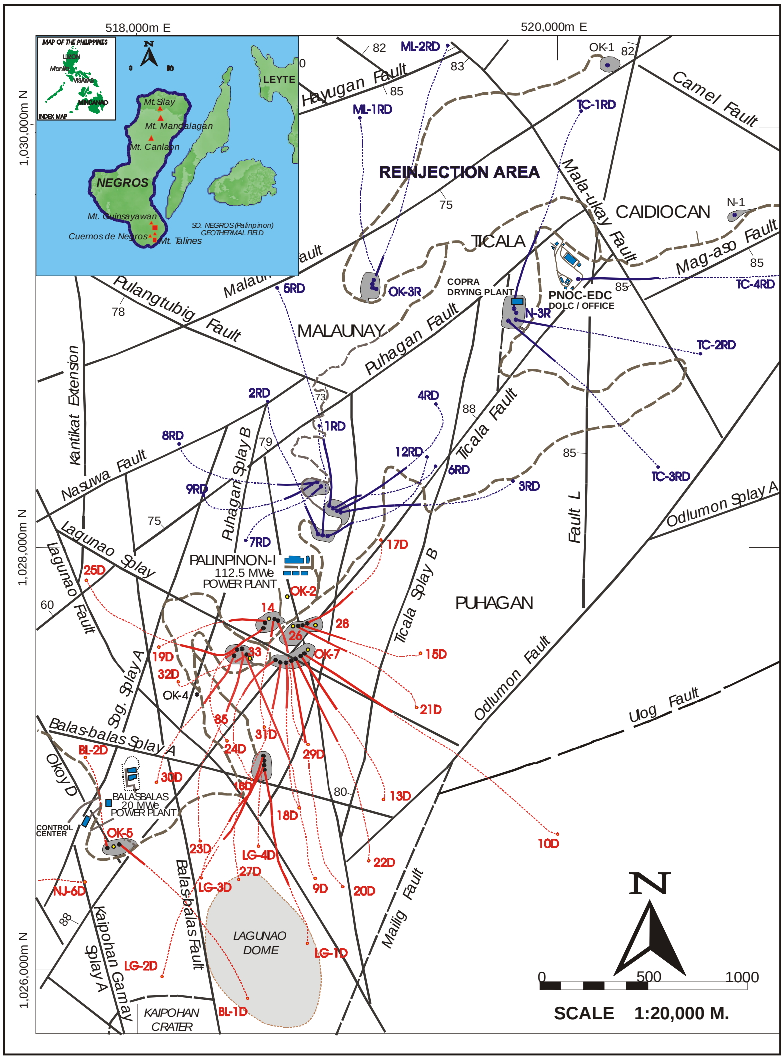

Figure 1: Southern Negros Geothermal Production Field Location Map

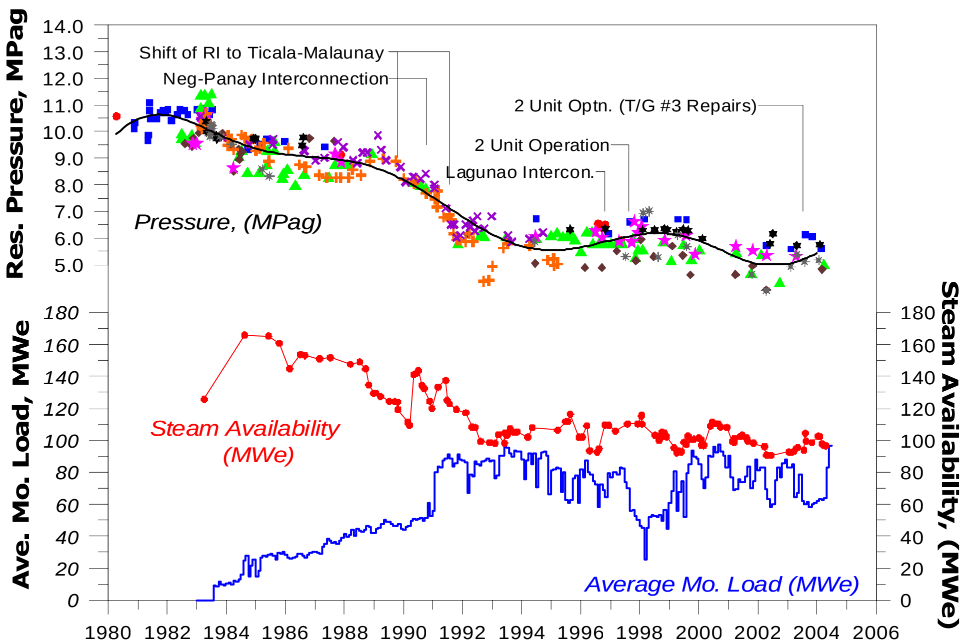

Figure 2: Steam Availability vs Drawdown