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The BacMan Geothermal Field, Philippines: Geochemical Changes and Operational Challenges After Ten Years of Production

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ABSTRACT

After ten years of production, the Bacman geothermal field has undergone geochemical changes and operational challenges unique to the field. The geochemical response of the reservoir to exploitation was distinct but rather benign. There was no indication of detrimental reservoir processes as experienced in other producing Philippine geothermal fields such as injection returns or groundwater intrusions. Acidic inflows were contained in a small and shallow portion of the field. Reservoir-related and other problems encountered are generally near wellbore and at very manageable levels. Results of the geochemical monitoring for the past ten years showed that most production wells have attained stable chemistry. Sound reservoir management strategy, intensive and pro-active geochemical monitoring, and the application of practical and innovative solutions to operational problems encountered resulted to a well-managed, stable, and sustainable resource.

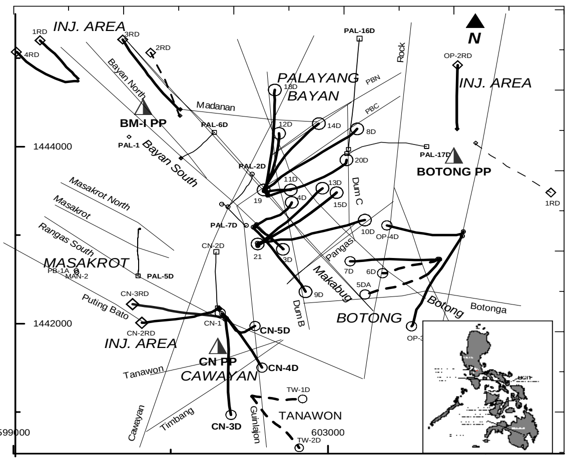

Figure 1: Well location map of the Bacman Geothermal Production Field

1. INTRODUCTION

The Bacon-Manito (BacMan) Geothermal Production Field is located near the southern tip of the Bicol Peninsula in Luzon Island, some 500 kilometers southeast of Manila, Philippines. The field derives its steam from three adjacent production areas composed of several production and injection wells (Fig. 1). It has three generating power plants – Bacman-I Palayang Bayan, and Bacman-II Cawayan and Botong. The first unit of the 110-Mwe (2x55Mwe) Palayang Bayan power plant was commissioned in September 10, 1993 and the second unit followed in December 12, 1993. The 20-Mwe Cawayan modular power plant was commissioned in March 15, 1994 while the 20-Mwe Botong power plant started commercial operation in April 27, 1998.

2. RESERVOIR RESPONSE TO EXPLOITATION

During exploitation, the typical response of a geothermal reservoir is decrease in pressure that leads to boiling and/or entry of outside or peripheral fluids to compensate for the mass extracted. In the case of the Bacman field, one area exhibited boiling while other areas showed outside fluid entry, indicating difference in reservoir characteristics.

2.1 Pressure Drawdown

Downhole pressure monitoring at the center of the field (Fajardo, 2003) showed that the highest rate of decline at 2.7 psig per month occurred from 1993 to 1996 (Fig.2).

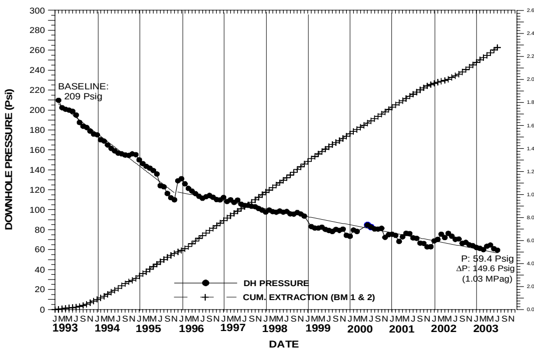

Figure 2: Downhole pressure decline in monitor well PAL-7D near the center of the field (RRMD data)

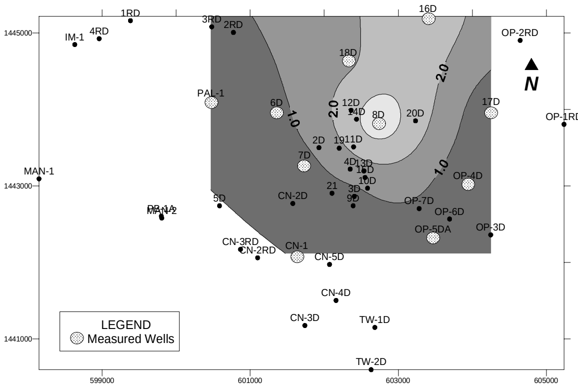

Figure 3: Field-wide downhole pressure decline

Total pressure drop during this period was about 100 psig. The biggest drop however was recorded with 605 psig in

1998 in well PAL-8D in the northeast area of the field (Fig. 3). The degree of pressure decline among the production wells was varied, ranging from 11 to 607 psig. This indicates limited and varying degrees of connections among the wells, and with the outside aquifers.

2.2 Geochemical Changes

Consistent with the general pressure decline, the geochemical response of the field was also varied. Some wells indicated the entry of outside fluids while others exhibited boiling and vapor formation. Geochemical trends also showed that the outside recharge fluid is relatively benign, i.e. no significant detrimental effects to the production wells. Through time, the field has exhibited stable geochemical trends as represented by some selected wells.

2.1.1 Well PAL-8D

The initial trends with time of PAL-8D (Fig. 4) showed the most drastic response among the production wells in terms of chemical and physical changes. During the first three years of extraction, the well exhibited increase in discharge enthalpy from about 1500 j/g to almost pure steam at 2500 j/g. Declining trend in TQuartz with corresponding increase in Clres and CO_2TD were also observed, typical of a well experiencing massive boiling due to pressure drawdown. At first, it appeared that the drawdown would spread in the area; however, as the Cl/B ratio and CO_2TD trends with time would show (Fig. 4), a low-boron recharge fluid from the northwestern part of the field, entered the well. This recharge fluid prevented the expansion of pressure drawdown, and eventually stabilized the well up to the present time. TQuartz has eventually stabilized at about 275 ^{o}C with no indication of a declining trend, while other chemical parameters have remained stable. To date, the well continues to provide about 15 Mwe of power.

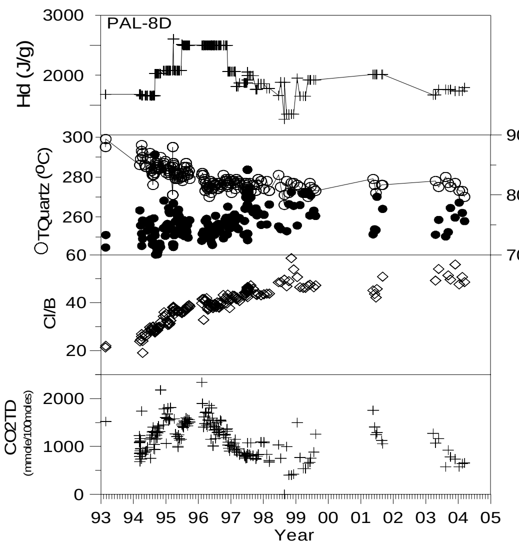

Figure 4: Geochemical trends with time of well affected by boiling and mixing with low-boron recharge

2.1.2 Well PAL-3D

Well PAL-3D (Fig. 5) exhibited a decline in TQuartz, CO_2TD, and increase in Cl/B ratio. However, discharge enthalpy and other chemical parameters remained relatively constant. The geochemical changes in PAL-3D are typical of those wells affected by Masakrot recharge fluid coming from the western part of the field (Fig. 8).

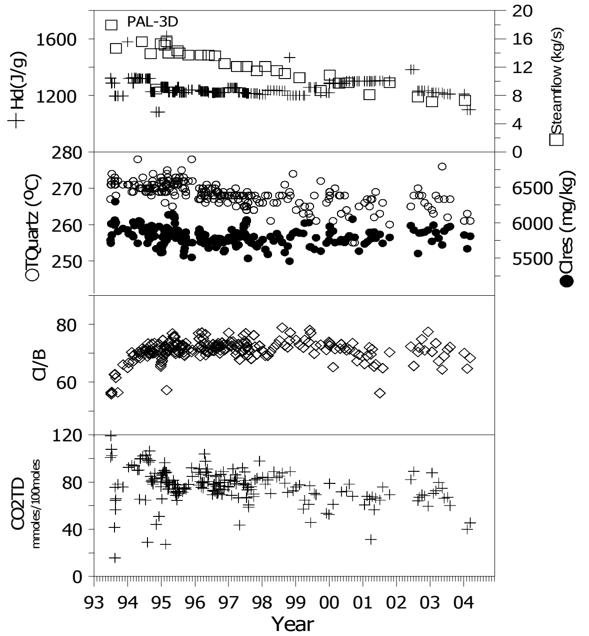

Figure 5: Geochemical trends with time of well affected by mixing with low-boron recharge from Masakrot

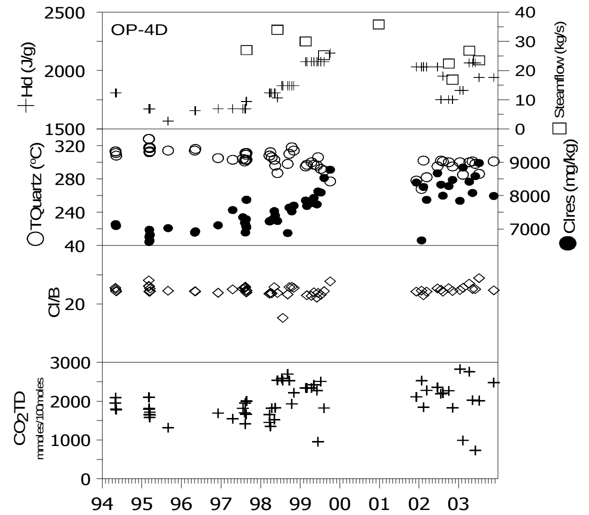

Figure 6: Geochemical trends with time of well affected by boiling and vapor formation

2.1.3 Well OP-4D

Well OP-4D represents the deep fluid in Botong area. Its chemical response to exploitation, which is boiling and vapor formation, is typical in the area. This has been shown in the HTQuartz vs. Clres cross plot (Fig. 9), as well as in the increase in discharge enthalpy. Trends with time of chemical parameters such as TQuartz, Clres, CO_2TD, as well as Cl/B ratio have shown relative stability (Fig. 6). As in other wells in the area, the chemical trends do not indicate intrusion of unwanted fluids such as injection return, acid-sulfate or condensates. Its chemical parameters also do not indicate any other detrimental reservoir process.

2.1.1 Well CN-4D

The chemical trends with time of CN-4D are typical of the wells in Cawayan area. Chemical and physical parameters like discharge enthalpy, TQuartz, Clres, SO_4res, Mgres, and pH trends with time are relatively stable (Fig. 7). The low concentrations of SO_4res and Mgres, as well the neutral pH are evidences that no acid inflow is present in the discharge fluid.

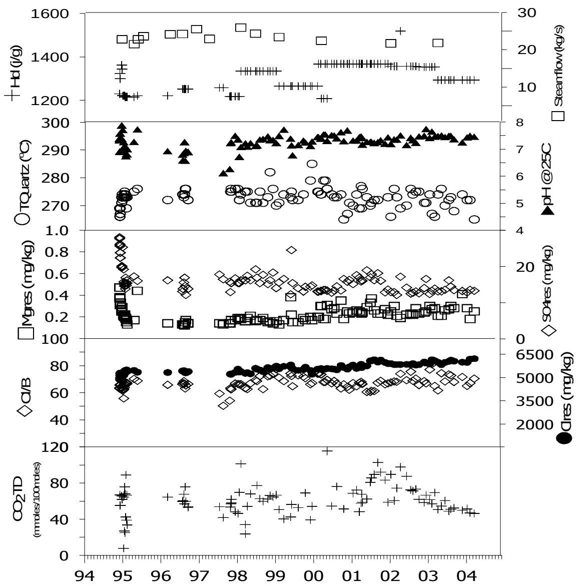

Figure 7: Geochemical trends with time of well CN-4D

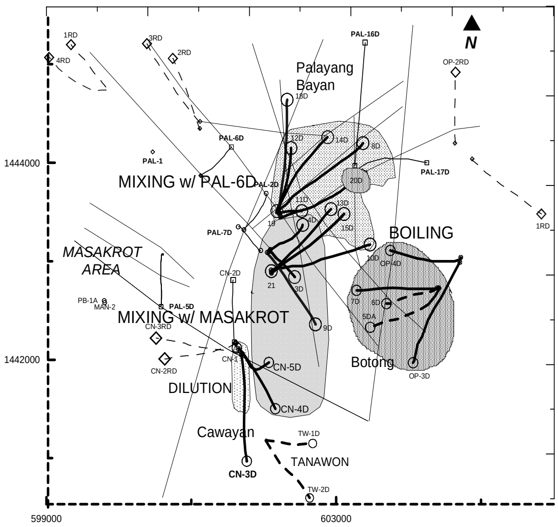

Figure 8: Reservoir processes

2.3 Geochemical Cross plots and Reservoir Processes

Similar with the individual wells' chemical trends with time, geochemical cross plots (Figs. 9 & 10) also exhibited stable overall field trends as indicated by data clustering. After several years of exploitation, the reservoir responded rather distinctively in each particular area of the field. The general response of the reservoir based on chemical and physical changes can be classified into four processes (See, 2001), affecting different areas of the field (Fig. 8). These processes are:

(1) boiling and mixing with low boron fluids from PAL-6D and PAL-7D areas, (2) boiling and vapor formation, (3) mixing with Masakrot fluid from the Western part of the field, and (4) dilution with cooler acid-SO_4 fluids from shallow feedzones in Cawayan area.

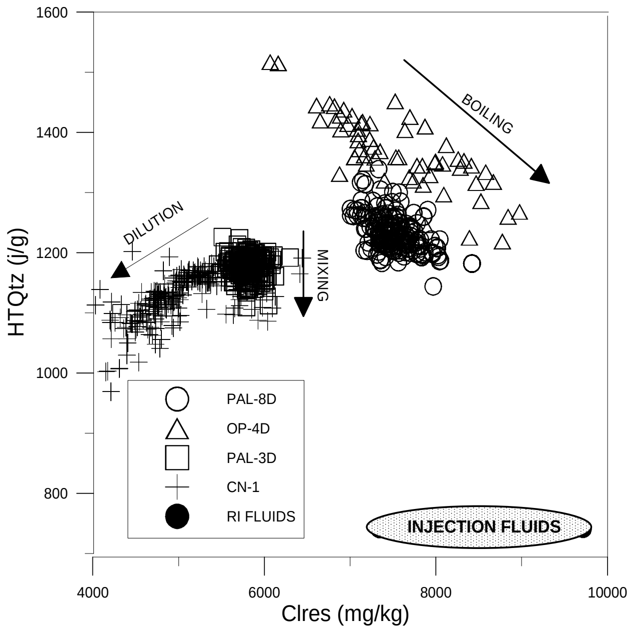

Figure 9: Geochemical cross plot of HTQuartz vs. Clres showing the different reservoir processes

Except for the last process, the response was mostly beneficial to the resource as indicated by the relatively stable chemical and physical trends. The processes are best represented by the HTQuartz vs. Clres (Fig. 9), and TQuartz vs. Cl/B (Fig. 10) cross plots. In Fig. 10 recent trends showed data clustering towards the end-member mixing fluids indicating stable reservoir processes. In both plots, no mixing trend towards the injection fluids could be discerned.

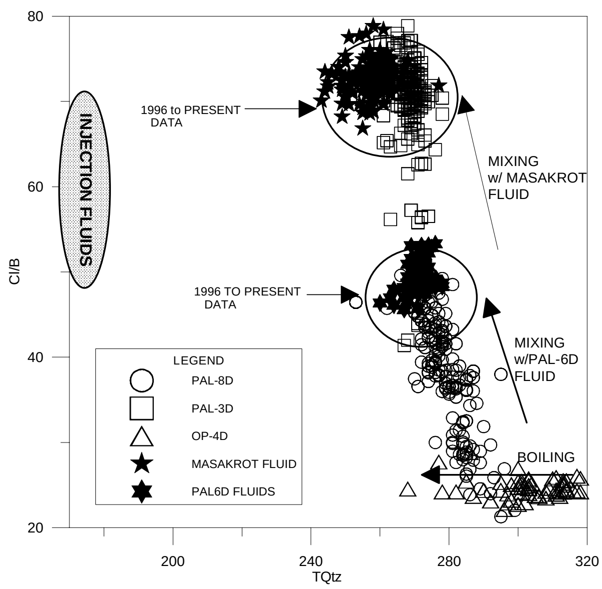

Figure 10: Geochemical cross plot of TQuartz vs. Cl/B showing mixing trends

2.3 Reservoir Temperature Decline

The average temperature decline of the reservoir fluid based on quartz temperature was about 10^oC. The most significant drop in temperature of about 8 ^oC occurred from 1993 to 1996 (Fig. 11), coinciding with the largest decline in pressure and other geochemical changes. The temperature drop has been attributed mainly to boiling and the entry of cooler recharge fluid from the western part of the field. However, from 1996 to present the quartz temperature has stabilized, and the drop in temperature during this period was relatively low at about 3^oC. The present temperature trend indicates stability, similar to the geochemical trends with time of the individual wells.

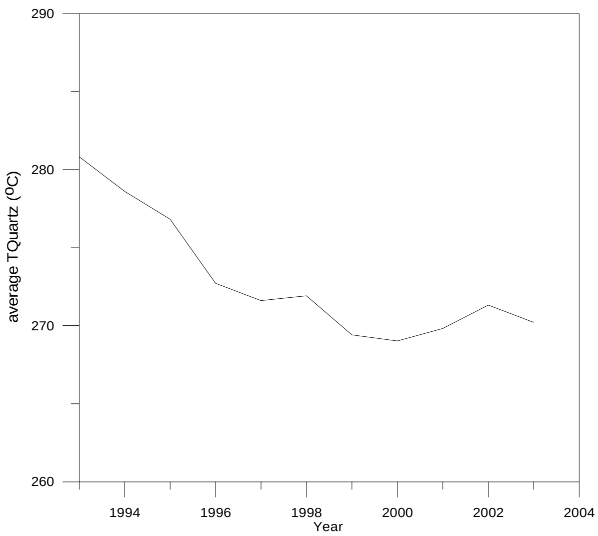

Figure 11: Average reservoir fluid temperature (based on TQuartz) trend with time

3. OPERATIONAL CONSTRAINTS AND REMEDIES

During the past ten years of operating the field, several operational challenges and constraints were encountered. These problems ranged from the bottom of the wells to the power plant interface. These constraints however, were all tackled and solved with practical and economically viable solutions.

3.1 Acidic-fluid intrusion and anhydrite deposition

This process, affected a number of production wells, two on a massive scale. In most cases the acid fluids enter the well bore above or just below the casing shoe at shallower feed zones. Once inside the wellbore the high-SO_4 fluid mixes with the upflowing deep fluid to form anhydrite deposits (See, 1995). As the mineral deposits grow, this progressively isolates the hotter, neutral, deeper fluids until the discharge fluid becomes acidic, dilute, and cooler. The chemical trends with time of well CN-1 as well as its casing profile (Fig. 12), illustrate this process. The well was eventually blocked by anhydrite and mechanically cleaned by means of a drilling rig. Remedial measures have been adopted to address this problem. These include maintaining the well at full-bore condition to prevent downflow, deepening the production casing shoe of new wells to case-off or avoid acid feed zones, calcium chloride injection during drilling, and use of corrosion-resistant casing at detected active acid depths.

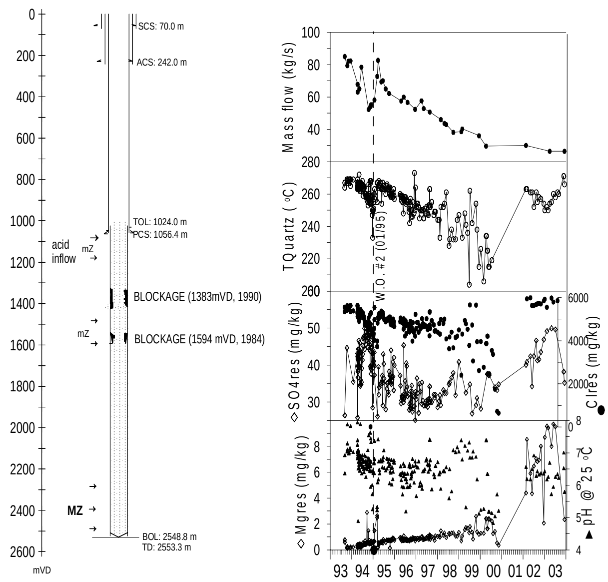

Figure 12: Geochemical trends with time and casing profile of well affected by acidic fluid

Some of these measures are best illustrated in Well CN-4D (Fig. 13) where the production casing shoe was deepened to 1495.5 mVD, and corrosion-resistant casings were used at acidic depths identified from drill cuttings through petrological analysis. So far, these acidic, high-SO_4 fluids are confined in a small, shallow portion of the field. The newly drilled wells have so far been spared from such problem indicating the effectiveness of measures implemented.

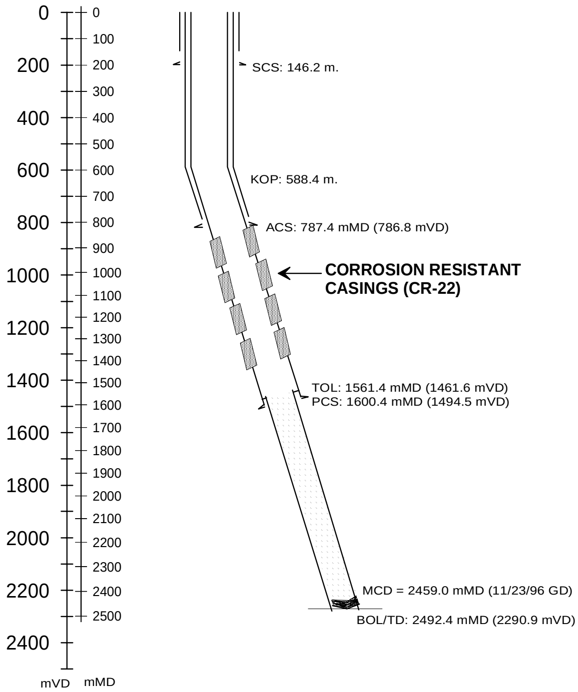

Figure 13: Casing profile of a well with corrosion-resistant casing to case-off acid fluids

3.2 Calcite deposition inside the wellbore

Another problem encountered was calcite deposition above the flash point inside the production casing of the well. This has caused one production well, PAL-21 to collapse or stop discharging at a regular, but relatively long interval of about twenty-one to twenty-eight months. The well has been characterized to be supersaturated with respect to calcite based on its chemical and physical parameters. At present, this problem is being addressed by means of regular mechanical clearing or work-over operation using a drilling rig. This method is the most practical and cheapest option at present. However, other options such as dosing or injecting with chemical inhibitor are also being evaluated.

3.3 Calcite deposition in surface pipeline

In BacMan-2 Botong Sector, the mixing of two-phase fluids from two production wells causes this problem. One fluid is a super-heated steam, and the other a high-enthalpy two-phase fluid with a small water fraction that is saturated with respect to calcite. When these two fluids mix in the two-phase header line, the superheated steam boils the water component of the mixture (Solis, et. al., 1999). This process causes calcite to supersaturate inside the line and induce calcite deposition that eventually blocks the two-phase header line. This problem was addressed by the construction of an over-sized drain pot (Fig. 14) along the high-enthalpy two-phase line, prior to the mixing point. This modified drain pot efficiently scrubs-off the water component of the two-phase fluid prior to mixing with the superheated steam at the header (Fragata, et.al. 2003) and thus with no or very minimal water to boil, calcite deposit is greatly reduced.

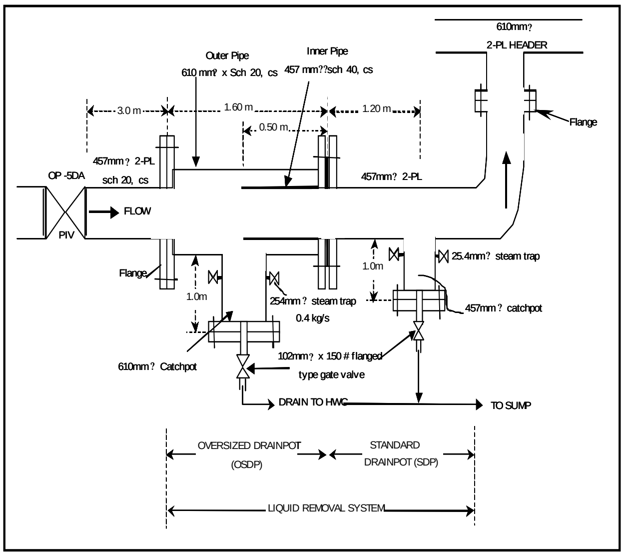

Figure 14: Schematic diagram of the over-sized drain pot and the two-phase line where calcite deposition occur

3.4 Silica scaling and injection well capacity

The very high silica content (~1100 mg/kg at atmospheric pressure separation), and saturation index of the separated brine at Botong could clog up the injection pipelines in a matter of weeks. This problem was addressed through the use of a chemical inhibitor injected in the two-phase line (Fig. 15). So far, this method has been effective in controlling silica deposition to manageable level. However, in spite of the chemical inhibitor's affectivity, gel-like silica formations caused injection problems. The capacity of the injection well was improved by regular pressurization of the well using an electric pump. This method has extended the the injection lifespan of the well thus minimizing costly acidizing and work-over operations.

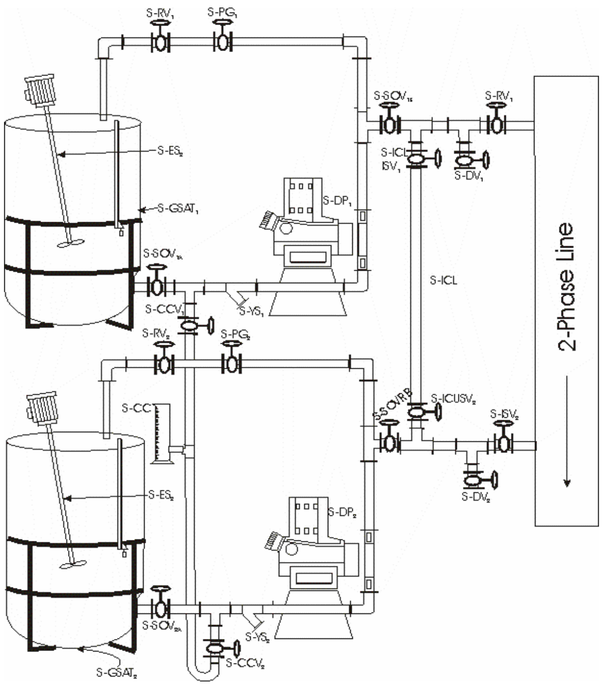

Figure 15: Schematic diagram of the silica inhibitor injection set-up

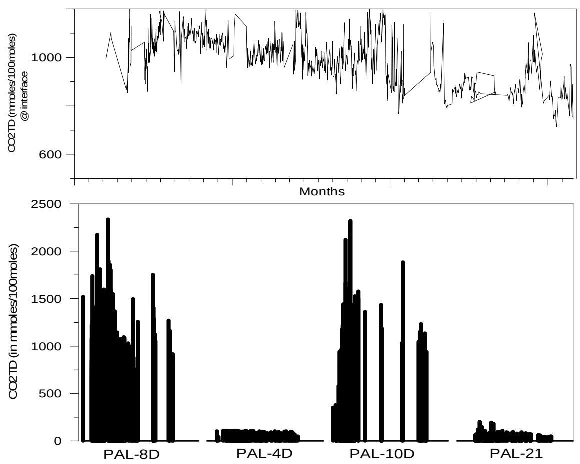

Figure 16: CO2TD content of some production wells and at the power plant interface

3.5 Non-condensable gas

One characteristic of the Bacman field is the wide variation in CO_2 concentration that range from about 100 to 3000 mmoles/100moles steam at total discharge (Fig. 16). The high-CO_2 wells sometimes lead to a relatively high percentage of non-condensable gas at the power plant interface. This in turn could affect the efficiency of the turbine. However, this problem is being addressed by effective well utilization and combinations, proper steam mixing before the interface, and in case of drilling new wells, targeting well-track towards the low gas areas of the field. Other practical options such as re-piping and/or steamline interconnections are also being evaluated to allow more flexibility in the steam mixing of the low and high gas wells.

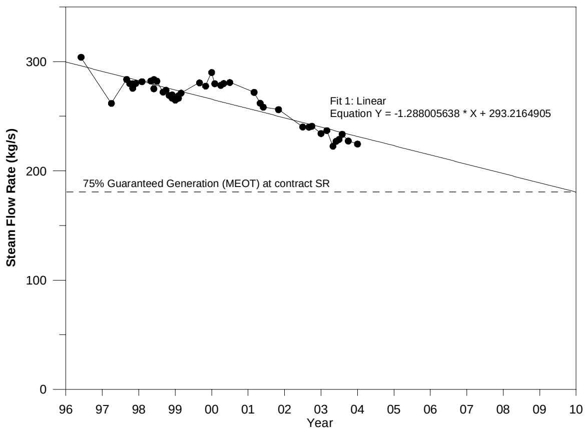

Figure 17: Steam flow rate trend with time of Bacman-I wells

3.6 Steam flow decline

Another cause of concern was the apparent decline in the steam flow of some production wells, and the steam availability of the field, particularly in BacMan-I area (Fig. 17). The declining trend with time however, could be attributed, to several factors some of which are well bore in nature such as calcite deposition in well PAL-21, and mineral blockages in some wells. Such factors could be immediately addressed by workable options such as mechanical clearing or work-over, acidizing, or drilling of additional wells. Furthermore the present steam supply is enough for the 110-Mwe capacity of the power plant, and above the seventy-five percent guaranteed generation, or the minimum economic off-take. The decline in the quartz temperature of some wells due to boiling and the entry of cooler recharge fluids may have also contributed to the decrease in steam flow. However, as the TQuartz trends with time of PAL-8D, PAL-3D and the average TQuartz of the field, as well as the other chemical parameters have shown, such trends have stabilized, and thus unlikely to contribute to any further decline in steam flow.

4. SUMMARY AND CONCLUSION

The response of the reservoir to exploitation was rather beneficial. Relatively hot recharge fluids provided pressure support that prevented the occurrence of a field-wide drawdown and the entry of cold peripheral waters and other detrimental fluids. No indication of injection fluid return has so far been detected among the production wells. The present chemical and physical trends have shown relative stability since 1996. Operational and reservoir-related problems encountered are mostly wellbore or superficial in nature and have been addressed with practical solutions. Based on the geochemical evidences, the deep resource has remained hot and liquid-dominated.

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