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Field Management Strategies for the Development of the Northern Negros Geothermal Field, Philippines

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ABSTRACT

The Northern Negros Geothermal Field in the northwestern slope of Canlaon Volcano, Negros Occidental province, Philippines is a high temperature (290^{o}C) liquid-dominated geothermal system with an upflow region southeast of the presently drilled sector and a major outflow towards the northwest. The heat source is associated with volcanism at a post-Canlaon caldera eruption center (Hardin Sang Balo) 3 km south of the main production pad. Reserve estimates predict a potential resource of 42-63 MWe for the field, which the Philippine National Oil Company - Energy Development Corporation will develop into a 40 MWe power project.

Developing the field presents major field management issues to be addressed. Production wells drilled are constrained within a limited area inside the geothermal reservation and outside the national park that exploit the upflow region while respecting environmental and socio-cultural interests. Drilling the production wells to the desired targets is difficult and discharging these wells requires stimulation methods such as airlifting and acidizing. Wells tested have indicated possible significant pressure drawdown and well interference during exploitation. Furthermore, the high potential for calcite deposition calls for novel solutions such as periodic acidizing and calcite inhibition.

Implementation of the strategies discussed is underway in preparation for the commercial operation of the power project by year 2006.

1. INTRODUCTION

The Northern Negros Geothermal Field in Negros Occidental province, Philippines is being developed by the Philippine National Oil Company - Energy Development Corporation (EDC) into a 40 MWe power project. A total of 17 wells have been drilled since the start of exploration in 1978, from 8 pad locations in 4 sectors (Mambucal, Catugasan, Pataan and Hagdan). Most of the wells were drilled during the years 2001-2003 after EDC secured financial support from the Japan Bank for International Cooperation for the development and production of the geothermal power project. Drilling has been concentrated in the Pataan sector where the highest temperatures are measured, being closest to the known heat source.

2. FIELD CHARACTERISTICS

The Northern Negros Geothermal Field is situated in the northwestern slope of Canlaon Volcano, Negros Occidental province, Philippines. It is a high temperature liquid dominated geothermal system with a heat source associated with volcanism at a post-Canlaon caldera eruption center known as Hardin Sang Balo, about 3 km southeast of the presently drilled production pads in the Puhagan sector (Figure 1) and 5 km north of the active Mt. Canlaon volcano. From the heat source, the major upflow region develops, trending towards the northwest as reflected by the temperature and pressure distribution in the field (Figures 2 and 3).

The highest measured downhole temperatures (~290^{o}C) occur in the vicinity of wells PT-5D and PT-7D, with an increasing trend towards the east and southeast. Towards the northwest, temperatures start to decline gradually near wells PT-1D and PT-2D then more sharply beyond well PT-6D to the northwest in the direction of the Catugasan and Mambucal sectors, where low temperatures prevail and neutral-pH chloride springs occur, thus defining the outflow region. The field pressure trend similarly indicates fluid flow from the southeast (highest pressure in the vicinity of well PT-3D), heading towards the northwest where the lowest pressures occur.

The fluids migrate along northwest-southeast trending faults that have served as the main source of permeability. Minor flows also occur along the boundaries between the volcanic and limestone formations and within intra-formational contacts, where minor permeability exists (PNOC-EDC, 2001).

The heat source and therefore the hottest regions of the upflow are within the Mt. Canlaon National Park, a 25,000 hectare nationally declared protected area surrounding Mt. Canlaon (CASDI and PNOC-EDC, 1997). Despite such a strategic location of the National Park, drilling has been confined from outside its boundaries to comply with environmental regulations and respect socio-cultural interests associated with the Park's protected area status.

3. RESERVE ESTIMATES

The exploitable resource area has been primarily defined by the geophysical boundaries, field temperatures and drilling accessibility. Interface elevation and resistivity contours generated from magnetotelluric surveys (Figure 2) suggest a 6-11 km^2 resource area between the Pataan and Sumaguan sectors. Based on field temperatures, the lateral extent of this resource area is further defined by well PT-6D and its surrounding vicinity in the north, near the existing drilled production pads outside the National Park in the west, and somewhere between wells PT-3D and HG-1D in the south. The eastern boundary towards the postulated upflow has yet to be clearly delineated for lack of any wells drilled inside the National Park.

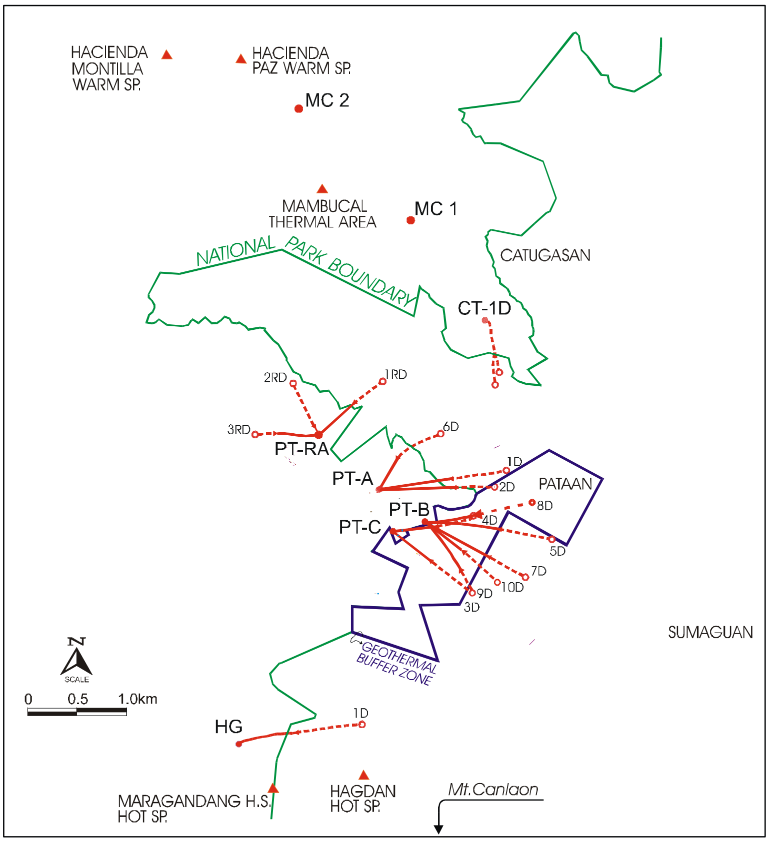

Figure 1: Map of the Northern Negros Geothermal Field.

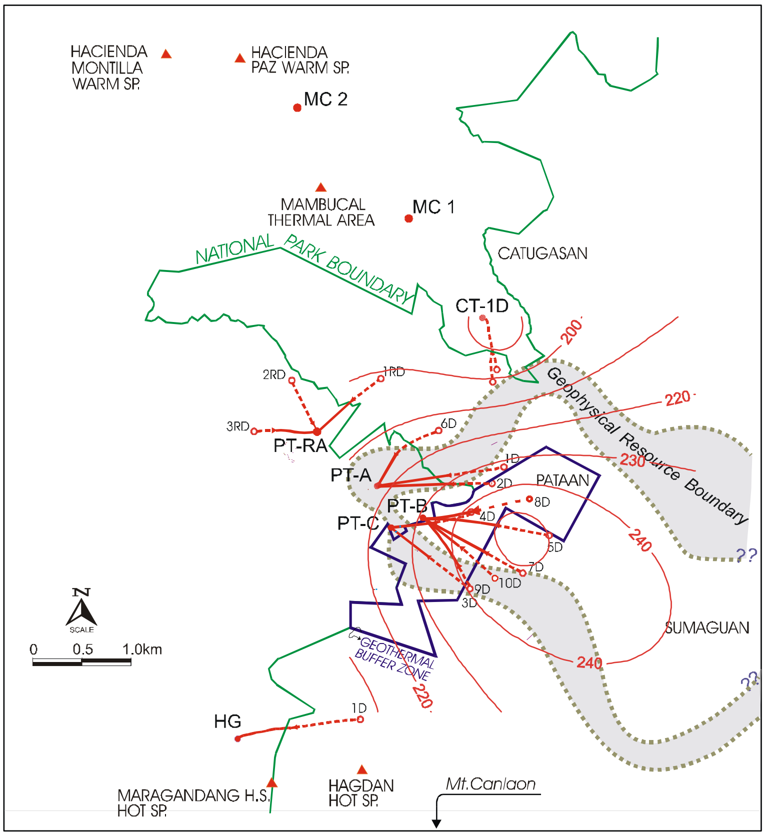

Figure 2: Temperature (^{o}C) contours at -1000 mRSL and geophysical boundaries of the Northern Negros Geothermal Field

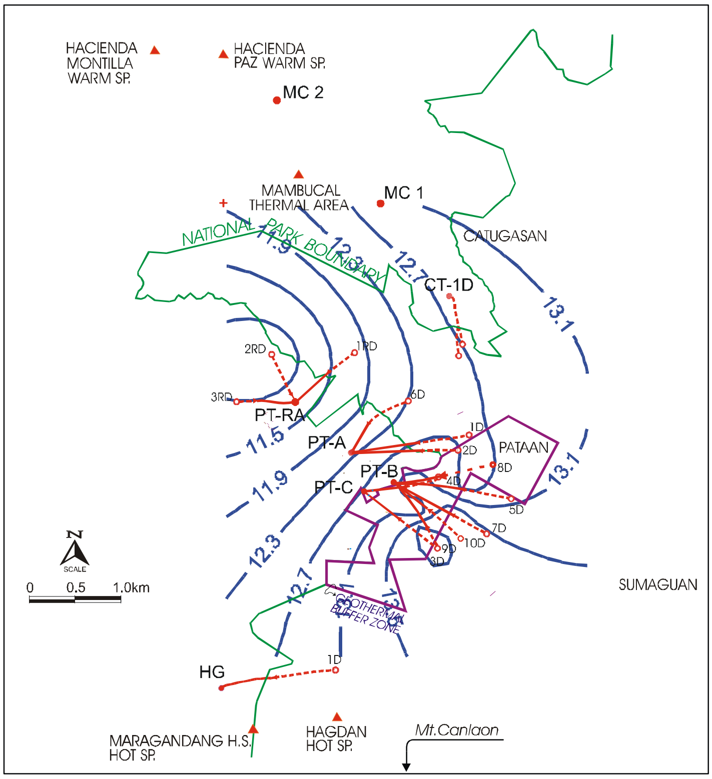

Figure 3: Pressure (MPag) contours at -1000 mRSL of the Northern Negros Geothermal Field

Integrating the geophysical and temperature boundaries and including the lateral distance that existing EDC drilling rigs can reach by directional drilling (drilling throw) plus a drainage radius factor, the actual exploitable area is limited to about 6-9 km^2. The top of the accessible reservoir is estimated at -1000 mRSL, the approximate depth where temperatures start to drop below 220°C at shallower levels; while the bottom is at -2200 mRSL, which is the maximum vertical depth that existing EDC drilling rigs can reach from an average well elevation in Northern Negros of 800 mRSL. Reserve estimates from stored heat calculations applied to this exploitable area, predict a potential resource of 42-63 MWe.

4. WELL CHARACTERISTICS

Only 5 wells, all in the Pataan sector, have been tested and found to be commercially productive, with a combined wellhead output of 26 MWe. A viable injection sector has also been established within the postulated outflow region northwest of the main production pads. The three injection wells already drilled in that sector can accommodate almost 400 kg/s of brine.

The highest downhole temperatures (Figure 4) have been measured from production wells PT-5D and PT-7D, which is expected given the wells proximity to the major upflow source relative to the other wells. Maximum temperatures at these wells reach almost 290°C at the bottom (-1500 to -1600 mRSL). Production wells PT-2D, PT-4D and PT-8D, being farther from the upflow have maximum temperatures of up to only 250°C. A similar pattern is also observed in the wells production characteristics (Figures 5 and 6). Well PT-7D produces the highest mass flow along with PT-2D and PT-8D at similar wellhead pressures, while PT-5D produces slightly lower. However, both PT-5D and PT-7D have higher enthalpies (~1200-1300 kj/kg) compared with the rest of the wells (~1100-1200 kj/kg), thus generating higher steam flow and power potential. Furthermore, the maximum discharge pressures of both PT-5D and PT-7D are considerably higher at about 3 MPag or greater, compared to the other wells at less than 3 MPag.

There are two other recently drilled wells intended for production but have not yet been discharged, PT-9D and PT-10D. With well tracks south of wells PT-5D and PT-7D and closer to PT-3D, and relatively colder downhole temperatures (<260°C), these wells delineate the southern boundary of the resource or a relatively cold block in the south, towards the Hagdan sector.

5. WELL DAMAGE

None of the commercially productive wells at present ever had the capability to self-discharge. Discharge was initiated by gas lifting the well with nitrogen gas or compressed air, conveyed through coiled tubing or drill string. Furthermore, the discharge of most of these wells were originally (after drilling) unsustainable and noncommercial, a condition which has been mainly attributed to the prevalence of wellbore and formation damage. At the present location of the well pads relative to the targeted higher potential region of the field closer to the upflow, successfully reaching such well targets has been difficult. Long throw wells, as much as 1.3 km had to be drilled, that are susceptible to problematic circulation losses and collapsing formations, requiring large quantities of mud and numerous cement plugs to control. This has caused significant damage to the wellbore and formation, thus limiting the wells production capacity. Matrix acidizing was applied to reduce if not totally remove the damage, and therefore maximize production. Post-acidizing results have been satisfactory. All except one of the commercially productive wells were acidized before their outputs became commercial. Results of the acidizing are summarized in Table 1. Better drilling technology more appropriate to the existing drilling conditions will be adopted in future drilling, to more effectively achieve the desired drilling targets and even minimize damage. Recent advances in loss control and drilling equipment will be studied and utilized if applicable.

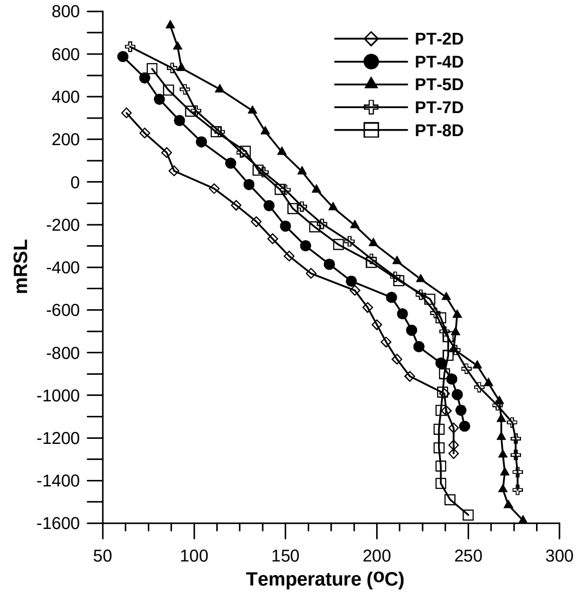

Figure 4: Downhole shut temperatures of Northern Negros production wells.

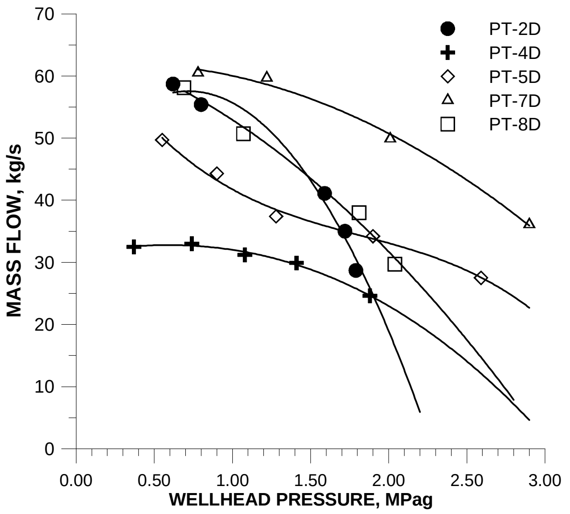

Figure 5: Mass flows at varying wellhead pressures of Northern Negros production wells.

6. PRESSURE DRAWDOWN AND INTERFERENCE

The distribution of wells is so dense and well track spacing is limited because the production wells can only be drilled from just a few pads where the resource is most accessible from outside the National Park. The main production pad alone is already occupied by 5 wells, which will become 6 wells before plant commissioning. Hence, it is suspected that pressure drawdown and well-to-well interference will be significant during the exploitation of the Northern Negros field with such a concentration of wells. Preliminary well tests conducted have initially validated such phenomena.

6.1 Pressure Drawdown Signatures

Well PT-5D is the hottest production well drilled and has one of the highest outputs (see previous discussion). After discharging the well continuously for almost 2 months, a decrease in mass flow and wellhead pressure (~1.2 bars) was measured at similar wellhead openings. No mineral deposition in the wellbore was detected that could have caused the decline. Furthermore, downhole pressure at discharging condition dropped by 40 bars from static condition (Figure 7). Assuming that no substantial deposition occurred in the formation during the discharge, these occurrences likely manifest significant pressure drawdown and poor recharge in the field.

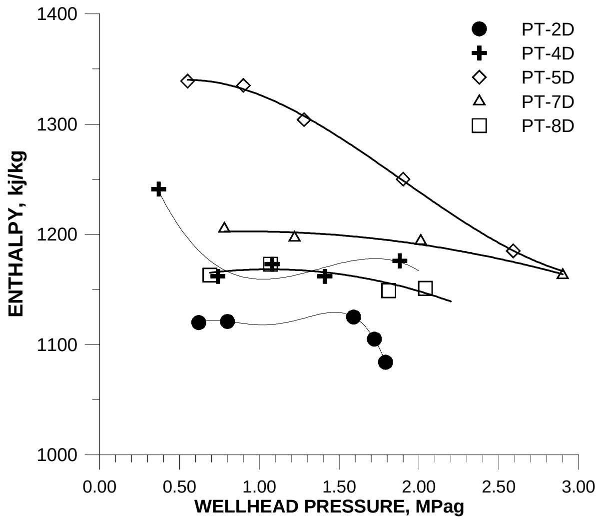

Figure 6: Enthalpies at varying wellhead pressures of Northern Negros production wells.

6.2 Interference Testing

An interference test was performed between wells PT-5D and PT-7D and between PT-5D and PT-8D, with PT-5D serving as the observation well in both cases. These three wells originate from the same drilling pad with the well track of PT-5D in between the well tracks of PT-7D in the north and PT-8D in the south, separated by a distance of about 450 meters and 385 meters, respectively. This range in well separation is representative of the distances between the existing production wells in Northern Negros.

The downhole static pressure of well PT-5D was monitored continuously for about 7 months while discharging well PT-7D followed by PT-8D. The pressure trend at PT-5D during that period is illustrated in Figure 8. The effect of the discharge of both wells on PT-5D is significant as shown by the declines in pressure by about 60-100 psi during both the full bore discharge (~60 kg/s mass flow) of PT-7D and PT-8D. Conversely, pressure recovery of about 25 psi was observed when the flow from PT-8D was throttled and reduced by half (~30 kg/s). Pressure transient analysis indicates a stronger communication between PT-5D and PT-8D compared to between PT-5D and PT-7D, consistent with the well track spacing difference of both well pairs. Such results suggest a considerable degree of interference among the production wells in Northern Negros.

The apparent pressure drawdown, interference and other major field phenomena will be subjected to more exhaustive evaluation vis-à-vis their impact on the development, operation and sustainability of the field. More thorough pressure interference testing and analysis will be programmed, including tracer tests, with more wells in production and for monitoring, to more accurately simulate actual operating conditions. The pressure interference data will help verify the reliability of the numerical model (reservoir simulation) and study sustainability, through history matching between measured and simulated pressure changes during interference tests. Results of the tracer tests will clarify the possibility of hydrological connections between production wells and between production wells and reinjection wells. A three-dimensional reservoir simulation will be undertaken to predict reservoir behavior during exploitation, which will be crucial in understanding the sustainability of the reservoir and developing the field.

Table 1: Summary of results of acidizing the Northern Negros production wells.

WELL	MUD LOST IN OPEN HOLE (Bbls)	BEFORE ACIDIZING		AFTER ACIDIZING	
		Inj. Index (li/s/ MPa) Skin	Output (MWe)	Inj. Index (li/s/ MPa) Skin	Output (MWe)
PT-2D	4,971	14.3 -5.8	Nil	27.5 -6.9	5.2
PT-4D	12,240	10.0 +10	Nil	16.1 -	3.2
PT-5D	14,600	10.5 -	Nil	29.9 -	5.4
PT-7D	28,000	10.3 +1.4	Not tested	17.0 -1.1	6.3

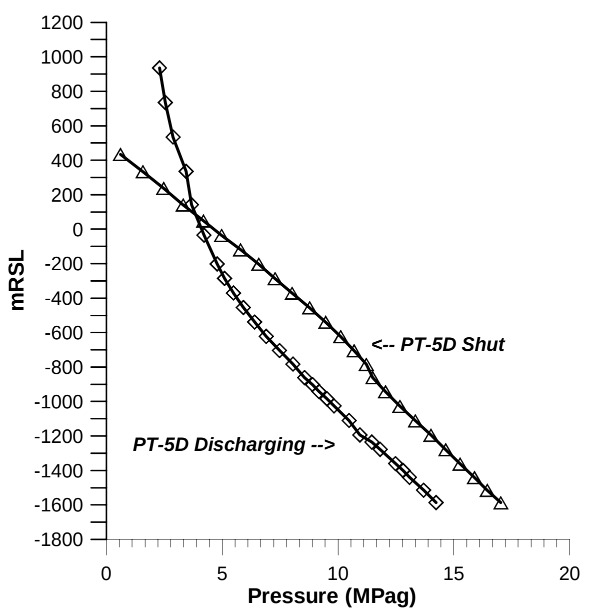

Figure 7: Downhole pressures of PT-5D at discharging and shut conditions.

Access to pads that can be located within the National Park is imperative so that future replacement production wells can be drilled with maximized spacing into the unexploited high temperature resource areas. This reduces the constraints and impacts imposed by limiting pad development outside the National Park, particularly the field phenomena discussed detrimental to operation, and improves the capability to achieve a sustainable development of the field.

7. CALCITE DEPOSITION

All Northern Negros production wells tested have a high potential for calcite deposition during production as indicated by the change in calcite saturation index during boiling (Sanchez, 2003). This has been most pronounced in well PT-2D, where calcite deposits were found obstructing the wellbore, which was accompanied by a drastic decline in output during the discharge. However, no wellbore calcite deposits were detected in the other wells when they were also discharged despite declines in mass flows, particularly at wells PT-4D, PT-5D and PT-7D. This suggests a varying degree in calciting in each well and also the possibility that calciting occurs outside the liner or in the formation. Since this has yet to be validated, the possibility that the declines in output are also caused by drawdown cannot yet be discounted.

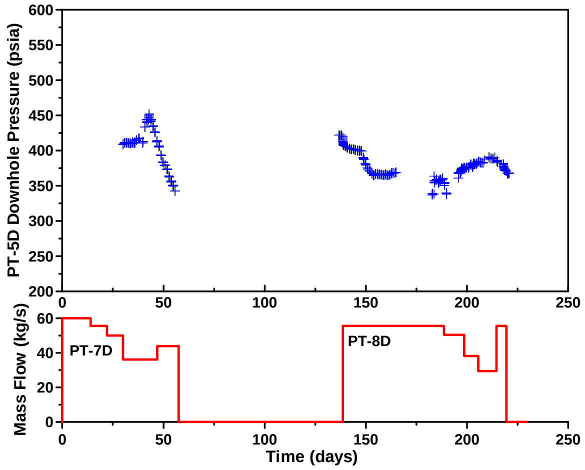

Figure 8: PT-5D downhole pressures while discharging PT-7D and PT-8D.

Measures to mitigate calcite deposition can be implemented to minimize if not totally prevent any calcite-induced production decline. Wells can be worked over and acidized periodically to clear the existing calcite deposits in the wellbore and formation. However, such operation requires cutting out production wells and reducing steam supply from time to time. A more preventive approach with minimal interruption to the operating field and also reduces the frequency of acidizing is to use an appropriate calcite inhibition system (Buñing, et al., 2000) to prevent or at least minimize calcite deposition (Figure 9). For the system to work, the inhibitor chemical must be injected and come in contact with the wellbore fluid initially below the flash point. Wells where boiling occurs outside the wellbore (within the formation) during full bore discharge, which explains the possible calcite deposition there, would have to be throttled to induce boiling inside the wellbore. Wellhead opening is therefore not maximized and mass flow is reduced.

Wellbore simulation was applied to initially predict the operating wellhead pressures that will cause flashing inside the wellbore for each production well. Downhole flow profiles at different wellhead pressures were modeled to determine the flash points for each wellhead pressure. This also provided information on the setting depth of the injection tubing for each well, and how much output reduction raising the operating wellhead pressures will cause. For the 5 production wells tested, it is estimated that the throttling of these wells will reduce their total output by 1 MWe. Further output reduction is likely during field exploitation, as a result of throttling the wells more in response to the expected pressure drawdown. Therefore, more production wells might have to be drilled to compensate for the output reduction.

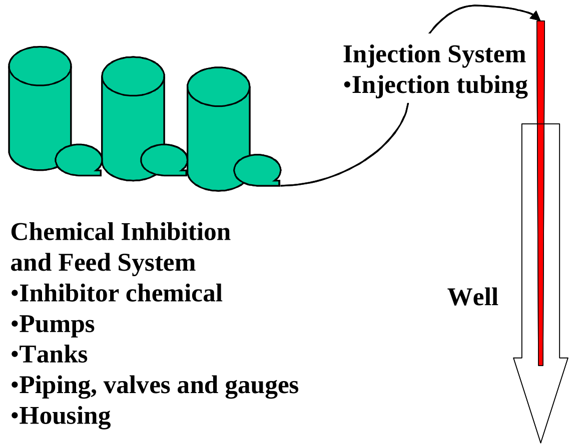

Figure 9: Typical calcite inhibition system set-up.

9. CONCLUSION

Management of the Northern Negros Geothermal Field is confronted with several major issues that would have to be sufficiently understood and addressed to fully exploit the geothermal resource. Limiting pad development outside the Mt. Canlaon National Park imposes difficulties in achieving strategic drilling targets and prevents a more effective distribution of wells. Consequently, pressure drawdown and interference effects are enhanced, which can heavily afflict the sustainable operation of the field. Managing the field is further constrained by the high calciting potential of the production wells.

Appropriate technologies such as acidizing and airlifting have been applied to commercially produce the wells despite their initially nonproductive state. Better technologies may be available and should be exploited. These remedial solutions to the chronic drilling problems should be supplemented by the opportunity to access drilling locations from within the National Park to tap the unexploited resource areas of likely higher potential closer to the heat source. This may also ease the negative impacts of pressure drawdown and interference, which have been made manifest through well tests and shall be more extensively understood and effectively managed together with other significant field processes through further well tests (e.g. interference and tracer tests) and reservoir simulation. Acidizing and calcite inhibition will be utilized to mitigate calcite deposition, complemented with well tests and wellbore simulation.

Implementation of the strategies discussed is underway for a sustainable development and exploitation of the Northern Negros field, which is programmed for commercial operation by year 2006.

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