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LEYTE-A GEOTHERMAL DEVELOPMENT; ASSESSMENT OF LIKELY CO2 EMISSIONS AND PROPOSED METHODS FOR REDUCTION

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ABSTRACT

It is proposed to develop 440 MWe of geothermal generation on the island of Leyte for export to Luzon. This is expected to produce a CO2 flux of 450,000 tonnes p.a. at commissioning in 1996, declining to 200,000 tonnes p.a. by the year 2020, i.e. a total emission of 7.5 million tonnes of CO2 over 25 years - less than 10% of that emitted from an equivalent size coal fired plant. Although this flux is relatively small both in country and global terms it is, nonetheless, desirable from the perspective of concerns with greenhouse gases and potential operational, environmental, commercial and social benefits to the steam field operator, to dispose of at least some of it. Disposal options are examined and it is proposed from CO2 solubility considerations to "wet" reinject approximately 50 % of the CO2 emission from Leyte-A. It is also recommended to implement additional forest protection/ reforestation programmes to preserve/ extend the potentially large biological sink for CO2 in the Leyte geothermal reservation forests. Potential reservoir problems associated with reinjection of CO2 are examined in some detail, particularly carbonate scaling in gas rich reinjection brines.

CO2 EMISSIONS AND THE GREENHOUSE EFFECT

Global atmospheric concentrations of CO2 are increasing at the rate of 3 billion tonnes per annum, due mainly to combustion of fossil fuels and deforestation. (Houghton and Woodwell, 1989). It is believed that at this rate atmospheric levels of CO2 will double by the year 2055 (Gates, 1985), and global temperatures will increase by 1.5 to 4.5 C due the greenhouse effect. It is anticipated that global warming on this scale will produce substantial changes in the world's climate, affecting agriculture worldwide and displacing large population groups presently resident at or close to present day sea level.

There is thus considerable international interest in reducing global emissions of CO2 which together with CH4 are the most significant of the greenhouse gases (GHG's). In the 1988 Toronto Conference on Climate Change, the Worlds industrialized nations agreed on a goal of cutting GHG emissions by 20% by the year 2005.

Further measures have since been proposed to reduce CO2 emissions to the global atmosphere:

Energy conservation and conservation:

Consumption of energy from fossil fuels in the developed countries, which constitute 75% of that used globally, could be reduced by 50% through conservation and efficiency measures alone (Goldemberg, 1990).

Expanded use of geothermal power and other non fossil fuel energy alternatives:

Although CO2 production from developing countries is presently less than that from developed countries, the contribution of the former contribution is growing. If the developing countries will follow conventional patterns of economic development, their contribution to global CO2 levels is potentially very large. It is thus most desirable that developing nations lessen their dependance on fossil fuels and increase the contribution of geothermal energy, solar energy and other renewable sources of energy in their energy supply mix. The considerable advantage that geothermal power generation offers in terms of reduced CO2 emissions in comparison to combustion of fossil fuels is readily apparent in the following data:

Table 1. *Comparison of CO2 emissions from various power plant fuels (Modified after Goddard et. al., 1989).*

Fuel	CO2 Emission Rate *(kg/sec CO2 per MWe)*	CO2 Emission Relative to Bituminous Coal Rate
Fossil Fuels:		
Gasoline	0.18	78%
Diesel Oil	0.19	83
Fuel Oil	0.19	83
Bit. Coal	0.23	100
Sub Bit Coal	0.25	109
Geothermal:		
Geysers	0.010	4
PG&E Unit 20	0.010	4
Tongonan I	0.018	7
Palinpinon I	0.021	9

The Philippines is presently a small contributor to global CO2, emitting 21.4 million tonnes per annum (8.4 tonnes from combustion of fossil fuels and 13 million tonnes from deforestation - Siddiqi, 1990); in total 0.7% of the annual global increase in CO2. It is expected that this contribution will increase rapidly due to ongoing rampant deforestation and the urgent need for development of additional electrical power for industrialization.

From the perspective of CO_2 emissions and global warming at least, the key future development objectives of Philippine government must be to promote non-fossil fuel power generation, particularly geothermal due to the abundance of high quality geothermal resources in the Philippines (see for example Barnett et al, 1984), reduce deforestation and expand reforestation.

THE LEYTE-A 440 MWe GEOTHERMAL POWER PROJECT

The Leyte-A project is an ambitious plan to fully utilize large, proven geothermal reserves on the island of Leyte in the Central Philippines for export of electricity to the major load center of metro Manila on the island of Luzon by 1996, over a distance of 1100 line-km . This would increase geothermal power generation on the Luzon grid to 1250 MWe with countrywide geothermal power generation totalling 1665 MWe. by the year 1996.

The Leyte-A project has generated considerable interest and is favoured by both Philippine Government and international funding agencies over alternative power generation from fossil fuels because of the much reduced environmental and atmospheric impacts, in spite of high costs associated with 1100 line-km of EHV surface transmission and a DC submarine cable.

An important requirement in comparing the technical advantages of geothermal power from Leyte against fossil fuel generation on Luzon has been to assess CO_2 emissions likely from the Leyte-A project and how these might be reduced to further improve the environmental and social desirability of the geothermal option.

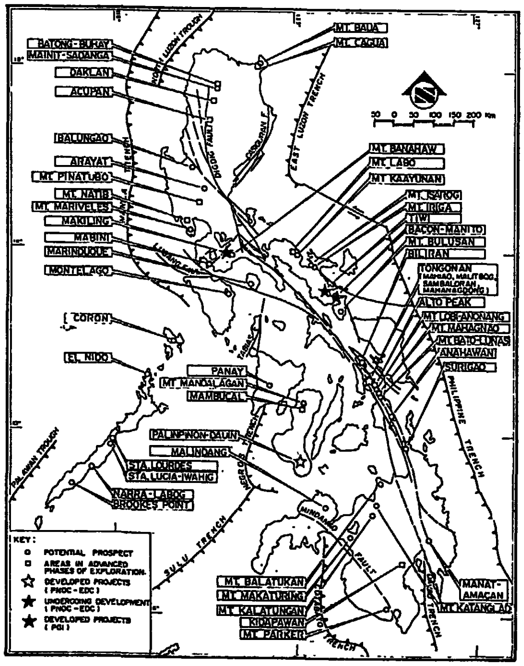


Figure 1 *Location of geothermal power developments in the Philippines.*

AN ASSESSMENT OF CO_2 EMISSIONS LIKELY FROM THE LEYTE-A POWER PLANTS

Development planning for the Leyte-A project is presently based on installing an additional 275 MWe of geothermal generation in the Tongonan field, which has been producing commercial geothermal power since 1977, and developing the Mahanagdong field (to a level of 110 to 165 MWe) and possibly the Alto Peak field (to at least 55 MWe), located 10 and 20 km respectively to the south east of Tongonan.

With 62 wells drilled in these three fields, 375 MWe of confirmed steam available at wellhead and nearly 10 years production experience operating the Tongonan I (112.5 MWe) geothermal power plant (see for example Sarmiento et. al., 1985) PNOC has available a substantial body of data from which to assess the likely level of CO_2 emissions from the Leyte-A power plants.

From combining enthalpy, mass and gas flow data for each of the drilled wells with production field development plans, CO_2 emission levels can be readily determined for the Leyte-A plants at commissioning in 1996:

Table 2 *CO_2 fluxes expected at Commissioning of Leyte-A plants in 1996*

Field	Sector	MWe	CO_2 Flux* *(kg/sec)*
Tongonan	U. Mahiao	110	3.5
	Malitbog	165	2.4
Mahanagdong		165	9.0

(* assuming 90% plant factor)

Of greater uncertainty, however, is the behavior of field gas levels with production time. Non-condensible gas in steam to the Tongonan I plant, of which CO_2 is greater than 97%, has shown a steady decline since plant commissioning in 1983. This has closely followed the decline in reservoir pressure and can thus be approximated by a first order exponential decline.

Accordingly, historical CO_2 data for Tongonan I has been fitted to an exponential regression extended over a 25 year plant life (Figure 2) which suggests that the long term CO_2 emissions from Tongonan I can be expected to decline at a rate of about 3.4% per annum, i.e. it will take some 20 years for field CO_2 emissions to decline by 50%. This rate of decline was then used to approximate long term CO_2 levels for the Upper Mahiao, Malitbog and Mahanagdong field sectors as shown in Figure 3.

It is thus indicated that CO_2 emissions from the proposed 440 MWe Leyte-A geothermal power development will be relatively small in global terms, ranging from 450,000 tonnes per year at commissioning in 1996, declining to about 200,000 tonnes by the year 2020.

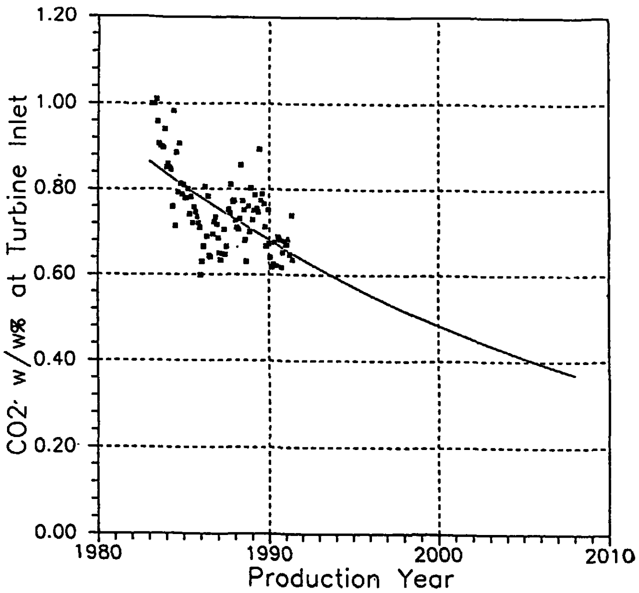


Figure 2 *Tongonan I power plant; Estimates of 25 year decline in CO2 emissions from exponential fit of decline measured over period 1983-1991*

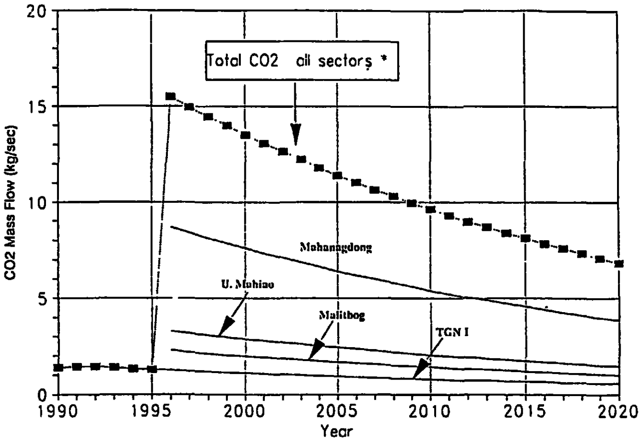


Figure 3 *Leyte-A power plants; Assessed CO2 flux from commissioning to 25 year plant life*

The total CO2 flux from the project over 25 years will be 7.5 million tonnes i.e. averaging 300,000 tonnes per annum, equivalent to 1.4% of the present total annual Philippine CO2 emission and 0.01% of the annual increase in global CO2 levels. This gas flux in terms of CO2 per unit of power generated from geothermal plant in Leyte would be only 8.6 % of that for power generated from bituminous coal, i.e. 440 MWe of Leyte geothermal power would produce the a CO2 emission equivalent to only 38 MWe of generation from bituminous coal (See Table 1.).

DISPOSAL OF CO2 FROM LEYTE-A PLANTS

Although the CO2 flux expected from the Leyte-A project is small in both country and global terms, it is nonetheless desirable from both the perspective of global concerns with greenhouse gases and potential operational and commercial benefits to PNOC examine disposal options to reduce CO2 emissions.

Reinjection

CO2 could be reinjected either "wet" into existing field-edge and in-field brine injection wells, or into dedicated "dry" gas injection wells drilled from off-field locations to minimize potential gas returns to production wells. "Wet" CO2 injection has been undertaken at the Coso geothermal field in California (Lovekin, 1990) and it is understood that trials are also being considered at two other U.S. fields, one in Nevada and the other in Hawaii.

"Wet" Gas Injection

It is considered technically feasible to inject CO2 into waste brine flows up to the level of CO2 solubility in the brine at the temperature at which brine/steam separation is carried out (typically about 0.3 wt% CO2 can be dissolved in brine at 165 C. and 0.8 MPa reinjection wellhead pressure, see Figure 4). Limiting the amount of CO2 injected in this manner to that which can be dissolved in the hot, waste brine is expected to minimize potential problems with CO2 exsolving from brine reinjected back into the reservoir which has, apparently, posed some difficulties at the Coso field (Lovekin, 1990). On the basis of these CO2 solubility considerations it is estimated that approximately half of the CO2 flux from the Leyte-A power plants could be disposed of by "wet" injection.

"Dry" Gas Injection

The remaining half of the CO2 flux exceeding the solubility of CO2 in the waste brine at the temperature and pressure at which reinjection is carried out could be disposed of into dedicated "dry" gas injection wells. There is no certainty, however, that suitable stratigraphic well targets could be located, nor whether the gas when injected could be contained underground in the highly faulted, seismically active region around Tongonan (see for example Bromley and Rigor, 1983).

Commercial Recovery

Although there is distinct potential for commercial recovery of at least some CO2 from the Leyte-A power plants, the supply of CO2 available far exceeds Philippine market demand (by approximately 100 times).

Venting to Atmosphere

This remains the means by which CO2 is disposed of at practically all geothermal plants worldwide. The impact of geothermal CO2 emissions on the global atmosphere can be mitigated to a very significant extent through biological absorption and photosynthesis, e.g. one hectare of tropical forest has the capacity to absorb 6.5 tonnes of CO2 per annum (Kryklund, 1990). Thus venting CO2 to atmosphere remains a disposal option, particularly if surrounding forest cover can be maintained, or preferably extended.

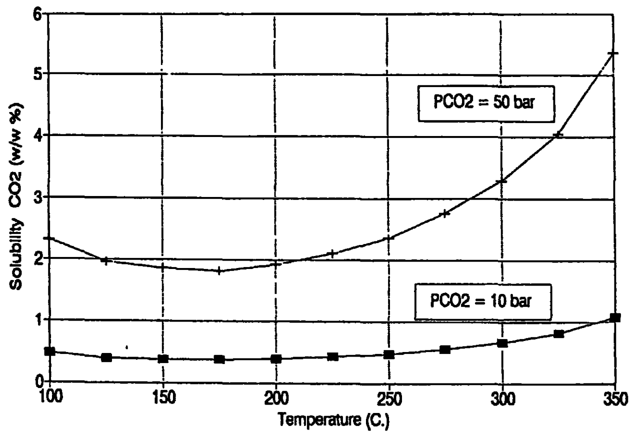


Figure 4 *Solubility of CO2 versus brine temperature and PCO2*

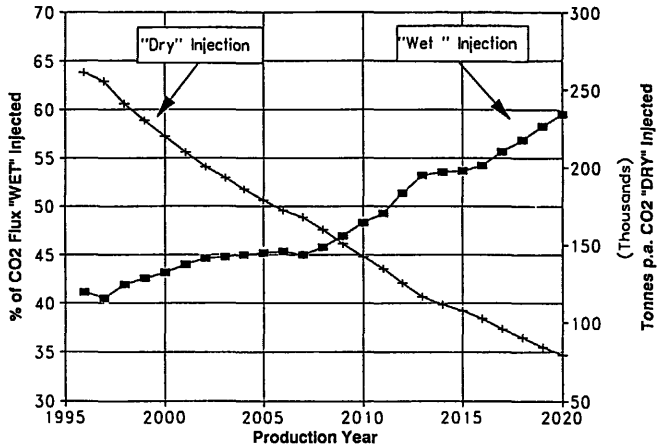


Figure 5 *Estimated CO2 flux from Leyte-A power plants that could be "wet" injected over 25 years*

The Leyte Geothermal Reservation comprises an area of 107.000 Ha of land which at one time was completely forested. Over the past 40 years this has become increasingly depleted through conversion to agricultural land, slash and burn cultivation, legal and illegal logging.

A forest area of half the size of the Leyte Reservation would provide a sufficient biological sink for all of the CO2 flux from the Leyte-A power plants. PNOC's ambitious water shed management programmes to protect and extend the forest remaining within the Leyte Reservation are thus very relevant to CO2 mitigation measures. These programmes should then be vigorously supported in the interests of both the local and global benefits that can, and are being, obtained.

POTENTIAL RESERVOIR/ PRODUCTION PROBLEMS ASSOCIATED WITH GAS INJECTION

As discussed above, it is believed that exsolution of gas from reinjected brine and segregation of CO2 within the reservoir will be avoided if the amount of CO2 injected does not exceed solubility relations in the brine. There remains, nonetheless, potential for problems with carbonate supersaturation in the gas rich brine during "wet" reinjection which could lead to deposition of calcite in both the reservoir and surface facilities, such as has been reported from the Coso field

In order to examine calcite over-saturation and deposition associated with CO2 injection, mass weighted average production well chemistries were calculated for each development sector and used to derive theoretical reinjection line brine chemistries at production separator pressure and temperature. The chemical consequences of then adding (injecting) CO2 to these reinjection brine compositions were examined through chemical speciation calculations (Henley et. al., 1984).

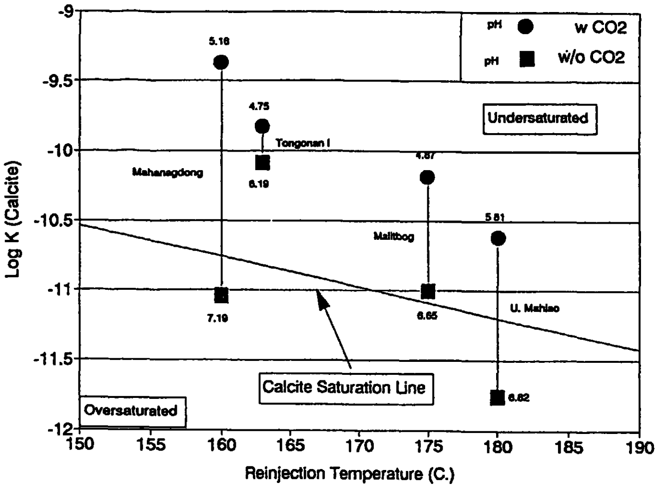
Calcite Saturation Upon Injection of CO2 into Reinjection Brine

Prior to injection of CO2, reinjection brine compositions from all development sectors were calculated to be either close to saturation, or over-saturated with respect to calcite (Figure 6.). Upon injection of CO2 into the brines, all compositions then showed a significant drop in pH of 1 to 2 units, becoming distinctly under-saturated with respect to calcite. The decline in pH is due to the solution of CO2 as carbonic acid H2CO3 which favours formation of the CaHCO3+ ion pair, reducing the availability of aqueous Ca2+ and thus the degree of calcite saturation.

It is thus concluded that at the levels of CO2 proposed here for "wet" reinjection for the Leyte-A power plants, the reinjection brine pH will decline by 1 to 2 pH units after solution of CO2 and there should be no immediate concern with calcite deposition around the reinjection wellbore. There are in fact several benefits that would be realized; the brine would be less susceptible to calcite deposition after CO2 injection, and the reduction in pH of the brine would improve markedly the "injectability" of the brine due to reducing the rate at which silica polymerizes and subsequently deposits from silica saturated brines (see Figure 7, and Hirowatari & Yamauchi, 1990).

Changes in Calcite Saturation With Distance From Reinjection Well

In spite of the above, it is not expected that the pH of the CO2 rich brine will remain low in the reservoir because of water/ rock reactions which will progressively remove H+ from solution thus increasing pH and calcite saturation, and increasing reservoir temperature as the brine moves away from the reinjection well.



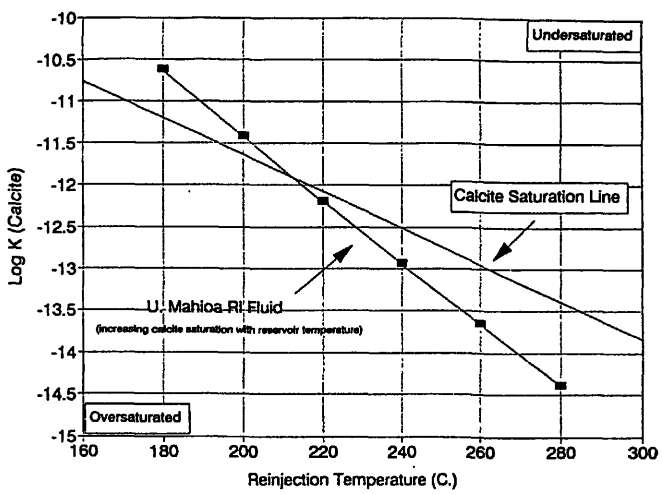


Figure 6 *Calculated calcite saturations for injection brines from each Leyte-A development sector, without and with injection of CO2 up to solubility limit.*

Figure 7 *Rates of polymerization of SiO2 in injection brines as a function of pH (from Brown and McDowell, 1983)*

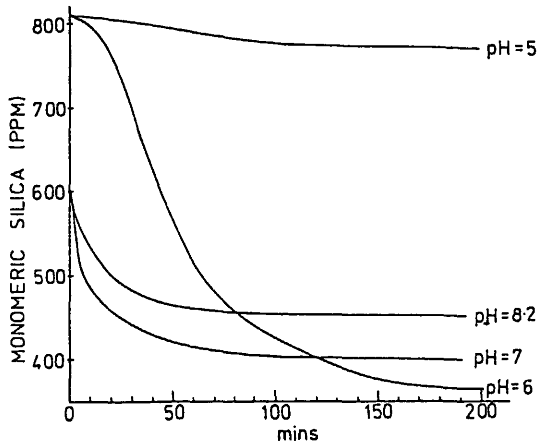


Figure 8 *Increase in calcite saturation in reinjected brine with reheating in reservoir*

An example of the effect of increasing reservoir temperature on calcite saturation is shown in Figure 8 for Upper Mahiao brine reinjected at 180 C. The brine becomes saturated after reheating to 215 C and can thus be expected to progressively deposit calcite as temperature further increases.

Whether calcite deposition in the reservoir volume contained between the injection sinks and production sectors will be damaging to future reservoir performance is debatable. PNOC experience todate at both the Tongonan I and Palinpinon I geothermal fields indicates that in spite of extensive deposition of silica which must be occurring in the reservoir between injection and production wells that interfere strongly, there is no reservoir damage observable.

In contrast to silica deposition in reinjection sinks involving the loss of several hundreds of mg/kg of silica from solution, the amount of calcite that can theoretically deposit in the reservoir after CO2 injection is in the order of tens of mg/kg. It is thus not expected that deposition of calcite will be a serious concern to reservoir performance or to surface operations, providing "fast track" returns from reinjection to production wells are avoided, thus allowing for re-equilibration and deposition of excess calcium bicarbonate in the reservoir volume contained between.

FUTURE PROGRAMME

PNOC is currently giving detailed consideration to including CO2 emission mitigation measures in the design of the Leyte-A geothermal power projects. Although the impact of CO2 emissions from Leyte-A on the global atmosphere will be small, PNOC, nonetheless, views the following as important factors in favour of adopting mitigation measures:

- represents a contribution from the Philippines toward international efforts to reduce global CO2 emissions
- enhances the "bankability" of the Leyte-A power project due to improved environmental "friendliness"
- provides immediate benefits to PNOC production operations with reduced deposition potential of silica in reinjection brines
- provides the opportunity for commercial recovery of CO2 for industrial use
- provides additional incentives for extending existing PNOC watershed management programmes in the Leyte geothermal reservation, with the specific objectives of both preserving the limited forest cover remaining in the Leyte geothermal reservation and increasing it through continued reforestation, social forestry and education programmes.

There remains some uncertainty whether calcite deposition in the reservoir resulting from injection of CO2 will pose a problem. A trial has thus been proposed to "wet" inject all CO2 from the existing Tongonan I power plant. The objectives with this trial are to:

- gain operating experience injecting CO2
- establish the technical viability of CO2 injection in a reservoir sector which is well understood after 10 years of production.
- reduce the high rate of capacity declines presently observed in Tongonan I reinjection wells caused by high silica supersaturations from high temperature production from the upflow area of the field.(see Malate, 1992, this Proceedings)

Providing the results of this trial prove satisfactory it is likely that PNOC will commit to the "wet" injection of approximately 50% of the CO2 flux from the Leyte-A power plants, with the balance vented to atmosphere, and extend water shed management programmes to ensure the continued availability of an adequate biological sink for CO2 within the forests in the Leyte geothermal reservation.

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