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MATERIAL PROBLEMS OF GEOTHERMAL POWER PLANTS: A PHILIPPINE EXPERIENCE

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ABSTRACT

Material problems, such as scaling, corrosion, sludge deposition, microbiological fouling and algal formation, affect the equipment and power generation or geothermal power plants in the Philippines. Higher operational expenses are incurred to prevent or check their occurrences, through cooling water treatment chemicals, plant rehabilitation and other preventive maintenance works.

This research study deals with probable causes of those material problems and researches on methods/measures to solve or lessen their occurrence. It also deals with case studies on lime treatment program, steam washing program and other issues of geothermal operation, such as sludge disposal, steam supply and quality.

INTRODUCTION

Geothermal steam is the most viable energy source in the Philippines based on separate studies made by the World Bank and an Italian energy consulting firm on the Philippine energy potential. The Philippine geothermal energy reserve, is estimated to excaed 8,000 MW. Of the 4,431 MW probable reserve, 1,640 MW have been tested and only 894 MW or less than 21% have been harnessed. This means that geothermal energy, which has a resource potential equivalent to 2 billion barrels of oil per year can more than adequately cover the equivalent 263 million barrels of oil energy requirement of the Philippines by the year 2000.

Geothermal development is very promising in the Philippines since the country happens to be situated in an area called the circum-Pacific "Ring of Fire". Within this "ring" are numerous dormant and active volcanoes whose subsurfaces smolder with intense geothermal heat. Because of the extensive vulcanism in the country and the presence of major faults traversing most of the major islands, the presence of thermal areas of varying magnitudes and intensities is expected, thus providing the right locale for the presence of worthwhile geothermal yossibilities.

OPERATIONS OF NPC GEOTHERMAL POWER PLANTS : EXISTING SYSTEM

The National Power Corporation (NPC) of the Philippines produces bulk electric power from operation of four (4) major geothermal power plants in Tiwi, Mak-Ban, Leyte (Tongonan), and Southern Negros (Palinpinon). Based on the 1988 NPC Annual Report, these plants contribute 894 MW (or 15%) to the installed plant capacity of 5,782 MW in the country.

At present, NPC geothermal power plants use the open recirculating cooling water system wherein water is continuously reused. Since the cooling tower is exposed to the atmosphere, make-up water must be added to replace the water being evaporated from the tower, aside from water lost through leaks and intentionally discharged (by blowdown) to maintain an acceptable level of salinity or alkalinity in the recirculating water.

The salient basic operations of NPC geothermal power plants are described below. From a well drilled tapping underground reservoir, hot water and steam pass through an elaborate system of valves and pipes. Through separators, steam is separated from hot water. Impurities like mud are also separated and discharged along with hot water into the disposal canals. Some of the excess hot water are reinjected back to reservoirs. The resulting mechanical energy drives a generator, which produces electric power. Electricity is stepped up by a transformer several times and then transmitted to a substation for distribution to franchise holders (electric power retailers). From the turbine, the steam goes to the condenser where it is blended and cooled by the cooling water and where the condensable gases are discharged through the ejector or gas compressor into the atmosphere.

Condensation of steam and the action of the ejector create a vacuum in the condenser which draws water from the cooling tower basin through the main cooling pipeline. The condensed water is collected in the hot well from which it is pumped up to the cooling tower.

The condensed water, which has been cooled in this tower. is collected in the cold water basin where the cooling water to the condenser, the oil cooler, the generator and exciter coolers and other auxiliaries, are taken. Excess water is reinjected back to reservoirs.

Inherent in the geothermal steam are hydrogen sulfide and carbon dioxide gases which constitute 99% of the condensables. The non-condensable gases (NCG's), 1% by weight of steam, are removed by the gas ejector system or scrubbed by the cooling tower fan while others are dissolved by hot water in the cooling tower.

COMMON MATERIAL PROBLEMS OF GEOTHERMAL POWER PLANTS

Water passing through the heat-exchanger equipment of the cooling water system contains and transports material problems. These problems are similar regardless of the size and type of cooling tower used. They vary only in degree depending on the water used, and the type of construction materials that come into contact with the cooling water.

Material problems occur in all water-carrying lines and aystem components that come into contact with the cooling water. These material problems are classified into 1) scales, 2) sludge or fouling deposits, 3) corrosion, 4) microbiological. growths, and 5) turbine nozzle/blade depositions.

Scales are dense coatings of predominantly inorganic materials due to supersaturation of water-soluble minerals. They interfere with heat transfer thereby reducing the efficiency of heat exchangers. Scale formation depends on water temperature, alkalinity or acidity, and amount of scale-forming materials in the cooling water. Typical scales consist of calcium carbonate. calcium sulfate, calcium phosphate, silica. and magnesium silicate.

Sludge or fouling deposits are formed by suspended solids in the circulating water and accumulated materials in the heat-exchanger surfaces. They are also caused by corrosion products and the by-products of reaction between inhibitors and process contaminants. Sludge foulants occur naturally or are produced artificially. They are either present in the atmosphere. scrubbed from the air in the cooling tower or originate from man-made sources through chemical addition in the system. They decrease the efficiency of heat exchanger through plugging and deterioration of the equipment.

Sludge/fouling deposits occur greatly in geothermal. power plants due to increased use of poor-quality and contaminated water, waste recycling, high water temperatures and heat transfer rates, and system operation for longer periods between cloanings. Their formation is affected by water velocity, temperature, equipment design, poor start-up techniques and plant operation controls. Typical. classes of sludges are lime-soda ash softening sludge, coagulation-softening sludge, and alum-coagulation sludge.

Corrosion causes deterioration and perforation of equipment resulting to lost product, inefficient operation and downtime for equipment maintenance and replacement, and increased production costs. Corrosion varies with chemical composition, temperature and velocity of a geothermal steam: geothermal source, and power cycle chosen, Geothermal brines contain hydrogen ion (pH), chloride. hydrogen sulfide (H_2S), carbon dioxide, ammonia, sulfate, and oxygen which produce significant corrosive effects on metallic components of the plant. The corrosion of metals destroy costly equipment and results in heavy deposition of corrosion products, considerable downtime, and costly production losses.

The amount and rate of corrosion are affected by:

1) Presence of dissolved O_2 which increases electrical conductivity of water through increased electron flow between metal Components and water.

2) Higher amount of dissolved solids resulting in higher conductivity and corrosion rate!.

3) Acidity which increases dissolution rate of base metal and oxide film formation an the metal surfaces.

4) Water velocity which brings O_2 to the metal, carry corrosion products and erode metal surfaces or protective films.

5) Temperature rise of every 25" to 50° up to 160°F which doubles the corrosion rates.

6) Microbial growth which promotes formation of corrosion cells and corrosive by-products of organisms.

Microbiological growths are created by large and microscopic organisms. such as algae, fungi. slime, and bacteria. They grow within a cooling system, coating all pipes and heat-exchanger surfaces. They plug water passages which lead to metal deterioration and cause under deposit corrosion and destruction of lumber materials of the cooling tower. Microbiological fouling occurs either in the heat exchanger and intake discharge canals.

Turbine nozzle/blade depositions are due to the gradual build-up of hard chemical deposits as steam temperature falls with expansion, thereby reducing the output of the turbine and upsetting its dynamic balance.

Blade failure due to resonant vibration results from blade fractures caused by metal fatigue. This is not a specific weakness of turbines, but can be aggravated by the build-up of chemical deposits on the blades and alteration of their natural resonant vibration frequency. Scale depositions on steam parts affect unit efficiency, capacity and reliability. The impact of deposits on turbine performance depends on their thickness, location and surface roughness. A rough, thin layer of deposit can substantially increase friction loss at the steam-flow boundary. If a portion of the deposit. flakes off, leaving an even rougher surface, friction loss increases and efficiency loss may be greater than for the same amount of deposit distributed uniformly. Mechanical hazards of deposit formation are governed entirely by the loss of unit capacity.

CHEMISTRY OF THE GEOTHERMAL ENVIRONMENT

Geothermal water exists either as corrosive or acidic water or slightly alkaline water which deposits protective scales of metal oxides, silica or calcium carbonate. Geothermal steam contains carbon dioxide, hydrogen sulfide, ammonia, traces of boric acid and other minor constituents, which limits the use of certain construction materials in geothermal power plants. Soluble gases, like carbon dioxide and hydrogen sulfide, in the steam cause corrosion of metals and alloys in these plants.

Steam is generated from geothermal hot water by steam generating equipment. e.g. separator and flasher. If these equipment are inefficient, wet steam with impurities will enter the turbine and cause serious troubles. When the steam generating system is operating under overload condition, wet steam with salt and iron impurities will also enter the turbine and cause sufficient damages. Steam impurities entering the turbine cause valve sticking, erosion, corrosion. download with scaling, or stress corrosion cracking of stainless, which are enough serious troubles in the plant.

Turbine manufacturers sat the limits of steam impurities to prevent erosion-corrosion troubles in the plant. Total dissolved solids in the steam should be lower than 5 ppm, chlorides, silica and iron should be lower than 1 ppm, non-condensable gases (less than 3% by weight) and 99.8% dry so as not to cause trouble in the turbine.

OBSERVATIONS

1) Sludge and scale accumulation problems are experienced in the cooling tower basins and turbine blades, respectively, of NPC geothermal power plants. Sludge consists of sulfur and iron oxide which are typical corrosion products of geothermal power plant operation. High concentrations of toxic metals such as arsenic, mercury, boron, lead, chromium, zinc, aluminum, calcium, magnesium, sodium and potassium are also present in the sludge (see Table No. 1). The occurrence of these metals is attributed to high concentration of hydrogen sulfide, increased amount of dissolved solids in the steam condensate, acidic nature of cooling water, and use of proprietary water treatment chemicals. Scales, consisting of silica and iron oxide, are found in the steam pipes, hot wells, condenser and air coolers.

2) Corrosion is prevalent in NPC geothermal power plants due to the highly corrosive cooling water.

3) Microbiological problems rarely occur in the Mak-Ban and Leyte plants due to biocide treatment and acidity of cooling water used which inhibits the growth of microorganisms. Microbiological problems, however, affect the cooling towers of the Tiwi and Southern Negros geothermal power plants. They attack the wooden parts of the tower and usually flourish on the distribution decks or louvers of cooling towers that are in direct contact with sunlight. Temperature and pH of the cooling water are also ideal for microbial growth. The presence of organic and inorganic salts from improper addition of fouling control agents or biocides ensures plenty of nutrients and enhances the favorable environment for microbiological growth (see Table No. 2 for algae analysis).

4) Geothermal brines from NPC geothermal power plants contain metals, non-metals and gases (see Table No. 3). Brines have inherent corrodents which cause corrosion. Chloride. sodium, silica, potassium, calcium, sulfur and other constituents are detected when entering the plant.. These cause the formation of sludge, scales. algae, and corrosive deposits.

5) Turbine deposits consist of iron, silica, sulfur and chloride. Scale carry-over resulting in deposits on steam-parts affects efficiency, capacity, and reliability of the turbine unit. Literature studies revealed that a deposit thickness of only 3 mils (0.003 inch) will decrease stage efficiency by 3 to 4 per cent and reduce flow capability by 1 per cent. The immediate effect of turbine blade deposits are not yet detected in NPC geothermal plants, although, turbine blade failures occurred in Tiwi in 1984 and 1985 due to resonant vibration. It was opined that this trouble

resulted from blade fractures caused by metal fatigue and aggravated by the build-up of chemical deposits on the blades. The turbine deposits also altered the blades' natural resonant vibration frequency causing breakdown and unexpected shutdowns in the plant.

SOLUTIONS TO MATERIAL PROBLEMS OF NPC GEOTHERMAL POWER PLANTS

Annually, NPC spends huge operational costs for different types of water treatment chemicals which have the same target results in all geothermal power plants. Furthermore, proprietary treatment programs are more expensive and corrosive than the baseline water treatment program which uses caustic soda as corrosion inhibitor. Typical costs of water treatment chemicals used in NPC geothermal power plants are shown in Table No. 4. Experiences showed that corrosion inhibitors account for the highest share of water treatment chemicals used in NPC geothermal power plants (see Table No. 5).

1. Corrosion Treatment.

Corrosion can be prevented or minimized by:

a) Corrosion inhibitors which reduce or stop corrosion by interfering with the corrosion mechanism through formation of a thin coating with no affect on heat transfer.

b) Lining the pipelines with polyethylene coating. epoxy coal tar, fiberglass-reinforced plastic (FRP), newflex pipeflex or other anti-corrosion coating materials.

c) Maintenance of pH of cooling water (steam condensate and domestic water) at 6.5 to 7.

d) Continuous blowdown of water flowing into the small orifice of pipeline.

e) Changing the metal parts/equipment.

f) Changing the environment through formation of a protective film of calcium carbonate on the metal surface using the natural calcium and alkalinity in the water.

g) Removal of corrosive oxygen from the water by mechanical or chemical de-aeration.

The most practical and cheapest way of corrosion control is through the formation of a protective film of calcium carbonate on the metal. surface using the natural calcium and alkalinity in the water. A uniform coating of calcium carbonate deposited on the metal surfaces will. physically segregate the metal from the corrosive environment. Theoretically. controlled deposition of calcium carbonate scale can provide a film thick enough to interfere with the corrosion mechanism, yet thin enough to affect heat transfer.

This is done through lime treatment, method which raises the calcium content, alkalinity. and pH of the cooling water system at a cheaper price than caustic soda. Lime treatment program was conducted in NPC geothermal power plants and results are encouraging and promising due to the substantial decrease in water treatment costs without sacrificing the operation of the plant as a whole. (see Table No. 6). The savings derived during the lime treatment program is approximately 75% of the actual costs of proprietary chemicals already in operation. Corrosion rates during the lime treatment program are also generally comparable or better than those using other treatment chemicals. Projected savings to he generated by NPC geothermal power planta during lime treatment program are shown in Table No. 7.

2. Treatment of Fouling/Sludge Deposit Problems

a) Dispersants can be used to break up the foulants into smaller particles and keep them suspended in the cooling water. They also prevent deposit formation and enable foulant removal from the system via blowdown and filtration.

b) Clarifiers and other solid separators reduce the amounts of suspended solids, debris, and dissolved minerals and organics in make-up water, thereby mechanically removing the foulants.

c) Fine filtering or sidestream filtration removes substantial concentrations of foulants from the entire recirculating water loop regardless of the water source. A 1% to 5% passing of the circulating water through a suitable filter can be very effective in keeping lower suspended solid levels. Cloth filters or screens at the cooling tower air intakes can reduce airborne contamination.

d) Foulants can be removed by injection of small rubber balls into and through heat-exchanger tubes during plant operation. These balls wipe the tubes clean as they pass through and repeat the scouring action on the tube surfaces. Highly abrasive coated balls can be used for very hard deposits but not with soft alloys. The process can be performed continuously or at periodic intervals, as needed.

e) Plant systems can also use plugs or brushes in plastic holders for scouring of steam pipes. Condenser water flow pushes the plugs through the tubes to wipe deposits from the heat-transfer surfaces. Reversing the water flow repeats the cleaning action.

3. Microbiological/Algal Treatment

Frequent blowdown controls microbiological growths, although this is not practical when expensive chemicals are used during treatment. Alternate microbiocides, therefore, are needed to inhibit the growth of microorganisms by altering the permeability of microbe cell walls and interfering with vital life processes. Microbiological plate counts should also be done at least twice per month to check the effectiveness of biocides and to optimize the concentration and frequency of feeding.

In the lime treatment program, calcium hypochlorite (70% chlorine), a compatible biocide to lime and caustic soda, , is regularly dosed during high incidence of microbiological/algal growths in the louvers and wood supports of the cooling tower. Whenever calcium hypochlorite is not sufficient to control microbiological growths in the system, an alternate microbiocide is used to supplement chlorine to prevent immunity from the existing microorganism.

4. Installation of Steam Scrubbers

Sludge accumulation problems can be lessened/remedied through installation of steam scrubbers in the steam supply system. In the absence of scrubbers, the pipelines serve as the scrubber itself as the steam is transported from the wells to the plant. In wet fields, however, separation of steam from water is imperfect if the bores are near the generating plant. With the smaller distance, the scrubbing effect of pipelines is lessened, and traces of solubles reach the turbine. A steam scrubber ensures a good and clean supply of steam to tha plant, but it cannot fully eliminate the non-condensable gases, impurities and other factors contributing to sludge formation. Usually, the Installation of a steam scrubber entails high investment cost.

5. Sludge Disposal

Toxic components of cooling tower sludge, e.g. As, Hg, Cr, Fe, Zn, can be insolubilized by mixing the sludge with suitable proportion of Portland cemant to fix heavy metals and precipitate the heavy metal hydroxides, substituted and adsorbed into cement hydrates. Leachate tests indicate that. the optimum dosage for fixation is 1 part cement to 3 parts sludge. This is based on the concentrations of metals leached as compared to pollution regulation and integrity of cement block. At the recommended treatment ratio of 1:3, cement cost is approximately $ 200 for every 4.2 cubic meters (20 drums) of sludge processed.

Proper disposal of sludge is done by:

a) Manual removal from cooling tower basins into suitable containers such as drums for easy hauling to a disposal pond. The pond has to be adequately located and designed to prevent any potential danger to the people, the river systems and adjacent lands for agricultural production.

b) Treatment with cement to fix hazardous pollutants present in the sludge and filling into a concrete-lined pond. The use of concrete liner is another safeguard employed to impede the exfiltration or hazardous substances.

c) Pond maintenance to include covering with plastic material when not in use; and concrete capping of the pond with appropriate thickness when it is already full.

6. Steam Washing Program

Italian Experience

Since 1959, ENEL-Italy has been successfully implementing a turbine descalinp program for lowering corrosion/scaling rates and decreasing incidences of turbine blade breakdowns and plant shutdowns in its geothermal power plants. These plants flush out the aggressive steam corrodents through spaced injection/spraying of an alkaline solution of water and caustic soda in the steam header. This is dons about 50 meters before the axial separator/interface scrubber or more preferably at the steam jet well head.

Philippine Experience

PGI (NPC Steam Supplier) is also implementing its own steam washing program in Tiwi and Mak-ban to prevent scale build-up and corrosion in steam turbines. This is done through space injection of water downstream of the NPC/PGI interface scrubber. Initial results show that the program is promising, whereby savings and increased generation are being realized.

OTHER TOPICS

1) Researches showed that dewatered sludge consisting of 6% to 35% solids has a heating value of 3,000 to 10,000 BTU per lb. Sludge can be used for landfilling, disposed in the ocean or incinerated with high premium-fuel consumption and energy recovery. Sludge combustion can be integrated with other solid-waste combustion facilities, sludge digestion can recover methane gas for use in gas turbine and engines, and can be combined with other waste minerals to form alternate fuels.

2) For scale deposition on turbine blades, titanium shrouds with stellite brazings should be installed in the stapes of turbine blades that are usually affected.

3) In Japan, sludge from geothermal power plants are synthesized into zeolite under mild hydrothermal conditions, through addition of aluminum ions and/or using different types of sludge. Sludge are converted into zeolites by changing the molar ratios of starting materials and using proper organic ammonium ions. The prepared zeolites are used for petroleum purification (Sato, et. al, 1984).

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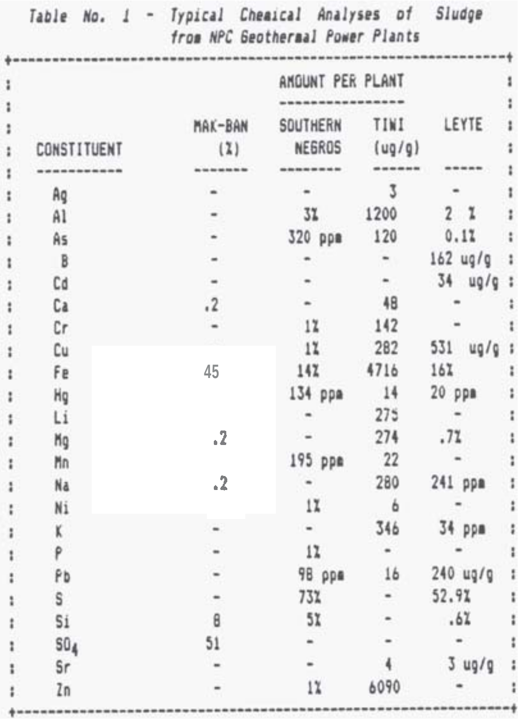

Table No. 1 - Typical Chemical Analyses of Sludge from NPC Geothermal Power Plants

	AMOUNT PER PLANT			
CONSTITUENT	MAK-BAN (%)	SOUTHERN NEGROS	TIWI (ug/g)	LEYTE
Ag	-	-	3	-
Al	-	3%	1200	2 %
As	-	320 ppm	120	0.1%
B	-	-	-	162 ug/g
Cd	-	-	-	34 ug/g
Ca	.2	-	48	-
Cr	-	1%	142	-
Cu		1%	282	531 ug/g
Fe	45	14%	4716	16%
Hg		134 ppm	14	20 ppm
Li		-	275	-
Mg	.2	-	274	.7%
Mn		195 ppm	22	-
Na	.2	-	280	241 ppm
Ni		1%	6	-
K	-	-	346	34 ppm
P	-	1%	-	-
Pb	-	98 ppm	16	240 ug/g
S	-	73%	-	52.9%
Si	8	5%	-	.6%
SO_4	51	-	-	-
Sr	-	-	4	3 ug/g
Zn	-	1%	6090	-

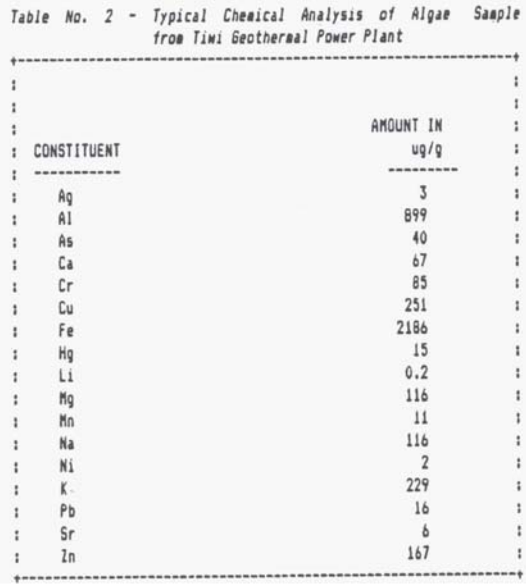

Table No. 2 - Typical Chemical Analysis of Algae Sample from Tiwi Geothermal Power Plant

CONSTITUENT	AMOUNT IN ug/g
Ag	3
Al	899
As	40
Ca	67
Cr	85
Cu	251
Fe	2186
Hg	15
Li	0.2
Mg	116
Mn	11
Na	116
Ni	2
K	229
Pb	16
Sr	6
Zn	167

Table No. 3 - Typical Chemical Analyses of Brine Discharge from NPC Geothermal Power Plants

	AMOUNT PER PLANT			
CONSTITUENT	MAK-BAN (mg/l)	LEYTE (mg/kg)	SOUTHERN NEGROS (ppm)	TIWI (mg/l)
As	-	5	5	-
B	-	220	69	70
Cd	-	-	.04	-
Ca	25	207	90	70
Cr	-	-	-	-
Cu	-	-	.06	-
Fe	-	.1	.2	-
Hg	-	-	nil	-
Li	-	27	15	-
Mg	-	.3	.2	.6
Mn	-	.3	.1	-
Na	1660	6656	3090	2383
K	346	1683	655	494
SiO_2	641	801	.8	482
SO_4	16	21	48	55
Zn	-	-	.04	-
Rb	-	9	5	-
Cs	-	3	3	-
Cl	2843	12410	5792	3870
F	-	.9	-	-
CO_2	-	8	-	-
H_2S	-	6	-	-
HCO_3	-	-	43	54

Table No. 4 - Costs of Water Treatment Chemicals Used in NPC Geothermal Power Plants (1985 Annual Costs, $ 1.00 = ₱ 21.00)

PLANT	TOTAL COST ($MILLION)	GROSS GENERATION (GWH)	COST PER MWH GENERATION ($/MWH)
TIWI	.557	1,827.5	0.30
MAK-BAN	.514	2,061.4	0.25
LEYTE	.152	425.7	0.36
SOUTHERN NEGROS	.200	232.1	0.86
TOTAL	1.423	4,591.7	0.31

Table No. 5 - Typical Costs of Water Treatment Chemicals Used in NPC Geothermal Power Plant (1985 Annual Costs)

CHEMICALS	COST ($M)	% OF TOTAL COST	COST PER KWH GENERATION ($/KWH)
Caustic Soda	.051	33.4	.1198
Corrosion Inhibitors	.063	41.3	.1480
Biocides	.027	17.4	.0634
Dispersants	.012	7.9	.0282
TOTAL	.153	100.0	.3594

GROSS GENERATION OF LEYTE PLANT (1985) = 425.7 GWH

Table No. 6 - Results of Trial Lime Treatment Programs and Previous Proprietary Chemical Treatment Programs in NPC Geothermal Power Plants

	PLANT		
PARTICULARS	LEYTE	SOUTHERN NEGROS	MAK-BAN
Treatment Period (Months)	3	3	A
Plant Capacity (MW)	37.5	37.5	55
Treatment Costs ($)			
Lime	664.17	340.17	7,583.11
Proprietary Chemicals	4,295.68	5,513.62	27,211.3
SAVINGS	3,631.51	5,172.91	19,628.10
%	84.54	93.82	72.13
Corrosion Rate (Mils per year)			
Lime	20.88	21.51	39.7
Proprietary Chemicals	52.50	37.82	15.6
ABSOLUTE INCREASE (DECREASE)	(31.62)	(16.32)	24.1
%	(60.23)	(43.15)	154.5

Table No. 7 - Projected Savings for Lime Treatment Program in NPC Geothermal Power Plants

PLANT	AVERAGE MONTHLY COST OF PROPRIETARY CHEMICALS ($M)	AVERAGE MONTHLY COST OF LIME TREATMENT ($M)	MONTHLY SAVINGS TO BE DERIVED ($M)
Mak-Ban	.163	.045	.118 or 72.39%
Leyte	,013	,002	.011 or 84,622
Negros	.017	,001	.016 or 94,122
T O T A L	.193	.048	.145 or 75.13%

ANNUAL SAVINGS OF NPC (WITHOUT TIWI) = $ 1.74 Million