PREDICTING FCDS AND POWER PLANT CHEMISTRY OF THE DIFFERENT POWER PLANTS IN THE LEYTE GEOTHERMAL POWER PROJECT

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Abstract

Two new power plants were installed in Malitbog and Upper Mahiao sectors of Leyte Geothermal Power Project in 1996. Three more will be commissioned in Mahanagdong A & B and South Sambaloran sectors in 1997 bringing the total power output of the entire field to about 650 MWe. These forthcoming operations entail massive extraction of fluids which, consequently, will generate waste brines and condensates. It is therefore, essential to predict the chemistry of the fluids from each power plant and fluid collection and disposal system (FCDS) prior to commercial operation in order to formulate field-wide management schemes.

Each FCDS and power plants has exclusive features. Upper Mahiao's Ormat power plant utilizes a geothermal combined cycle unit (GCCU) consisting of a back pressure turbine and binary cycle units (OECs). This will be supplied with steam from a single-stage flash FCDS at 1.2 MPa separation pressure. Malitbog and South Sambaloran power plants have an integrated bottoming cycle plant, while Mahanagdong A & B power plant include a topping cycle plant upstream of their respective condensing turbines. Mahanagdong will utilize two-stage flash FCDS. The first flashing happens at 1.2 MPa which will run the topping cycle plant at 1.2 MPa. The brines will be flashed further at 0.7 MPa to supply the low pressure condensing turbines together with the topping cycle exhaust steam.

All the physical and chemical data used in the simulation process were taken from the results of the medium-term discharge (MTD) testing of all production wells. The table below summarizes the results of the simulation:

SECTOR	***NCG % (w/w)***	***SSI***	Cl_{BRINE} ***, (mg/kg)***	B_{STEAM} ***, (mg/kg)***
Mahanagdong-A	*2.33*	*1.05*	*3628*	*0.29*
Malitbog	*0.85*	*1.19*	*8826*	*2.4*
Upper Mahiao	*0.95*	*0.89*	*7700*	*5.1*

1.0 INTRODUCTION

The Leyte Geothermal Power Project (LGPP) of the Philippine National Oil Company-Energy Development Corporation (PNOC-EDC) covers the two geothermal systems of Tongonan and Mahanagdong in the north-central Leyte island (**Fig.** 1) within the Ormoc City and Kananga town. It has six major on-going power development projects. The Upper Mahiao sector (125 MWe) and the Malitbog Sector (77.5 MWe) are intended to supply part of the 200 MWe Leyte-Cebu Power Interconnection.. The South Sambaloran sector will supply 155 MWe while the Mahanagdong A and B will generate about 120 MWe and 60 MWe, respectively, to complete the 400 MWe requirement for the Leyte-Luzon Power Interconnection.

Since the geothermal system of Tongonan and Mahanagdong are both liquiddominated, the generation of steam in the Fluid Collection and Disposal System (FCDS) is attained by flashing either at 1.2 MPa or 0.7 MPa or both depending on the type of FCDS. Due to the pressure and temperature drop and consequently the separation of steam and water, the chemistry of the fluids also changes. This paper presents the summary of power plant scheme, FCDS scheme, and results of the simulation of the three FCDS in Upper Mahiao, Malitbog, and Mahanagdong-A. The results of the study are intended to be the basis of the future field-wide management schemes.

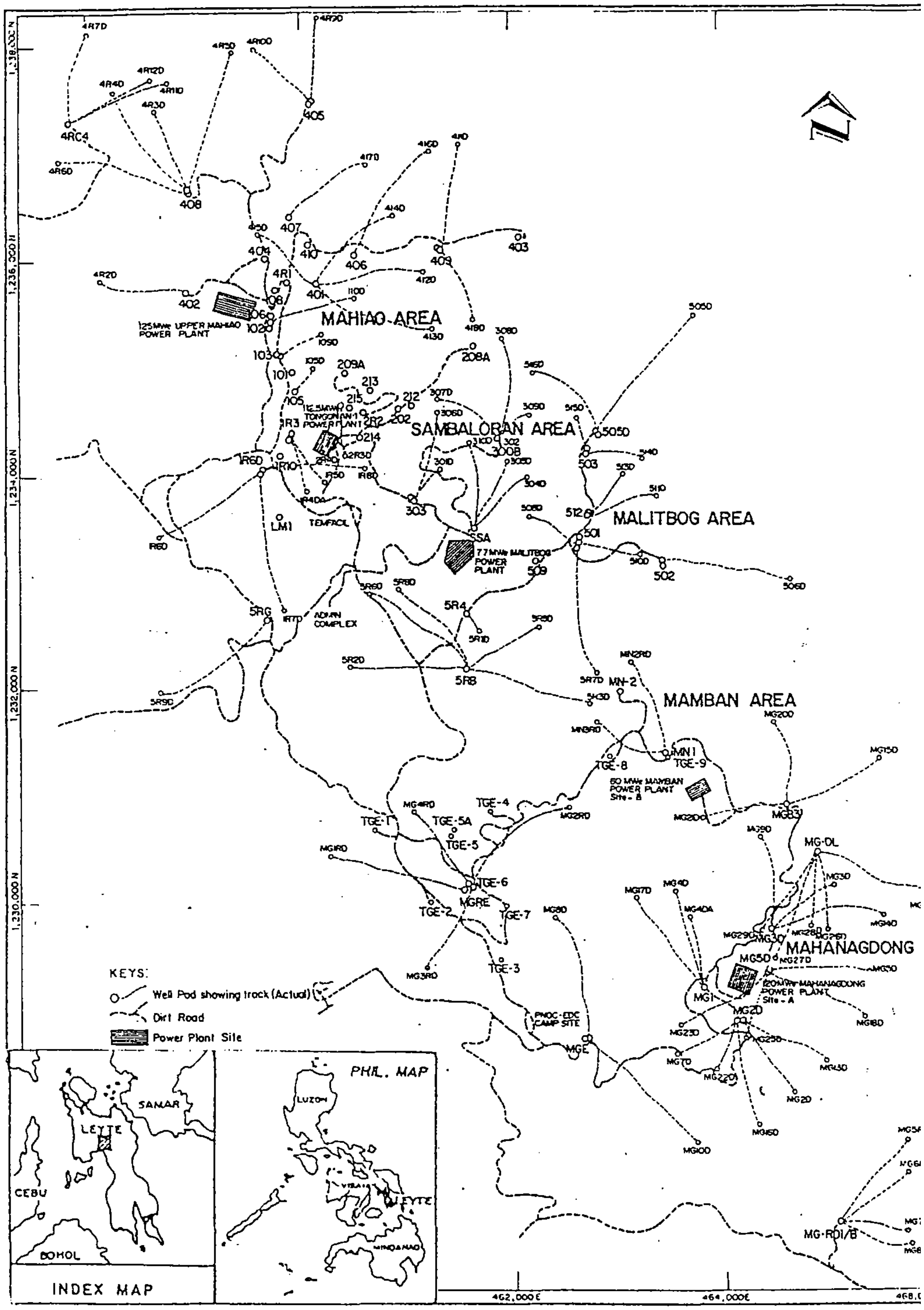


Figure 1: Location Map of Greater Tongonan Geothermal Field

2.0 METHODOLOGY

The basic assumptions used in carrying out the calculations of the fluid chemistry along the three FCDS are: (a) steady-state occurs in any stream point in order to apply a simple mass balance across a system; (b) two or more streams combining always result to a fully mixed system having a chemistry represented by the weighted contributions from each stream; (c) a system dividing into two or more streams will have an identical chemistry with that of its parent stream (i.e. no preferential flow occurs); and (d) all processes occur adiabatically (no or minimal heat loss to the environment).

The simulations are based on the representative discharge chemistry of the production wells utilized by the three FCDS. Chemistries of these wells at varying wellhead pressure (WHP) were characterized during their medium-term discharge (MTD). Five chemical parameters, namely, CO_2 and H_2S (for NCG determination), SiO_2 and Cl (for SSI evaluation), and Boron were plotted against the prevailing WHP during discharge. Regression lines were fitted in the plots to generate an approximated behavior of the chemical parameter against WHP. At the recommended operating wellhead pressure (OWHP), the representative chemistry for each well was interpolated from these regression lines.

The distribution of the more soluble gases like CO_2 and H_2S between liquid and vapour is expressed by the gas coefficient B, defined as:

$$B = Cgas_v / Cgas_l \qquad \text{Eqn. 1}$$

where $Cgas_v$ is the concentration of the gas in the vapour **phase** and $Cgas_l$ is the concentration of the gas in the liquid phase. Basing on gas solubility **data,** Giggenbach (1980) evaluated gas coefficients for a temperature range **and** derived the following regression **equations** for CO_2 and H_2S valid from **100** to **340°C:**

$$\log B_{CO2} = 4.7593 - 0.01092{*}t \qquad \text{Eqn. 2}$$
$$\log B_{H2S} = 4.0547 - 0.00982{*}t \qquad \text{Eqn. 3.}$$

where *t* is in "C. At high pressure separation, where the **operating** temperature is **188°C**, the gas coefficients for CO_2 and H_2S calculated from Eqns. 2 and **3** are **508.56** and 162.34, respectively. These values indicate that 0.20% of CO_2 and **0.61%** of H_2S are retained in the remaining liquid. It **is,** therefore, valid to assume that at this separation temperature **(188°C)**, all *gas* components partition into the vapour phase and that negligible amounts are retained in the remaining liquid.

Boron is more resident in the liquid phase **of** geothermal two-phase fluids. However, during separation of the steam, Boron partitions between the vapour and liquid phases. Incorporating previous works of other authors, Glover in 1988 **derived** the following equation relating the distribution **of** Boron into the liquid and vapour phases directly to temperature, applicable over the range **150** to 320°C:

$$1/K_D = 10^{[3.0506 - 0.00669{*}t]} \qquad \text{Eqn. 4}$$

where t is in °C and $K_D = B_v / B_l$ is the partitioning coefficient **of** Boron, *equal* to the ratio of the concentration of Boron in vapour and liquid phases. In these simulations, application of the Glover simplified equation for K_D (Eqn. 4) was limited to the high and low pressure separation processes where the operating temperatures are 188 and **166°C** respectively.

3.0 THE UPPER MAHIAO POWERPLANT

The *steam* for the 125 MWe Upper Mahiao (UM) sector will come from thirteen (13) production wells i.e. 401, 406, 407, 409, 410, 411D, **412D, 413D,** 414D, **415D, 416D, 417D** and **418D**. The waste brines will be reinjected to five *(5)* reinjection wells i.e. 408, **4R3D, 4R4D, 4R5D** and **4R6D**. The FCDS *utilizes* three separator vessels named as **SV-401, SV-402,** and SV-403.

3.1 Upper Mahiao Power Plant Scheme

The Upper Mahiao power plant is **of** Ormat hybrid-binary type whch utilizes four (4) geothermal combined cycle units (GCCU). Each GCCU consists of one **(1)** 20.3 MWe back-pressure steam turbine, and three **(3)** 3.84 MWe Ormat Energy Converters (OEC) with iso-pentane as the motive **fluid.** The power plant (Fig. 2) will operate at a pressure **of 1.1** MPa with a steam rate of **2.26** kg/s-MWe. **A** total of **283 kg/s** steam is needed to run the power plant at a base load of 125 MWe. Around **1.0**%(w/w) or 2.8 **kg/s** of NCG **will** be sent to the H_2S abatement plant **for** treatment. The total condensate produced will be around 270 to **280 kg/s**, and these will be *directed* to the spray tower for cooling prior to its disposal. On the other hand, the total brine produced will be around 258 **kg/s**. This brine and with part **of** the South Sambaloran brine will run the brine OEC power plant which will generate an additional **power of 4.6** MWe.

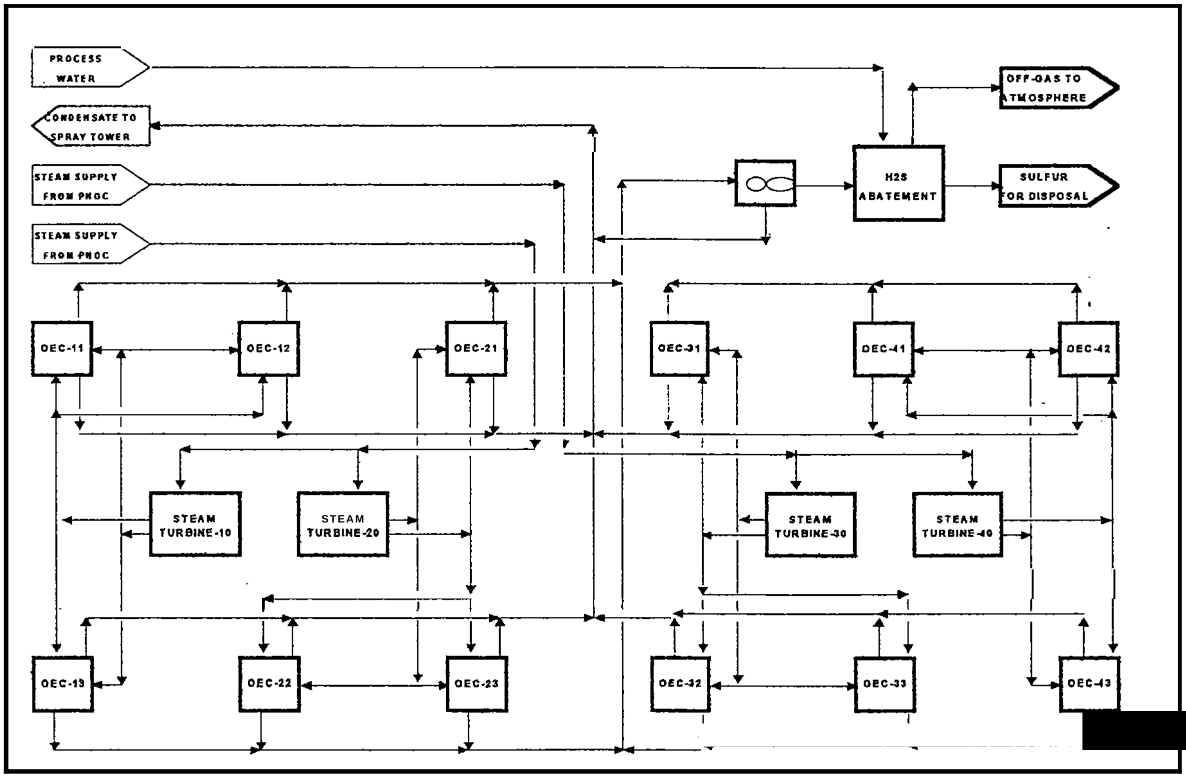


Figure 2: Simplified Process Flow Diagram of the 125 MWe Upper Mahiao Power Plant

3.2 Upper Mahiao FCDS Process Flow Description

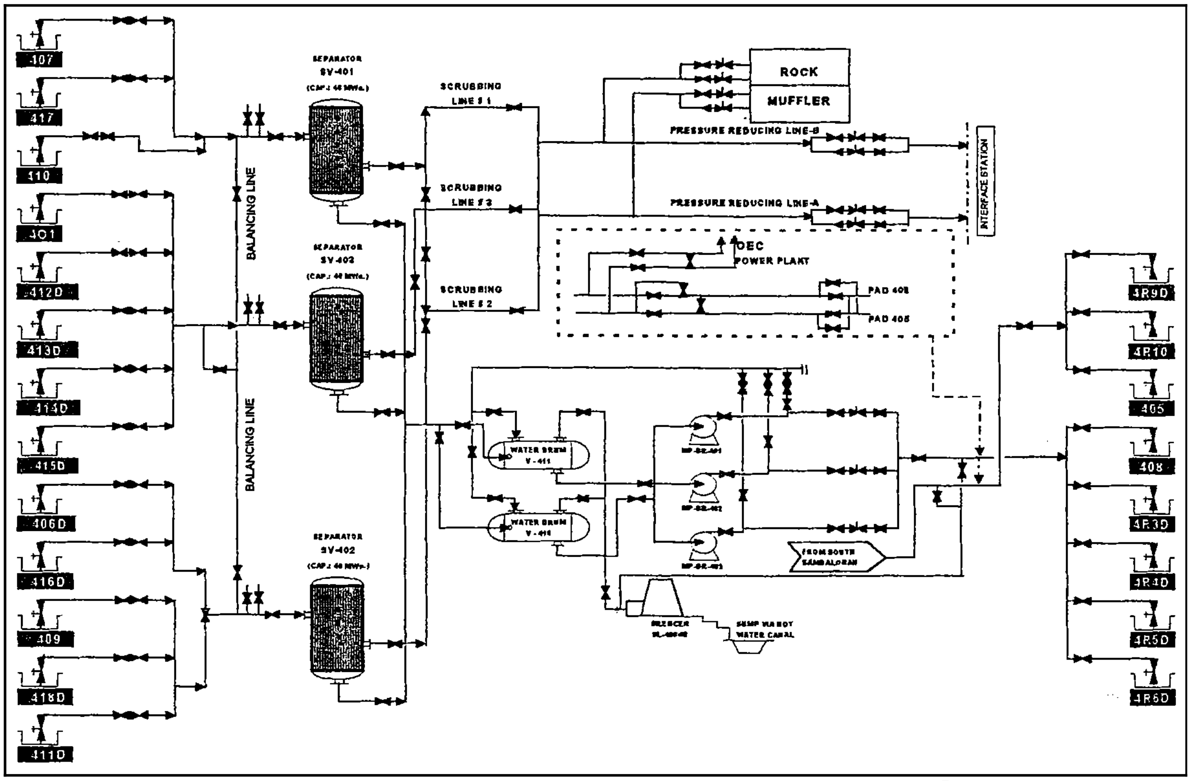
Two-phase fluid separation is carried out in the three (3) separator vessels operated at 1.2 MPa (Fig. 3). Each vessel has a designed capacity of 40 MWe. The steam from the three separators will pass through individual scrubbing line. After combining in a header, the steam will be sent to the power plant via a two pressure-controlled line. The brine from the three separators will be collected at the two water drums to provide a constant head for the brine pump. This brine will be added with part of the brine from South Sambaloran and will be pumped to pads 408 and 405, after passing through the brine OEC where fluid temperature will be dropped by 20°C as a result of the heat exchange process at the OEC prior to reinjection.

3.3 Results of the Chemical Simulations

Table 1 shows the results of the chemical simulation. The NCG level of the steam supplied to the power plant interface at 125 MWe (283 kg/s) plant load is 0.95% w/w. This will have a boron in steam of around 5.10 mgkg and % H_2S of 4.53% of the dry gas. The combined brine SSI at the brine line prior to the brine OEC plant is estimated to be at 0.89. After passing through the brine OEC heat exchanger with the South Sambaloran fluids (SSI = 0.84), the 20°C temperature drop (188°C-168°C) will elevate the SSI to 1.06.

	SV-401	SV-402	SV-403	Power Plant Interface	Upper Mahiao Brine	South Sambaloran Brine	Post-OEC Brine
SF (kg/s)	61.3	106.3	115.1	282.8	-	-	-
WF (kg/s)	70.3	123.8	63.7	-	257.8	95	350
NCG(% w/w)	1.49	0.99	0.63	0.95	-	-	-
SSI	0.92	0.77	1.06	-	0.89	0.84	1.06
Cl Brine (mg/kg)	10578	7028	5600	-	7700	8300	7866
B_{steam} (mg/kg)	4.65	3.43	7.62	5.10	-	-	-
MWe	27.14	47.06	50.94	125			

Table 1: Summary of Upper Mahiao FCDS Chemistry Simulation



igure 3: Process Flow Diagram of the Upper Mahiao Fluid Collection and Disposal System

4.0 MALITBOG-SAMBALORAN POWER PLANT

The Malitbog-Sambaloran Power Development is intended to supply 77.5MWe of electricity in addition to the 125 MWe from Upper Mahiao for the 200 MWe Leyte-Cebu interconnection and 155 MWe of the 400 MWe Leyte-Luzon interconnection. The Malitbog FCDS will utilize nine production wells namely, 501, 508D, 510D, and 511D supplying separator station SS51 and 503, 509, 514D, 515D, and 513D supplying separator station SS52. Reinjection of waste brine in the FCDS will utilize seven reinjection wells namely, 5R1D, 5R3D, 5R4, 5R5D, 5R6D, 5R7D, and 5R8D.

4.1 Malitbog-Sambaloran Power Plant Scheme

Shown in Figure 4 is the simplified process flow diagram for the generation of the first 77.5MWe in the power plant. The thin lines represent the flow of steam going to the power plant, the thick lines represent the flow of circulating waters and the broken lines indicate the flow of non-condensable gases (NCG) and water loss evaporated dunng water circulation process, condensation and separation of NCG. The steam at the interface is scrubbed off at the steam scrubber to remove the superheat prior entry to the turbine. The exhaust steam from the turbine goes to the condenser for condensation and cooling.

The method of steam condensation is a direct contact condensation similar to the existing power plant in Tongonan. Condensation of steam is attained by allowing contact of cooling water to steam by spraying inside the condenser. The liquid temperature at this stage is 45.55°C and the pressure in the condenser is vacuum at 0.12 kscg. Furthermore, the mixed water in the condenser is pumped to the cooling tower to decrease the water temperature to 25.50°C. During the cooling process, part of the fluid is evaporated to atmosphere and the excess fluid will be disposed of. The cooling tower cools the fluid coming from the condenser and at the same time continuously supplies coolant to the condenser and to the gas removal systems. The Gas Removal Systems (GRS) of the power plant consists of three, 3-stage steam-jet ejectors and intercondensers. It is used for the efficient separation of non-condensable gases before they are sent to the H_2S abatement system for H_2S gas removal.

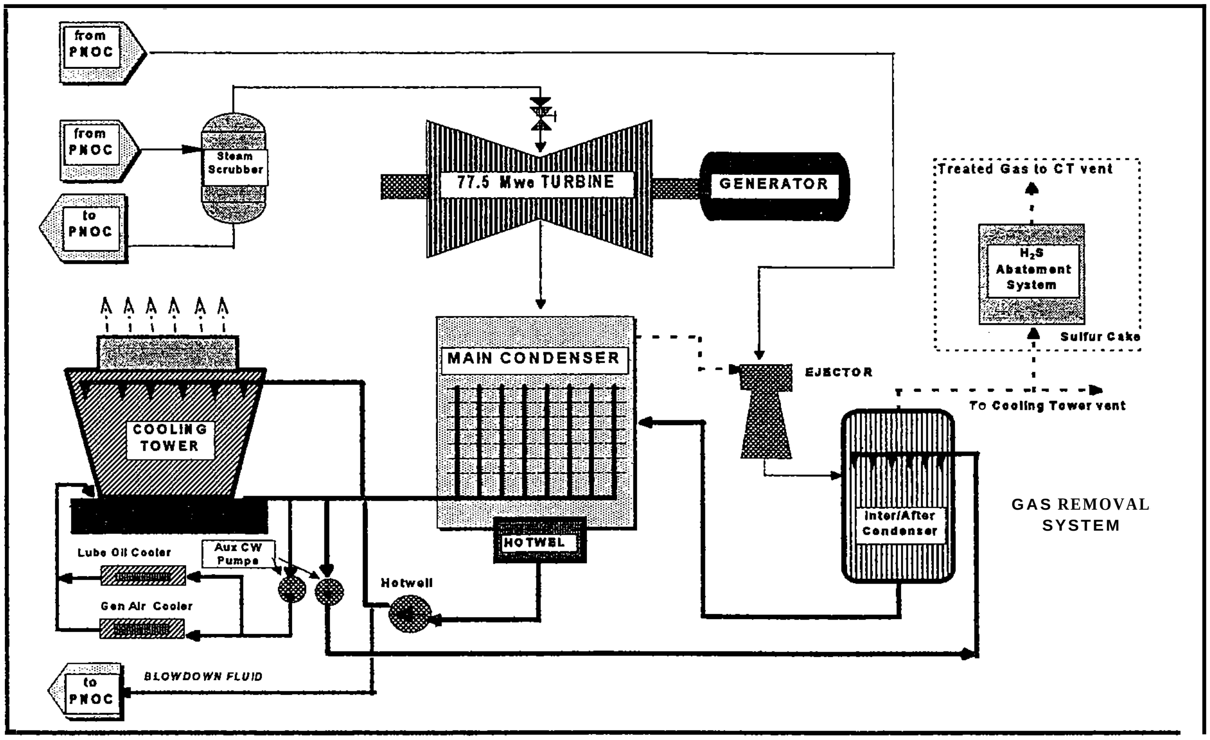


Figure 4. Simplified Process Flow Diagram of the 77.5MWe Power Generation

For the generation of 77.5 MWe, about 507,933 kg/h of *steam* with 1.15%(w/w) NCG is supplied to the turbine and about 20,500 kg/h of *steam* is supplied to the ejector in the gas removal system for the efficient separation of NCG. During cooling about 470,249 kg/h is evaporated to the atmosphere at the ideal conditions of 50% relative humidity and wet bulb temp of 25.5 °C. The estimated rate of blowdown fluid from the power plant at the above condition is about 51,600 kg/h.

4.2 Malitbog FCDS Process Scheme

To optimize the *steam* generation in Malitbog, double-stage flashing will be installed for the main plant and the bottoming plant (Fig. 5). Four separator vessels will be operated, two at the first flashing of 1.2 MPa (i.e. SV-501 and SV-502) and another two at the second flashing of 0.7 MPa (i.e. FV-511 and FV-512). Upon flashing at 1.2 MPa, the generated *steam* from two separator vessels is about 161.5 kg/s. At a *steam* rate of 1.91kg/s-MWe, it is equivalent to 84.5 MWe. The generated *steam* from SV-501 and SV-502 are combined to supply the first 77.5 MWe turbine of the Malitbog power plant. The separated brine from SV-501 and SV-502 is further flashed at separator vessels FV-511 and FV-512, respectively, at a pressure of 0.7 MPa. The generated steam at this stage is approximately 26 kg/s or equivalent to 11MWe at a *steam* rate of 2.26 kg/s-We. The waste brine of about 497.5 kg/s from vessels FV-511 and FV-512 will be injected to seven reinjection wells in the FCDS.

4.3 Results of Chemical Simulation

Summarized in Table 2 are the results of the chemical simulation in the interface and at the major stream points in the Malitbog FCDS. The NCG levels of the main and bottoming plant interface are 0.85 % (w/w) and 0.04 %(w/w), respectively. The SSI level of the waste brine after the second flashing at 0.7 MPa is 1.19,' which is slightly saturated with respect to the amorphous silica. The computed level of boron in steam in the main plant and bottoming plant interfaces are 2.4 and 1.6 mg/kg, respectively. The power output at the main plant is 84.2 MWe and 11.8 MWe at the bottoming plant for a total of 96 MWe in the sector.

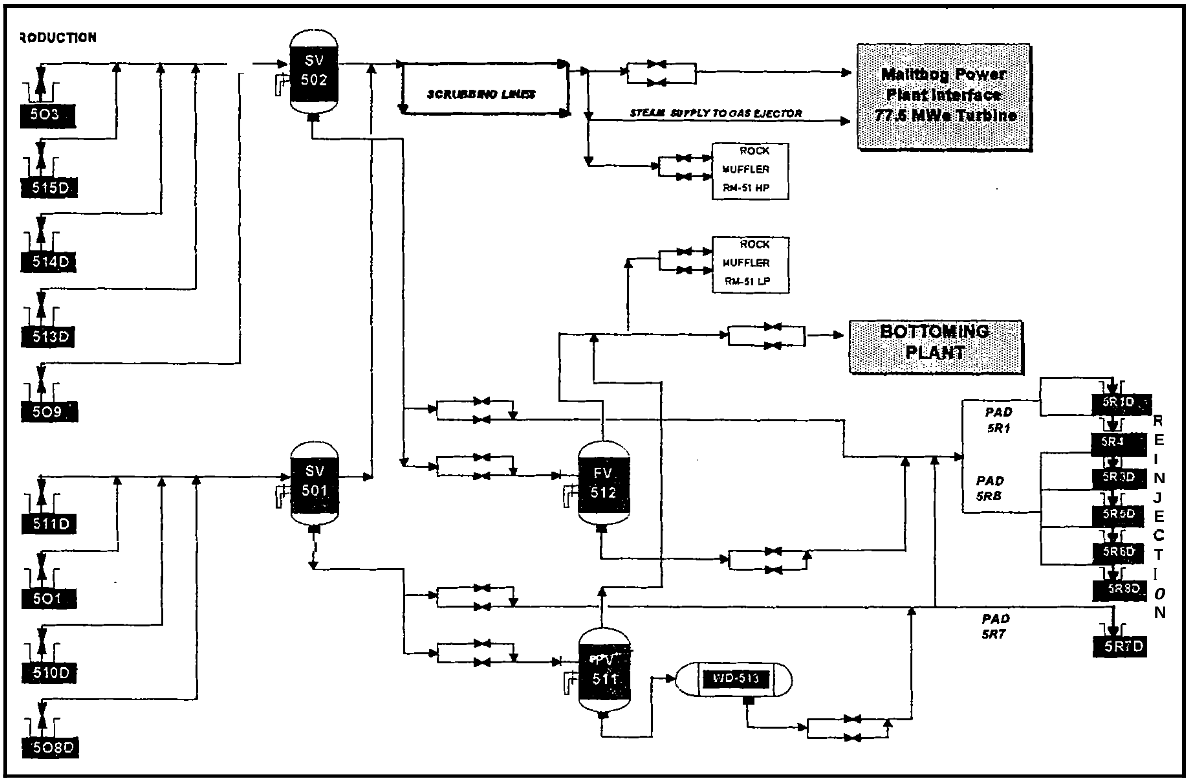


Figure 5: Process Flow Diagram of the Malitbog Fluid Collection and Disposal System

	1.2 MPa Sep. Press.		0.7 MPa Sep. Press.		Brine Line	Main Plant	Bottoming Plant
	SV-501	SV-502	FV-511	FV-512	5R1/5RB Pad	Interface	Interface
SF, *(kg/s)*	71.3	89.6	11.3	15.3	—	160.9	26.6
WF, *(kg/s)*	227.3	296.6	216.0	281.4	442	—	—
NCG, *(% w/w)*	0.90	0.81	0.04	0.04	—	0.85	0.04
SSI	0.87	0.92	1.15	1.22	1.19	—	—
Cl, *(mg/kg)*	7450	8907	7840	9390	8826	—	—
B_{STEAM}	1.88	2.81	1.42	1.80	—	2.4	1.6
MWe	37.3	46.9	5.0	6.8	—	84.2	11.8

Table 2: Summary of Malitbog FCDS Chemistry Simulation

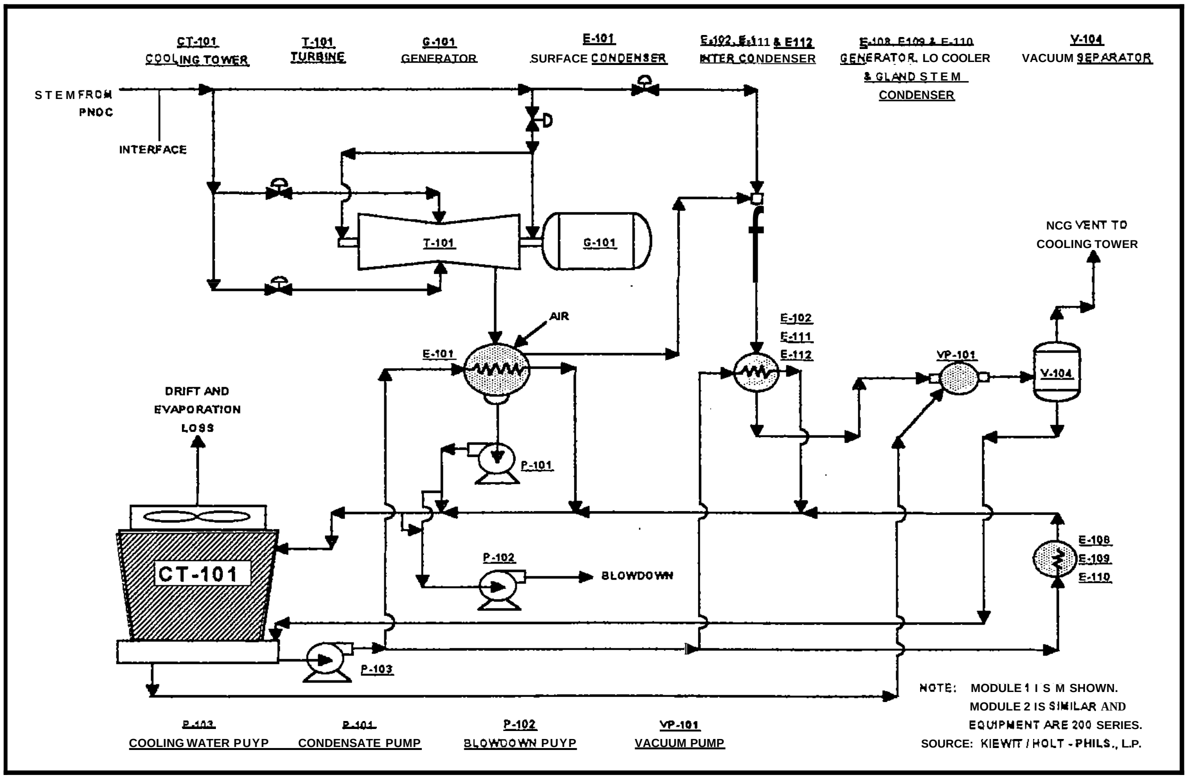
5.0 THE MAHANAGDONG-A POWER PLANT

The Mahanagdong-A (MG-A) power development is intended to supply part of the 400 MWe Leyte-Luzon interconnection due for commercial commissioning by mid-1997. It consists of two power stations, the 120 MWe main power plant and the 12 MWe Topping Cycle plant. The MG-A FCDS will utilize 12 production wells, namely MG-1, MG-2D, MG-7D, MG-13D, MG-16D, and MG-22D supplying Separator Station 1 (SS-1), and MG-3D, MG-5D, MG-14D, MG-18D, MG-19, and MG-23D supplying Separator Station 2 (SS-2). The waste brines will be reinjected back to the reservoir through 5 reinjection wells, namely MG-5RD, MG-6RD, MG-7RD, MG-8RD, and MG-9RD.

5.1 Power Plant Process Scheme

The Mahanagdong-A power station consists of 2 modules of 60 MWe condensing turbine operated at 0.7 MPa with a steam rate of 2.258 kg/s-MWe. A topping cycle plant, consisting of 2 modules of 7.0 MWe non-condensing turbine operated at 1.2 MPa, is incorporated upstream of the main plant. The topping plant generates additional power of around 12.0 MWe at a steam rate of 18.6 kg/s-MWe. The partially condensed steam from the condensing turbines will be fully condensed in a non-contact surface condenser, where the chemistry of the blowdown condensates will not significantly change compared to that of the degassed steam

(Fig. 6). The vacuum separated NCG will be vented to the cooling tower. The steam condensates blowdown will be **disposed** through injection at wells MG-4DA, MG-17D, MG-9D and MG-20D. A total of 271 kg/s of steam is needed to supply the condensing turbines operated at their base load of 120 MWe. At this steam flow, around 29.5% or 80 kg/s will be **disposed** as waste condensates, 2.9% or 7.9 kg/s of NCG will be vented out through the cooling tower, and 67.5% or 183 kg/s will be lost through **drift** and evaporation at the cooling tower.



NOTE: MODULE 1 I S M SHOWN. MODULE 2 IS SIMILAR AND EQUIPMENT ARE 200 SERIES.

SOURCE: KIEWIT / HOLT - PHILS., L.P.

Figure 6 : Mahanagdong-A Power Plant Process Flow Diagram (Module 1)

5.2 Mahanagdong-AFCDS Process Flow Description

The Mahanagdong-A FCDS employs a double flash method to extract the maximum amount of steam from its two-phase fluids feed. The steam separation is carried out in two identical separator stations each consisting of 3 units of 20 MWe load separator vessels and a flashing vessel (Fig. 7). The two-phase fluids from the 6 production wells supplying each station are collected in a header and equally distributed to the three separator vessels, where the high pressure (1.2 MPa) first separation occurs. The high pressure steam are collected in a steam header and sent to the topping plant. The separated brines are sent to the flashing vessel where its pressure is dropped to 0.7 MPa to allow additional steam to separate from the brine. The separated steam from the second flash goes to a header for low pressure steam, while the remaining waste brines are reinjected back to the reservoir.

At the topping plant., the steam from first flash coming from SS-1 and SS-2 are mixed in a header before going into two streams to run the 2 modules of non-condensing turbines. Each module is provided with a scrubber immediately downstream to scrub-off some steam condensates in the wet steam exiting from the high pressure turbines. Downstream of the scrubbers, the dry steam are mixed and returned for use in the main power station. The topping cycle exhaust steam are mixed with the second flash separated steam and sent downstream to the main power plant.

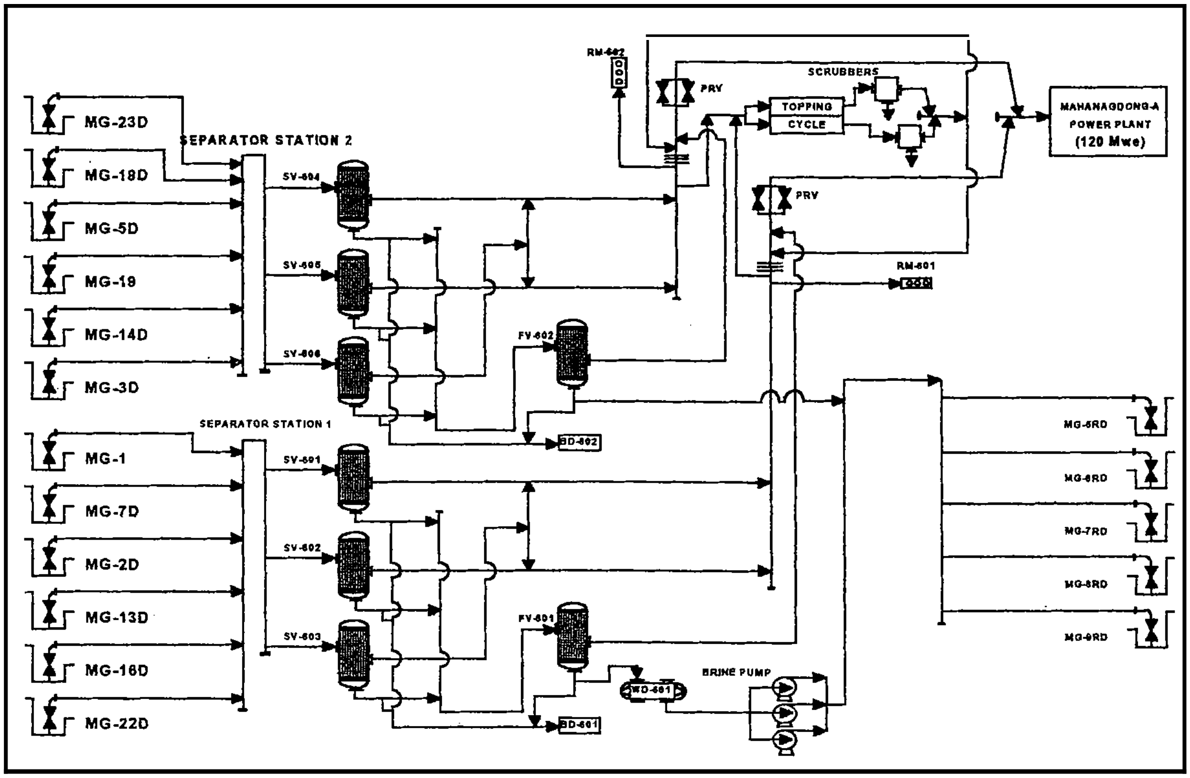


Figure 7 : Mahanagdong-A FCDS Process Flow Diagram

5.3 Results of Chemical Simulations

Presented in Table 3 are the results of the chemical simulation predicting the fluid chemistry of the MG-AFCDS. The NCG levels at the steam interface for topping cycle plant and main power station are 2.62 and 2.37% w/w, respectively. Some 678.6 kg/s of waste brines are to be reinjected. These are slightly saturated with silica at SSI of 1.05. The boron concentration in mainplant interface steam and condensates blowdown are approximately at 0.29 mgkg level. The output at the main power station is 130.2 MWe while that generated from the topping cycle plant is 14.2MWe, for a total of 144.4MWe of power that can be harnessed from this sector.

	Separator Station 1	Separator Station 2	Brine for Reinjection	Topping Cycle	Main Plant Interface
SF (kg/s)	122.1	143.4		265.5	293.9
WF (kg/s)	361.6	317.0	678.6	5.6	
NCG (% w/w)	1.62	3.45		2.62	2.37
SSI	1.03	1.07	1.05		
B_{STEAM} (mg/kg)	0.81	0.65		0.72	0.26
Cl_{BRINE} (mg/kg)	3701	3544	3628		
MWe	61.0	69.2		14.3	130.2

6.0 CONCLUDING REMARKS

The pre-commissioning of Malitbog and Upper Mahiao FCDS were conducted during the early to the middle part of 1996 to evaluate the performance of different separator vessels and the control systems. On the other hand, the pre-commissioning of Mahanagdong-A is scheduled to start January of 1997. Simultaneous with the testing, geochemical monitoring activities such as steam quality, NCG, and SSI level in brine at the reinjection lines were conducted to compare the actual values with the simulated values.

Pre-commissioning of the Upper Mahiao was conducted from November 1995 to September 1996 and tested only to a maximum capacity of 50 MWe. The monitored NCG level of steam at the interface during the pre-commissioning ranged from 0.50 %(w/w) to 0.90 %(w/w) which agrees well with the predicted level of 0.60 to 1.14 %(w/w) (Villa, 1996). The waste brine SSI level ranged between 0.80 to 1.10, likewise, within the predicted level of 0.70 to 1.15 (Villa, 1996).

The pre-commissioning of Malitbog FCDS was conducted from February 1996 and temporarily ended on August 1996 to modify and repair part of the FCDS and control system . The precommissioning was intended only for the first stage flashing at separation pressure of 1.2 MPa because the bottoming cycle in the FCDS is not yet constructed. The result of NCG monitoring in the FCDS are not yet conclusive. However, the SSI level of brine ranged between 0.81.to 0.92 which agrees well with the predicted level of 0.87 to 0.92 at the first flashing, (Salazar, et al., 1996).

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