

## Steam Supply Sharing Through Steamline Interconnection – The Tongonan Geothermal Field Experience, Philippines

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### ABSTRACT

Since the commissioning of the new power plants in the Philippine National Oil Co. – Energy Development Corporation (PNOC-EDC) operated Tongonan Geothermal Field and its adjacent Mahanagdong Geothermal Sector in Leyte Philippines in 1996 under the Build-Operate-Transfer (BOT) scheme, there have been a number of reservoir management strategies formulated and implemented to ensure continuous supply of the required steam to the installed power plants. One of these field management strategies is the construction of a cross-country steamline interconnection called the “steam-highway” which links the different sectors of the Greater Tongonan Geothermal Field. The steam highway pipeline network interconnects all three major sectors of the Tongonan Geothermal Field, namely the Tongonan 1, Upper Mahiao and Malitbog-South Sambaloran, with the adjacent Mahanagdong Field.

This inter-sectoral / field linkage, commissioned in year 2000, provides flexibility in the operation of the field by allowing delivery of excess steam from the Upper Mahiao, Tongonan 1, Malitbog-South Sambaloran up to the Mahanagdong sector to ensure optimized power generation from the BOT plants.

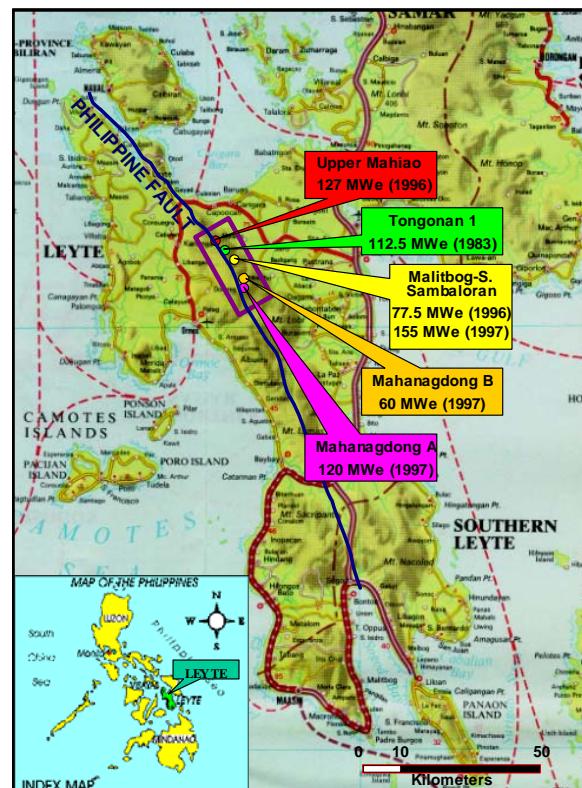
Historical and present distribution of the excess steam is discussed and the reservoir response of the supplying sectors / field as a result of this scheme were reviewed. Reservoir trends since the commissioning of the steamline interconnection have indicated that the Upper Mahiao and Tongonan 1, the main supplying sectors, can sustain additional extraction for the supply of steam to the recipient sectors.

### 1. INTRODUCTION

Inter-sectoral steam sharing is one of several reservoir field management strategies formulated (Sta. Ana, F.X.M., et al 1999 and Seastres et al., 2000) and eventually implemented to provide flexibility to field operations by making the excess steam from the Tongonan Geothermal Field available for use by the adjacent Mahanagdong sector in the Philippine National Oil Co. – Energy Development Corporation (PNOC-EDC) operated Greater Tongonan Geothermal Production Field.

The Greater Tongonan Geothermal Production Field (Figure 1) is divided into four major sectors: Tongonan 1, Upper Mahiao, Malitbog-South Sambaloran and the Mahanagdong sectors with the Mahanagdong further subdivided into Mahanagdong A and Mahanagdong B. Commercial exploitation of the field began in 1983 with the operation of the 112.5 MWe power plant in the Tongonan 1 production sector which supplies the power requirement of the Leyte and Samar islands. It was only in the late 90's

that large scale exploitation in the Greater Tongonan Geothermal Field began with the commissioning of new power plants having a total rated capacity of 595 MWe under the build operate transfer (BOT) scheme to supply energy to the Leyte-Cebu and Leyte-Luzon power grids.



**Figure 1: Greater Tongonan Geothermal Field Location Map**

Upon commissioning of the BOT plants, the different production sectors were able to provide and meet the steam requirement of each of their respective power plants. Like most producing geothermal fields, reservoir changes associated with its operation and exploitation were observed after the new production sectors were commissioned. The available steam from the Upper Mahiao, Tongonan 1 and the Malitbog-South Sambaloran sectors initially increased as a result of discharge enthalpy increase in response to large-scale exploitation.

Mitigating measures are also being implemented to ensure continuous and sustained supply of steam to the existing power plants. These measures include 1) mechanical workover operations 2) installation of Calcite Inhibition Systems (CIS) to eliminate scaling or at least reduce the frequency of workover in Mahanagdong wells identified to be prone to calcite scaling 3) cement plugging of permeable

horizons channeling shallow groundwater such as in Mahanagdong well MG23D and 4) drilling of maintenance and replacement (M&R) wells.

For the long-term sustenance of the Mahanagdong sector, development of the eastern block outside the current production area was identified for future M&R wells. This however would take time before production in this area would be realized. The availability of this cross-country steamline interconnection, dubbed as the steam highway, would enable continuous and sustained operation of all the existing power plants at high loads through steam sharing even during implementation of the formulated short term and long term mitigating measures. This steam highway stretches from Upper Mahiao in the northwest to Mahanagdong in the southeast of the Greater Tongonan Geothermal Field having a distance of over 15 km. This scheme was envisioned to allow delivery of steam from Upper Mahiao, Tongonan 1 and the Malitbog-South Sambaloran to Mahanagdong.

## 2. FIELD OPERATING PRESSURES AND PLANT CAPACITIES

The combined total installed capacity of all the power plants in the Greater Tongonan Geothermal production field is about 708 MWe. Background studies on the field's development scheme, ie., plant size, configuration and optimization had been carried out by Sarmiento et al. (1992) and Sarmiento et al. (1993).

The Upper Mahiao production sector employs a single flash system using separator vessels to extract steam from the reservoir at an operating pressure of 1.2 MPaa (Figure 2). The steam is then delivered to the 4 x 31.815 MWe Geothermal Combined Cycle Units (GCCU's).

The Tongonan 1 production sector was originally designed as a single flash system having an operating pressure of 0.7 MPaa with the steam supplied to the 112.5 MWe power plant. The system was later converted to double flash with the high pressure steam, extracted at 1.2 MPaa, delivered to the newly installed non condensing 17.25 MWe Topping Cycle Plant (TCP). Exhaust steam is then conveyed to the original 112.5 MWe main power plant (Figure 3). High pressure brine extracted from the high pressure separator vessels on the other hand are passed through the flash vessel, operated at 0.7 MPaa to extract additional low pressure steam for the main plant.

Double flash system is also employed in the Malitbog-South Sambaloran production sector with the geothermal fluids separated at 1.2 MPaa and 0.7 MPaa. The high pressure steam is delivered to the 3 x 77.5 MWe condensing main plant while the low pressure steam is supplied to the 14.56 MWe condensing bottoming plant (Figure 4).

The Mahanagdong production sector is subdivided into 2 areas which are Mahanagdong A and Mahanagdong B. Similar to the Tongonan 1 Fluid Collection and Recycling System (FCRS), a two pressure system is also employed in the extraction of steam in Mahanagdong A at pressures of 1.2 MPaa and 0.7 MPaa. High pressure steam is delivered to the 2 x 6.38 MWe non condensing Topping Cycle Plant (TCP) with the exhaust steam conveyed to the 2 x 60 MWe condensing main plant. The separated high pressure brine is further passed through the flash vessel for the extraction of low pressure steam which is also delivered to the main plant.

The Mahanagdong B sector also extracts steam at a high pressure of 1.2 MPaa but does not have a 2<sup>nd</sup> flash system. The high pressure steam is supplied to the 1 x 6.38 MWe non condensing Topping Cycle Plant (TCP) with the exhaust steam going to the 1 x 60 MWe condensing mainplant.

## 3. STEAMLINE INTERCONNECTION SCHEME

The cross-country steamline interconnection (SLI) stretches from the Upper Mahiao sector in the northwest of the field to Mahanagdong in the southeast, passing through the Tongonan 1 and Malitbog-South Sambaloran sectors (Figure 5).

The steamline interconnection taps the high pressure steamline of the supplying sectors, Upper Mahiao, Tongonan 1 and Malitbog-South Sambaloran, and is connected to the low pressure steamlines of the Mahanagdong A and Mahanagdong B Fluid Collection and Recycling System (FCRS). With this long length of steamline, high pressure steam from the supply side reaches the Mahanagdong at a lower pressure, but enough to meet the pressure requirement of the Mahanagdong A and Mahanagdong B main plants (Figure 6 and Table 1).

**Table 1. Tabulated Design Pressures Along Interconnection Line**

Designed Press., kscg	UM	TGN1	SS	MGB	MGA
	12.5	11.6	11.0	6.1	6.0

*Source: Eng'g Design Group*

### 3.1 Steamline Interconnection Stages 1 and 2

The first stage steamline interconnection which links the Malitbog-South Sambaloran sector with the Mahanagdong sector was commissioned in August 2000, marking the start of the inter-sectoral steam sharing. The second stage which connects stage 1 to the Tongonan 1 and Upper Mahiao sectors became operational by November of the same year.

Upon commissioning of the steamline interconnection, separator pressures in the supplying sectors were slightly raised to attain the interconnection design pressures and fully optimize steam delivery to the Mahanagdong sector. Steamline interconnection capacity test later showed that the line is capable of actually delivering 40 MWe to the Mahanagdong sector. It is believed that the 36" stage 1 interconnection line can accommodate more than 40 MWe but steam flow from the main supplying sectors Upper Mahiao and Tongonan 1 is limited by the constricted stage 2 steamline which is composed of a 24" and 30" diameter pipelines. The stage 2 interconnection line was originally a portion of one of the injection lines designed and used to convey separated brine from South Sambaloran to Upper Mahiao but became available with the change in injection strategy.

### 3.2 Steamline Interconnection Stage 3

In 2003, the stage 3 of the steamline interconnection which is basically a complementary line to the stage 2 interconnection line, was commissioned. The SLI stage 3 was designed to optimize the capability of the stage 1 interconnection line to deliver steam to Mahanagdong from 40 MWe to 50 MWe while at the same time provide more flexibility to the existing SLI network as it offers the option to divert high pressure steam from Upper Mahiao to the high pressure Malitbog-South Sambaloran steamline. This is achieved by allowing the Malitbog-South Sambaloran FCRS to admit steam from either Upper Mahiao or

Tonganan 1 through stage 3 and passing it on to stage 1 in addition to the steam conveyed by the stage 2 steimeline (Figure 7). Like the stage 2 steimeline, the stage 3 interconnection line utilized a portion of the existing second injection line originally used to convey the South Sambaloran separated brine to the Upper Mahiao sector. This line however has a larger diameter than the stage 2 line which became available with the full diversion of the remaining South Sambaloran brine to the Tongongan 1 sector.

Subsequent simultaneous test of the stage 1, 2 and 3 steimeline interconnection, although not at full capacity, was able to yield an actual measured steam delivery equivalent to about 18 MWe to Malitbog-South Sambaloran, and 38 MWe to Mahanagdong distributed to sector A and sector B at 11 MWe and 27 MWe respectively.

#### 4. LOADING OF POWER PLANTS WITH SLI

The commissioning of the stage 1 and 2 steimeline interconnection in year 2000 as envisaged, provided flexibility in the operation of the FCRS in the Greater Tongongan Geothermal Production Field. Excess steam coming from the Upper Mahiao and Tongongan 1 can already be transported to the Mahanagdong sector to optimize power generation. Continuous supply of steam to the power plants can already be maintained even during periods of sudden and unscheduled FCRS maintenance activities requiring temporary isolation of the affected part of the system, implementation of mitigating measures such as workover and drilling of M&R wells.

Of the 40 MWe stage 1 & 2 carrying capacity measured during the test in 2001 with the steam supplied by the Tongongan Geothermal Field, about 25 MWe was delivered to the Mahanagdong A main plant, allowing it to operate at full load while the other 15 MWe was utilized to operate the Mahanagdong B main plant at full load as well.

Since the combined total excess steam coming from Upper Mahiao, Tongongan 1 and Malitbog-South Sambaloran sectors was more than the capacity of the installed steimeline interconnection during that time, it also provided operational flexibility in terms of switching steam supply contribution from the three supplying sectors. With this scheme, the high pressure steam requirements of each of the Greater Tongongan Field BOT plants were met, allowing its full utilization.

The commissioning of the stage 3 interconnection provided the Malitbog-South Sambaloran with the option to utilize the excess steam available in Upper Mahiao and Tongongan 1 during implementation of work-over and M&R drilling activities, thereby ensuring continuous operation of the power plant at full load.

#### 5. MASS EXTRACTION AND RESERVOIR PRESSURES

##### 5.1 Mass Extraction

Mass extraction in Tongongan 1 (Figure 8) after the steimeline interconnection was commissioned only increased sharply in 2002. The Tongongan 1 production sector showed peak monthly average mass extraction in mid 2002 as all three turbine generator units of the Tongongan 1 main power plant were operated continuously at high loads while at the same time, the sector was supplying steam to the steimeline interconnection during this period. Tongongan 1 steam contribution to the steimeline interconnection was stopped from June to November 2001 due to FCRS

equipment rehabilitation. The occasional operation of the main plant at low or limited loads due to various turbine and plant equipment problems and the variation of steam contribution to the steimeline interconnection also contributed to the fluctuation of monthly mass extraction.

The Upper Mahiao average mass extraction initially increased when it began contributing to the interconnection line but later showed a downtrend as a result of continuing increase in discharge enthalpy due to pressure drawdown. Recovery in discharge enthalpy was likewise noted in some of the Upper Mahiao wells previously affected by injection fluids in response to the shift in injection strategy. Injection fluids from South Sambaloran in 1999 was diverted to pad 4RC4, a pad located farther from the Upper Mahiao production sector. The South Sambaloran brine was later diverted to the Tongongan 1 injection sink. It was only in late 2003 that the mass extraction increased as watery reserve wells were commissioned to supply additional steam to the SLI stage 3.

Overall average field mass extraction declined since steam sharing began in year 2000 even though the Upper Mahiao and Tongongan 1 sectors supply excess steam to the steimeline interconnection for delivery to the Malitbog-South Sambaloran and Mahanagdong sectors.

##### 5.2 Reservoir Pressures

The Malitbog-South Sambaloran display a uniform pressure drawdown across the sector which was initially steep during the early stages of exploitation but eventually tapered off (Figure 9). The presence of blockages in most of the Upper Mahiao and the Tongongan 1 production wells made it difficult to conduct downhole measurements to obtain downhole data. In the Upper Mahiao, available pressure data from 2 production wells indicate a linear decline which when projected to the pre-commissioning period more or less falls close to the average baseline field pressure data. This may imply that there has been no significant change in the drawdown trend since the start of the steimeline interconnection operation.

The processes earlier noted to be affecting the output of the production wells remain unchanged which had been identified as peripheral cold fluid intrusion affecting the Upper Mahiao and Malitbog-South Sambaloran eastern periphery, injection returns in Malitbog and Tongongan 1, mineral blockages and pressure drawdown. The recovery in discharge enthalpy of some Upper Mahiao production wells and the decline in discharge enthalpy of some wells in the Tongongan 1 are due to the change in injection strategy implemented.

#### 6. DISCUSSION

The implementation of the inter-sectoral steam sharing scheme provided flexibility in the operation of the FCRS in the Leyte Geothermal Production Field. Some of the benefits that this scheme has offered are: a) optimized use of the available Tongongan Field steam as well as BOT power plants and b) continuous supply of steam to the power plants even during implementation of minor unscheduled FCRS maintenance and servicing activities requiring temporary isolation of the affected part of the system and implementation of short-term and long-term mitigating measures such as workover, drilling of M&R wells and field expansion program.

Reservoir changes noted after operation of the interconnection line started are more related to the changes

in injection strategy implemented on the Tongonan Field such as the diversion of brine disposal initially at pad 4RC4 and later to the Tongonan 1 injection sink.

The recovery in discharge enthalpy of some Upper Mahiao with the transfer of South Sambaloran brine injection from pad 408 to pad 4RC4 initially then to Tongonan 1 resulted to an increase in steam component in the fluid discharge thereby reducing the mass extraction required for the full load operation of the Upper Mahiao power plant and contribution to the steimeline interconnection.

As a long-term measure, expansion of the Mahanagdong field is still more desirable than to rely on the steam coming from the Tongonan 1 and Upper Mahiao sectors. For one, the steimeline interconnection capacity is limited, and two, the existing available Upper Mahiao, Tongonan 1, and Malitbog-South Sambaloran pads / cellars identified for future M&R drilling may well be reserved for the future requirements of these sectors. New areas in Mahanagdong have to be developed to increase available steam in the sector, ensure continuous supply of steam to the existing power plants, relieve or at least reduce the extraction in the supplying sectors and ensure sustained operation of the Tongonan Geothermal Field.

## 7. CONCLUSIONS

The installation of the steimeline interconnection network provided operational flexibility to the operation of the Tongonan Geothermal Field ensuring optimized utilization of the available steam as well as that of the existing BOT power plants. Continuous supply of steam to the power plants is now possible even when minor unscheduled maintenance activities, workovers, drilling of M&R wells are being implemented.

Although reservoir pressure data suggest no significant change in field trends that can be attributed to the steam sharing scheme so far, it is still more desirable as a long

term plan to pursue development of new areas in Mahanagdong to maintain adequate supply of steam to the Mahanagdong power plants and ensure sustained operation of the Tongonan Geothermal Field.

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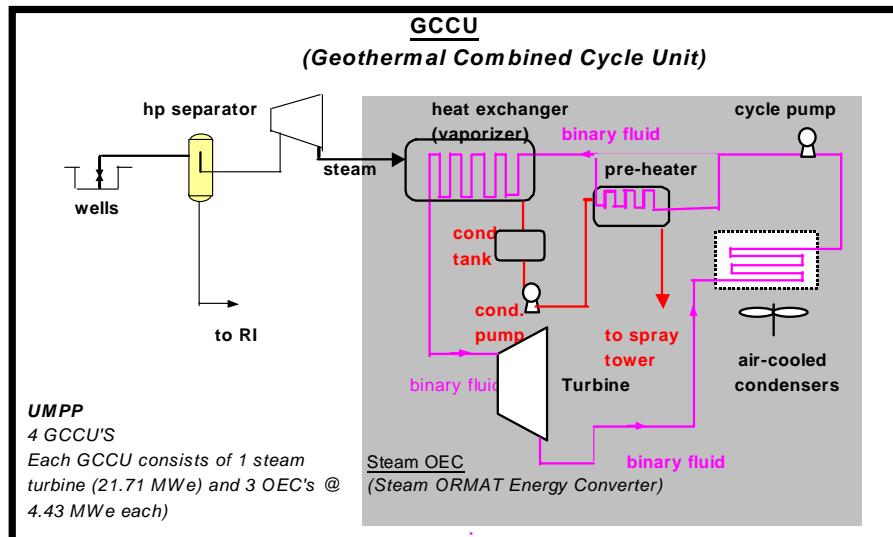


Figure 2: Upper Mahiao FCRS / Power Plant Schematic Diagram

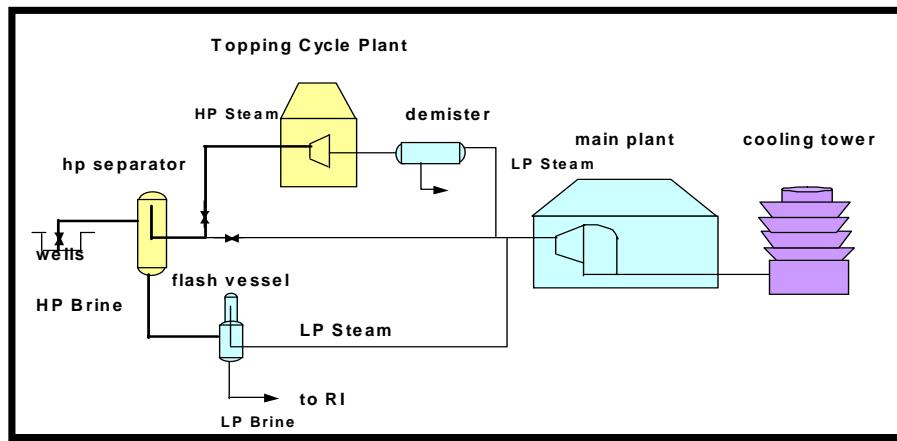


Figure 3: Tongonan 1 and MGA FCRS / Power Plant Schematic Diagram

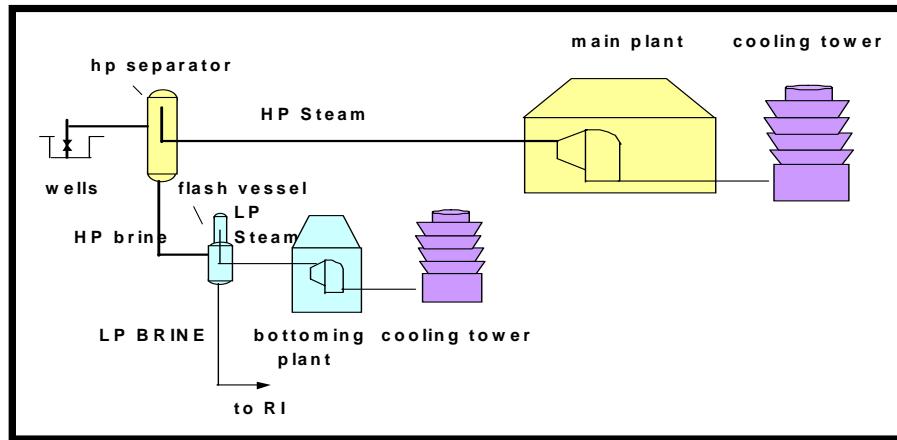
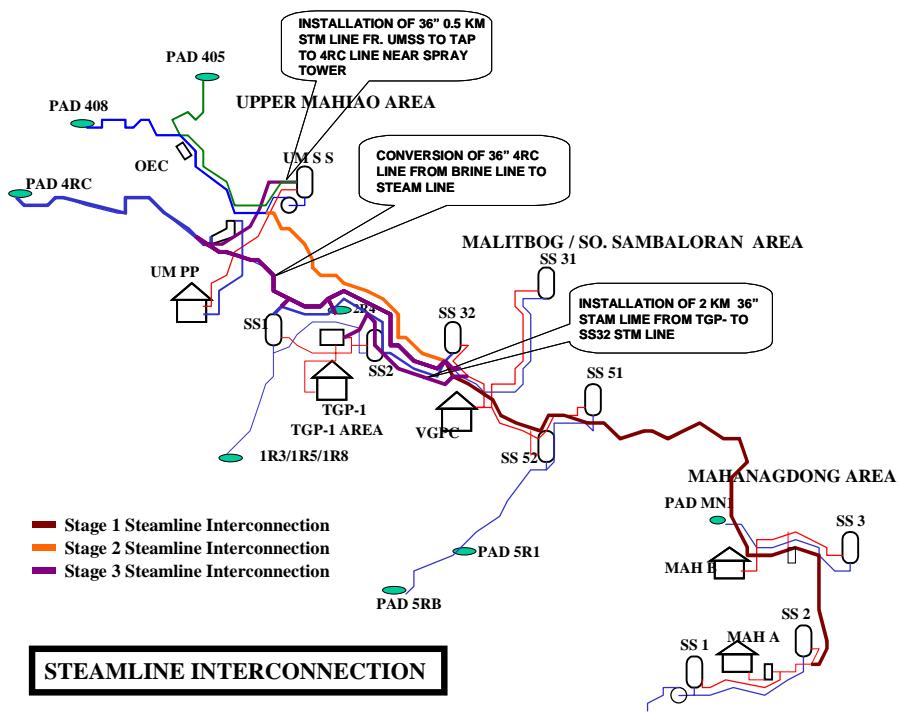
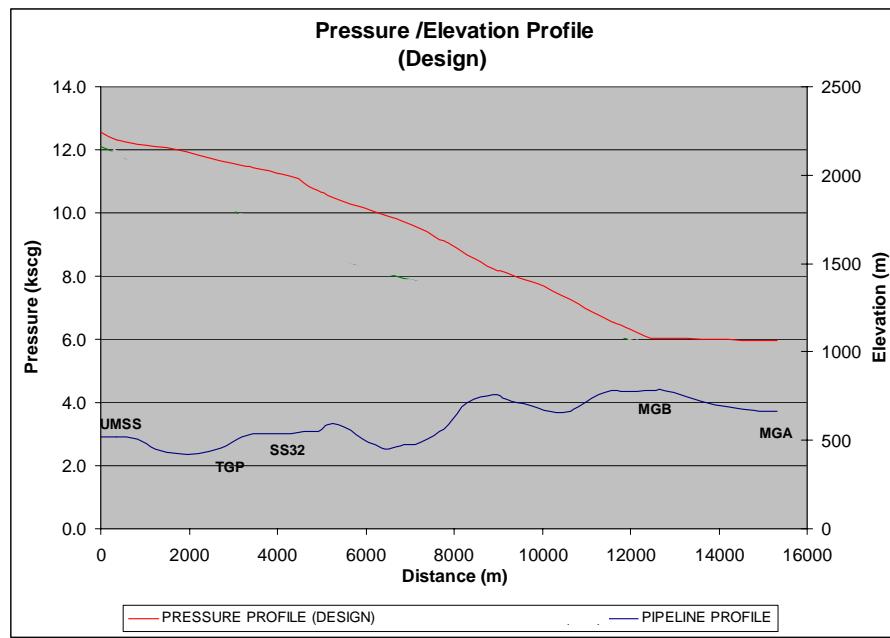


Figure 4: Malitbog FCRS / Power Plant Schematic Diagram



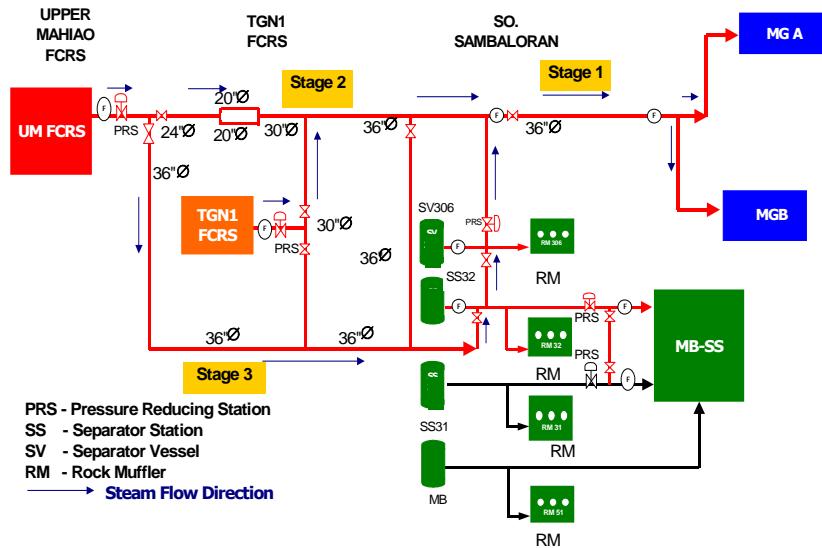
Source: Eng'g Design Group

Figure 5. Steamline Interconnection Layout



Source: Eng'g Design Group

**Figure 6. Steamline Interconnection Design Pressure / Pipeline Elevation Profile**



Source: Production Group

**Figure 7. Steamline Interconnection (SLI) Schematic Diagram**

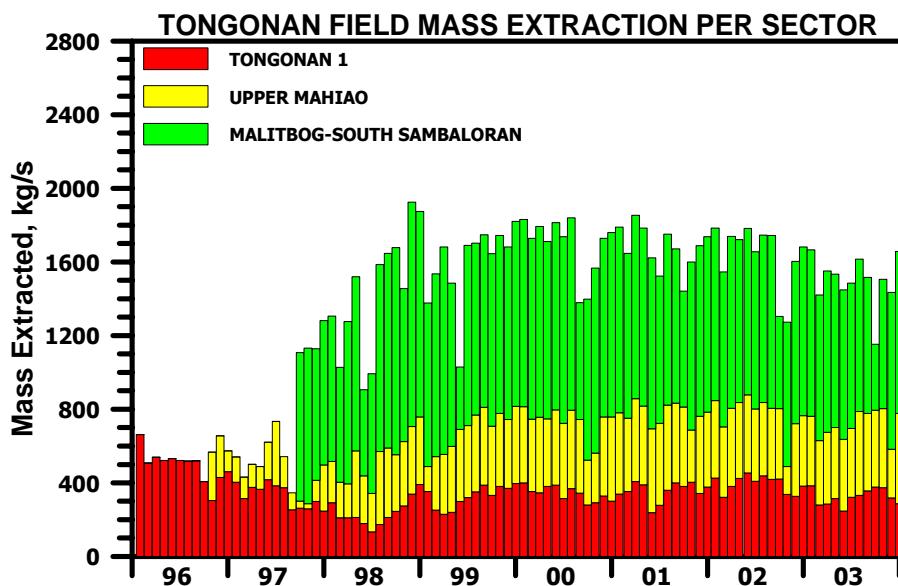


Figure 8: Tongonan Geothermal Field Mass Extraction

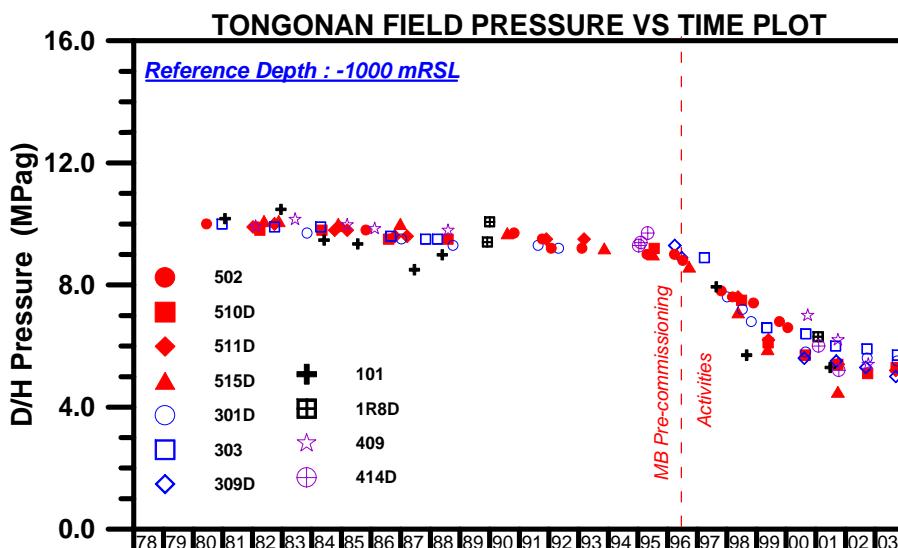


Figure 9: Tongonan Geothermal Field Pressure vs Time