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SENSITIVITY ANALYSIS OF THE GREATER TONGONAN FIELD RESOURCE ASSESSMENT

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ABSTRACT

An integrated resource assessment of the Greater Tongonan geothermal field was conducted using the volumetric stored heat method. The Greater Tongonan field covers an area of about 40 sq. km., encompassing the current Mahiao-Sambaloran production sector (installed 112.5 MWe Tongonan I plant), the Upper Mahiao and Malitbog proposed development areas, and the separate Mahanagdong system. The assessment considered only the existing producing field and the likely production areas for future development and did not take into account the resupply of heat from the field's peripheries. Assuming conservative values for the various input parameters and a 25-year plant life, the total volumetric stored heat for Greater Tongonan is estimated at 362,330 MWt-years, equivalent to 530 MW of assessed electrical power.

To appraise the effects of different estimates of recovery factor CRf) on the total assessed power capacity of Greater Tongonan, a sensitivity analysis was carried out. Similar analysis was done for conversion efficiency <CEf), load factor (Lf), rock density (/>r), rock specific heat (Cpr) and porosity. Results of the analysis indicate that the power estimate responds variably to the various parameters for each individually specified parameter increment. Power capacity is most sensitive to variations in Rf, moderately sensitive to increments in CEf and Cpr and slightly to almost insignificantly, to changes in Lf, /Or and porosity.

INTRODUCTION

Geothermal energy resources consist of both the natural surface heat flow seen in hot springs and fumaroles and the heat stored in underground reservoirs. Geothermal resource assessment, thus is the estimation of this thermal energy in the ground for use at a specified time under generalized technological and economic assumptions (Muffler and Cataldi, 1978). It is the **recoverable** geothermal energy however, that is useful and meaningful to man and therefore termed the geothermal resource.

Volume Method of Geothermal Resource Assessment

The volume method is also known as the method of "volumetric heat" (White and Williams, 1975) or "stored heat" (Bolton, 1973). The method involves the calculation of the thermal energy contained in a given volume of rock and water and the estimation of how much of this energy might be recoverable. The thermal energy in the ground is calculated as the product of the volume of a geothermal reservoir, the mean temperature, the porosity and the specific heats of rock and water using the formula:

Total Stored Heat = Difference in Heat Content in Rock + Difference in Heat Content in Water

$$Ht = Hr + Hw$$

$$= (1-\phi) \times Cpr \times \rho r \times V \times (T - To) + (\phi) \times Cpw \times \rho w \times V \times (T - To)$$

where, Cpr and Cpw = specific heats of rock and water
/Or and fivi = densities of rock and water
To = reference temperature
and T = temperature of the volume of rock and water under consideration.

Only a small fraction of the accessible resource base, however, is brought to the surface and thus constitute the geothermal resource (HRf). Many authors have resorted to the so-called **recovery factor (Rf)** that allows one to express recoverable geothermal energy as a percentage of the thermal energy contained in a given subsurface volume (V) such that:

Recoverable Heat, $HRf = Rf \times Ht$

where, Rf is dependent on the hypothesized production mechanism, on the effective porosity of the formations and on the temperature difference between the volume and the wellhead. Calculation of the amount of recoverable thermal energy is however, more complex and requires a knowledge of reservoir properties such as permeability. In most cases, the recovery factor can be specified only approximately (Nathenson, 1975).

Muffler and Cataldi (1978) favoured and recognised the volume method as giving the most comprehensive and reliable depiction of the accessible resource base and showing promise of rapid improvement in the evaluation of recoverability and resupply. They further concluded that the volume method appeared to be the most useful because: (1) it was applicable to virtually any geological environment, (2) the required paramaters could in principle be measured or estimated, <3) the inevitable errors were in part compensating, and (4) the major uncertainties (the recovery factor and the resupply of heat) can be resolve in the foreseeable future.

For these reasons, we likewise adopted the volumetric stored heat method in our estimation of the geothermal energy in place in the integrated appraisal of the Greater Tongonan field resource potential.

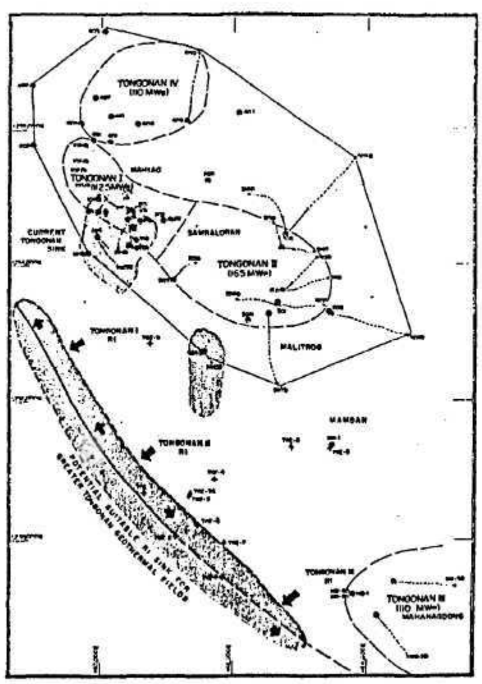


Figure 1. Greater Tongonan Development Plan (from Vasquez, 1987).

GREATER TONGONAN RESOURCE ASSESSMENT

Background

The Greater Tongonan field which covers an area of about 40 sq. km., emcompasses the existing Mahiao-Sambaloran production sector (installed 112.5 MWe Tongonan I power station); its northern and southern extension - the Upper Mahiao and Malitbog proposed development areas, and the separate Mahanagdong system further south (Figure 1). The Mamban-Bao Valley area serves as the interphase between the Mahiao-Sambaloran-Malitbog and the Mahanagdong geothermal systems. Todate, a total of 52 deep wells and 11 shallow thermal gradient wells have been drilled in the entire Greater Tongonan area. The Tongonan I power plant is served by a steam collection and waste disposal system from 12 production and 5 reinjection wells in the Mahiao-Sambaloran field. The majority of the remaining wells which were originally drilled as delineation wells, have become producers and have been allocated for the three other proposed future development areas: 9 wells in Uppper Mahiao, 15 wells in Malitbog and 3 wells in Mahanagdong.

Previous Sectoral Stored Heat Estimates

KRTA (1980, 1981, 1982) published individual feasibility reports including volumetric stored heat estimation in Upper Mahiao, Malitbog and Mahanagdong which were based on data available from completed wells. Table 1 shows a summary of KRTA's stored heat estimates for specific Tongonan field sector and the various assumptions used in the calculations.

Table 1. Sunmary of KRTA Sectoral Stored Heat Estimates and Assumptions

PARAMETERS	"FURTHER TONGONAN. ." (1980) Mahiao	Malitbog	UPPER MAHIAO (1981)	MALITBOG (1982)	MAHANAGDONG (1982)
WELLS USED	Not Specified (N.S.)		8A	12B	«G1,MG2D
AREA km.2	8.6-11.4	6..6-10.8	3.85	N.A.C	0.9
RESERVOIR THICKNESS	2.5 km.	2.0 km.	-2200 m.RSL	500 m. frcm TD	500 m belou well TD
VOLUME km3	21.5-28.5	13,.2-21.6	N.S.	N.S.	N.S.
T °C	300	270	N.A.	250	250
To °C	180	180	180	180	180
ρ_w kg/m3	712	768	N.A.	800	500
CpW kJ/kg °C	5.65	5.10	N.A.	4.87	.4.87
ϕ	N.A.	N.A.	0.1	0.1	0.1
ρ_r kE/m3	Volumetric Specific Heat = 2500 kJ/m3 °C		2400	2600	2600
Cpr kj/kg *c			0.9	0.9	0.9
Rf	5CS	SOS	507:	50K •	50S
CEf	13%	1CW	10%	105!	'.0%
Lf	N.A.	N.A.	N.A.	N.A.	N.A.
PL	25	25	25	25	25
POWER CAP. We	532-704	1(33-308	110	N.D.D	N.D.
AVE. POWER RATIMG MWe/km2	£2	2?	23	23	23

NOTES: A - Includes 401, 403, 404, "05, 40-., 407, 409 and 410 (•xcluding 402 and 408).
B - Includes 303, 501. 502, 503, 505D, 506D, 508D, 509, 510D, 511D, 514D and 515D. W<Us 505D and 506D were included although both wells were non-productive.
C - N.A., Not Applied.
D - N.D., Not Derived.

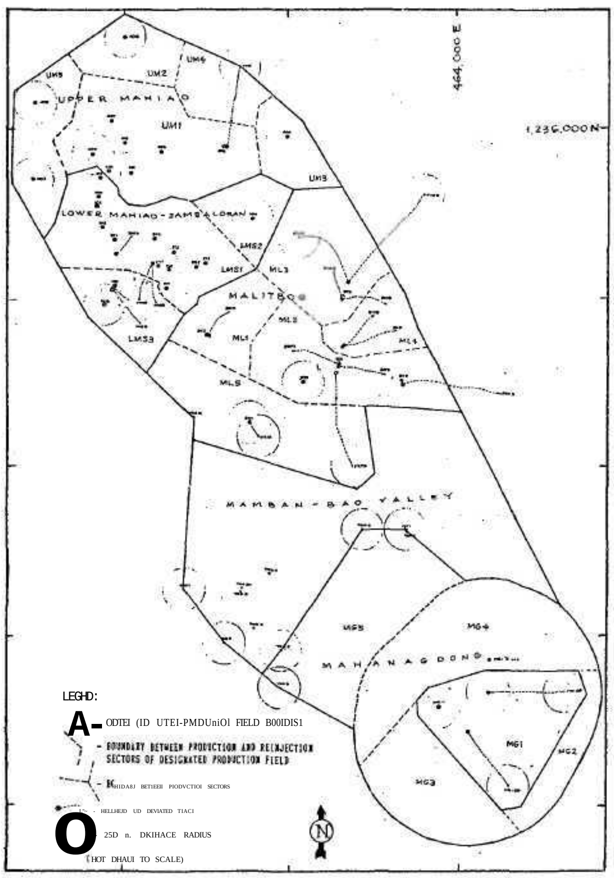
KRTA- (1980) initially estimated the potential electrical generating capacity available from the Mahiao-Malitbog areas as being between 720 and 1000 MWe for 25 years, corresponding to the 15.2 and 22.2 sq. km. total minimum and maximum resource areas postulated from resistivity data. Subsequent re-assessment and feasibility reports (KRTA, 1981; 1982) however, did not expressly indicate the power capacity potential for these areas. Our derivation of the power capacity based on the given average stored heat rating for each sector and similar minimum and maximum resource area limits, indicated a reduced total electrical energy potential for Mahiao and Malitbog of between 400 and 570 MWe. The lower power estimate is primarily related to lower mean reservoir temperatures used in the calculation and secondly, to variations in the assumed input values for the rock properties and conversion efficiency. A uniform recovery factor of 50% was assumed in all the reports, a value which is quite large as compared to the 25% or less, range of recovery factors suggested for hot-water reservoirs which takes also into account the inhomogenous nature of the reservoir rocks (Nathenson, 1975; Muffler and Cataldi, 1978). As shown, the variations in the power estimate for Mahiao and Malitbog, and to any other stored heat calculation, is in general dependent on the assumed values for the recovery factor, conversion efficiency, load factor and the various rock properties. On these parameters, one can ascribe some degree of uncertainty on the choice of values through the technique of analogy with other fields.

Current Greater Tongonan Assessment of Stored Heat

o General Considerations and Assumptions

The Greater Tongonan resource appears to be very extensive and with the numerous boreholes scattered around the field, it is possible to infer some boundaries from well measurements and surface exploration data and divide the entire area into independent but contiguous sectors for the purpose of stored heat calculation. The amount of energy that might be available for high-grade utilization in each of the defined reservoir area, thus has been assessed on the basis of a set of guidelines and assumptions. These are discussed below, with the deductions made illustrated in Figure 2.

Figure 2. Greater Tongonan Field Resource Boundaries and Sectoral Allocations



A-Reservoir Lateral Extent and Boundaries

A horizontal "drainage radius" of 250 m. beyond the bottomhole locations of the drilled wells has been adopted. This drainage radius, however, is restricted only to existing production wells and does not consider shallow thermal gradient wells, non-commercial wells and wells exhibiting large temperature reversals. The line which connnects the vertical projections of the 250 m. drainage radii of the outermost wells defines the boundary of the field, except the area south of Mahanagdong. The boundaries between the different identified resource sectors are further described as follows:

1. Mahiao-Sambaloran-Malitbog Area

a. Upper Mahiao Field (Proposed Tongonan IV)	Includes all 400 **series** wells.
b. Lower Mahiao-Sambaloran (112.5 MWe Tongonan I)	Includes all 100 and 200 series wells.
c. Malitbog Field (Proposed Tongonan II)	Includes all 300 and 500 series wells.

The separation between the production and reinjection sectors for each of the resource field is determined by connecting the trace of the arc equidistant between the 250 m. drainage radii of adjacent wells allocated for production and wells likely to be used for injection. Between closely-spaced (<250 m. drainage radius) wells with overlapping drainage radii, the equidistant line is defined by connecting the points of intersection between drainage circles.

Segregation between production sectors within each field is described by grouping production wells according to: (a) similar well characteristics such as well location (with respect to field upflow, outflow regions and field margins defined by geophysical data) and production data (injectivity/transmissivity, total massflow, discharge enthalpy and downhole temperature profiles), and (b) distance between wellheads (with respect to the ease and economics of interconnecting wells to the most likely fluid collection and pipeline system).

2. Mahanagdong Field (Proposed Tongonan III)

A "positive" or identified resource that has been delineated by drilling, covers the area enclosed by the line connecting the 250 m. drainage radii of MG-1, MG-2D and MG-5D.

"Probable" resource areas exist to the southeast, southwest and north-northwest around the "positive" resource area. The SE and SW areas were defined on the basis of a 1400 m. throw radius from existing MG-1, MG-2D and MG-5D pads. The NNW resource covers the area within a 1000 m. throw radius from MG-1 and MG-B pads. This area may serve as a "buffer" zone between the "positive" resource and the reinjection sector further to the NW. The Mahanagdong reinjection sector is bounded roughly by wells TGE3, TGE7, TGE8 and MN1.

The inferences drawn above are combined in Figure 2 to give an estimate of the total greater Tongonan resource area. The area has been divided into blocks with each block in the Mahiao-Sambaloran-Malitbog areas assigned an average block temperature based on temperature contours while those in Mananagdong, were based on stabilized temperature profiles of the three completed wells.

B- **Reservoir Thickness**

A reject or minimum temperature of 180°C is assumed such that for the stored heat calculation, all the heat in the rock and fluids above 180°C only is summed. At the initial separation pressure of 0.77 MPa(abs), the temperature of the separated water is approximately 170°C and the energy contained in the hot water is not used and reinjected back to the ground. To account for some wells in the field not giving a good discharge when the production temperature is less than 180°C, the energy below this temperature is hence, neglected in the stored heat assessment.

In the Mahiao-Sambaloran-Malitbog areas, the upper reservoir limit is thus represented by the 180°C isothermal contour which varies across the area with the highest level at the upflow and lowest at the field margins. In Mahanagdong, the upper reservoir limit is defined by the mean depth of the 180°C formation temperature measured in the wells.

The lower reservoir limit is the> horizontal plane defined by the -2500 m. RSL subsurface depth, 350 m. beyond the deepest production bottomhole in 513D. The highest elevation for a production pad is 812 m. (403) and any well drilled to a depth of -2500 m. RSL at this elevation will have a total drilled depth of 3312 m. VD. This depth is within the capacity of PNOC Rig 10. It is also assumed that during production, heat is drawn off by the fluids not only from the lateral peripheries of the well but also from the bottom, therefore, the assumed "bonus" depth of 350 m. is deemed appropriate.

C. **Recovery Factor**

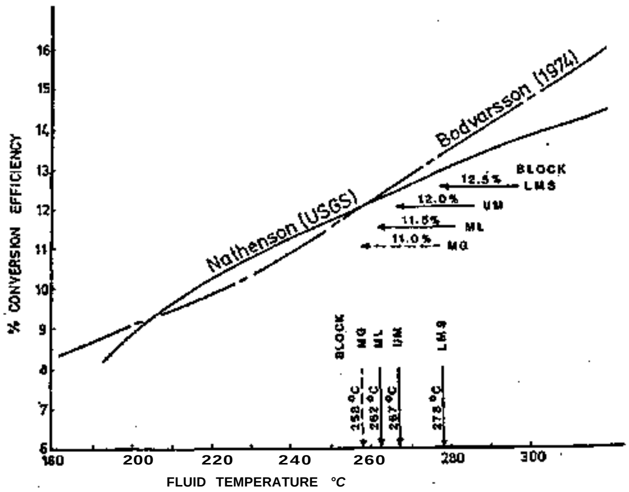
For an ideal uniformly permeable liquid-dominated reservoir, the recovery factor has been estimated at about 50% (Nathenson, 1975). To allow for the inhomogenous nature of the structures in the reservoir, this figure is reduced and a subjective halving of the ideal recovery factor has been suggested by Nathenson and Muffler (1975). A recovery factor, therefore, of 25% is used in the present stored heat assessment.

D. **Conversion Efficiency**

The question of how much of the recoverable thermal energy can be converted to electricity is really **a** function of the thermodynamic processess and the optimum plant/turbine specifications desired for each of the proposed new development areas. Assuming a 55 MWe plant unit, a conversion efficiency of 16% was calculated for a single-flash system based on design ratings of 0.668 MPa(abs) turbine inlet pressure, 52°C condenser temperature and a separator pressure of 0.77 MPa(abs).

Bodvarsson (1974), Bodvarsson and Eggers (1972) and Nathenson (1975) graphically illustrated the efficiencies of real thermal engines as a function of temperature (Figure 3). The graph is a representation of efficiency between energy and power generation varying with fluid enthalpy and source temperatures. *It is* logical therefore, to derive the conversion efficiency from this graph, given the mean resource temperature for each production block. Compared with the results of Nathenson and Bodvarsson, the assumed efficiencies for Lower Mahiao-Sambaloran (12.5%), Upper Mahiao (12%), Malitbog (11.5%) and Mahanagdong (11%) are conservative.

Figure 3. **Variation of Conversion Efficiency with Geothermal Fluid Temperature CReproduced from KRTA, 1980 based on data" from Bodvarsson C1974); Bodvarsson and Eggers (1972) and Nathenson 1975)11.**



E. **Load Factor**

A plant load factor of 0.80' is used which is conservative as compared to the projected average load factor of 0.70 for the entire Luzon Power Grid (NPC, 1986) assuming all the additional power that can be harnessed from Leyte will be exported via submarine cable to Luzon.

F. Plant **Life**

The designed life of a power station is usually taken to be 25 years (Watson, 1987).. This is the usual lifetime sought in a resource assessment and is therefore, used in our calculation.

o Stored Heat Calculation

A list of the assumed parameters used in the calculation is given in Table 2. Application of these parameters and of the temperature distribution within the resource block leads to the values of volumetric stored heat and power capacity contained also in Table 2 for each of the resource block and for Greater Tongonan as a whole.

Table 2. Summary of Stored Heat Calculation per Resource Block

TOTAL HEAT IN PLACE = DIFFERENCE IN HEAT CONTENT IN ROCK + DIFFERENCE IN HEAT CONTENT IN WATER

Ht = V x (T - To) X c:(l-i(i) X Cpr X *firi* + ϕ x Cp_w x/Un

POWER CAPACITY , PC = (H+ X R-F X CE-F) / CL-F X 25 YEARS)

ASSUMPTIONS:

To = ISO DE6. C.		R-F	= 257.
ρr = 2650 KB/CU. M.		CE-F	= 0.11, 0.115, 0.12 AND 0. 12E
Cpr = 0.9 KJ/KG °C		L-F	= 807.
ϕ = 0.10			

BLOCK	AREA sq.kn.	THICK-NESS k«.	VOL. cu.kn.	TENP. Deg.C	/OH kg/s	CpH kJ/kg C	Ht U or kH-sec.	Ht NHt-Yr.	Conv. EH.	Power Cap. HWe
LMS1	2.4		6.67	276.	757	5.180	1.63E+15	5.15E+04	0.125	80.5
LHS2	0.8		1.70	28B	735	5.390	4.67E+14	1.48E+04	0.125	23.1
TDTAL	3.2		B.37	M - 278					0.125	103.6
ML1	1		2.66	257	788	4.940	5.19E+14	1.65E+04	0.115	23.7
ML2	2		4.37	252	800	4.890	7.98E+14	2.53E+04	0.115	36.4
ML3	I.B		3.91	276	757	5.180	9.53E+14	3.02E+04	0.115	43.4
NL4	0.8		1.81	267	773	5.060	4.00E+14	1.27E+04	0.115	18.2
TOTAL	5.6		12.75	11 - 262					0.115	121.7
HS1	2.2	2.2	4.84	267	773	5.064	1.07E+15	3.39E+04	0.11	46.6
NS2	0.7	2.2	1.54	264	777	5.020	3.28E+14	1.04E+04	0.11	14.3
HG3	1.8	2.2	3.96	266	774	5.052	a.64E+14	2.74E+04	0.11	37.7
MG4	3	2.2	6.60	270	768	5.100	1.51E+15	4.78E+04	0.11	65.7
TOTAL	7.7	4.8	16.94	H - 268					0.11	164.3
Uin	2.7		7.24	284	743	5.314	1.91E+15	6.07E+04	0.12	91.0
UJI2	0.8		2.02	238	816	4.760	2.97E+14	9.42E+03	0.12	14.1
UH3	0.8		1.79	262	780	5.010	3.72E+14	1.18E+04	0.12	17.7
UM4	0.8		2.09	239	814	4.770	3.13E+14	9.91E+03	0.12	14.9
TDTAL	5.1		13.14	« -267					0.12	137.7
GRAND TOTAL	21.6		51.20	M - 268					0.116	527.3

The principal conclusions that can be drawn about the resource potential from the stored heat calculation are:

- o that approximately 10,510 Mwe-years of recoverable stored heat above a temperature of 180°C have been identified, of which 2755 Mwe-years is available for development in Upper Mahiao and 2435 MWe-years in Malitbog. The identified resource in these two areas corresponds to 260 MWe of electrical power suitable for utilization outside of Leyte's power demands.

- o that within a reach of 1400 m. of existing well pads, a further 3290 MWe-years of recoverable heat corresponding to 164 MWe of power is probable in Mahanagdong of which 932 MWe-years or 47 MWe has already been identified by drilling.

- o that the Greater Tongonan field has an overall potential electrical generating capacity of about 530 MWe for 25 years which includes the 112.5 MWe Tongonan I already in production. This leaves about 420 MWe still to be harnessed in the three proposed development areas around the current producing field.

Sensitivity Analysis

As shown by previous sectoral assessments and the current estimates for the various Greater Tongonan production sectors, the calculation of stored heat is in fact based on the parameters only in part known and involves assumptions and hyphotheses that *are* to a great degree subjective. Hence, the method is dependent on the geological situation, amount of subsurface information, the scope of investigation and the purposes for which the assessment is intended. It is imperative, therefore, to evaluate the practical limitations of the stored heat method using the assumptions and results of the Greater Tongonan assessment as our test data.

o Need for Sensitivity Analysis

Muffler and Cataldi (1978) have recognised that the principal weakness of the volume method concerns the estimation of the recovery factor and that the value chosen depends on the assumed fluid production model and then on the evaluation of how the recovery factor varies with temperature, effective porosity and depth for the particular model. Although there are some theoretical formulations and field examples that allow evaluation of the recovery factor for steam-producing systems, the estimation of a recovery factor for a hot-water system and the manner in which the recovery factor varies with effective porosity, are little more than educated guesses. Consequently, a sensitivity analysis was carried out to assess the extent to which the total power capacity estimate for Greater Tongonan responds to a change in recovery factor upon which the final estimate depends. Similar analysis was done for conversion efficiency, load factor, rock density, rock specific heat and porosity. The sensitivity analysis' functions were to establish the change in power capacity that results from a change in the chosen input parameter and to reveal the mimimum and maximum limits within which the power capacity can vary for each specified incremental change of the input, while other parameters remain unchanged.

o Choice of Individual Input Parameter Increment

The various input parameters analysed were made to vary according to individually specified constant step changes or increments. The choice of the amount of change for each input parameter has been taken on the basis of what others would perceive as the reasonable range of values for each of the parameters, if a similar stored heat calculation is conducted given the same Tongonan set of data. The choice and the range of values for each parameter is based on; physical measurements already taken such as rock density, rock specific heat and porosity, on historical NPC data for load factor and plant conversion efficiency, and from literature for estimates of recovery factor in real field situations applicable for hot-water systems similar to Tongonan. Each range of input parameter values, therefore, includes both pessimistic and optimistic considerations which do not deviate much from the initial values and assumptions used in the current stored heat calculation. The need to use a uniform increment, say 5% for each parameter was earlier recognized, however, the resulting range of values at this chosen step change, does not represent the realistic range of values that has been based on laboratory measurements. For example, at a 5% constant step change, the resulting range of values for rock specific heat is 0.5, 1.0 and 1.5 kJ/kg °C; for rock density 2518, 2650 and 2782 kg/cu. m. and; for porosity 0.05, 0.1 and 0.15. At the 5% step change, the conversion efficiency range is 0.05, 0.1 and 0.15 with the value of 0.05 quite unrealistic.

The incremental change ascribed to each input parameter is summarized in Table 3. Only one input parameter is made to vary at a time according to the given rate of change with the rest of the parameters unchanged for which the initial value indicated were taken. All the parameters were analyzed over five step changes.

Table 3. Input Parameters Analyzed and Corresponding Initial Value and Increment Change

PARAMETER	INCREMENT CHANGE	INITIAL VALUE	RANGE OF VALUE
1. Recovery Factor, Rf	5%	25%	15 - 35%
2. Conversion Eff., CEf	1%	10%	9-13%
3. Load Factor, Lf	5%	80%	75 - 95%
4. Rock Density, /Or	50 kg/cu *m*	2650	2500 - 2700
5. Rock Spe. Heat, Cpr	0.10 kJ/kg °C	0.9	0.07 - 1.10
6. Porosity, ϕ	0.02	0.10	0.04 - 0.12

o Results of Sensitivity Analysis

The relationship between power capacity versus each input parameter is best illustrated in graphs as shown in Figures 4-9. The graphs show that plots of power capacity and of the input parameters, all lie on a straight line. The straight line plots indicate that power capacity is a linear function of recovery factor, conversion efficiency, load factor, rock density, rock specific heat and porosity with the relation defined by the first-degree equation; y = a + bx , where a and b are constants and b is the slope, the ratio of the increase in power capacity over the increase in each of these input parameters. The slope of the line plots demonstrates that power capacity increases as Rf, CEf, ρ_r, Cpr and ϕ is increased except for Lf where power capacity decreases with increasing load factor.

Figure 4. Sensitivity of MWe vs Rf.

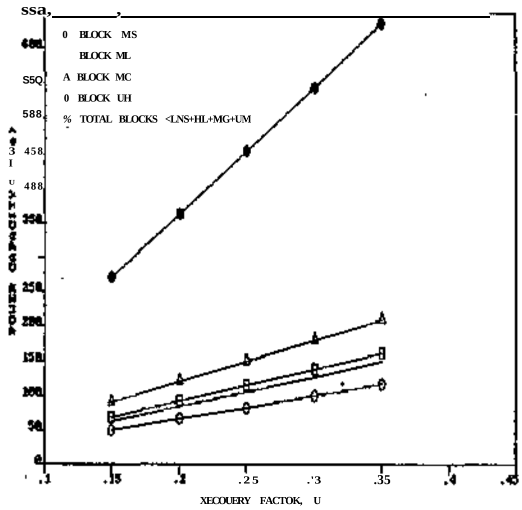


Figure 7. Sensitivity of MWe vs ρ_r.

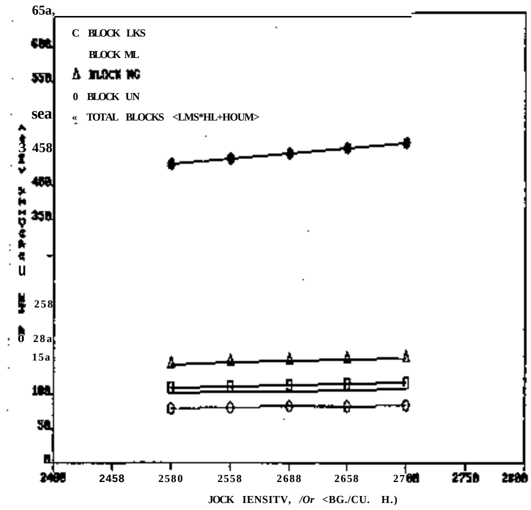


Figure 5. Sensitivity of MWe vs CEf.

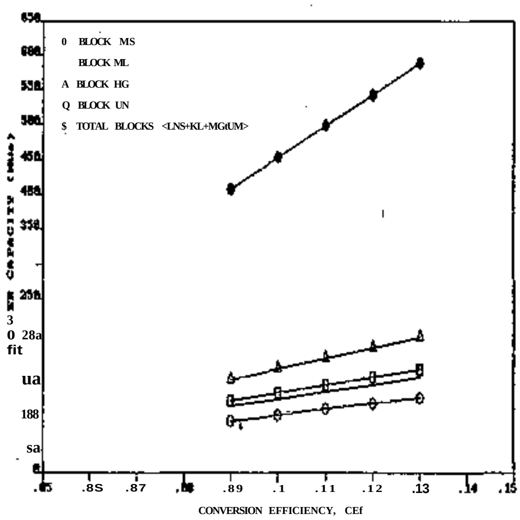


Figure 8. Sensitivity of MWE vs Cpr.

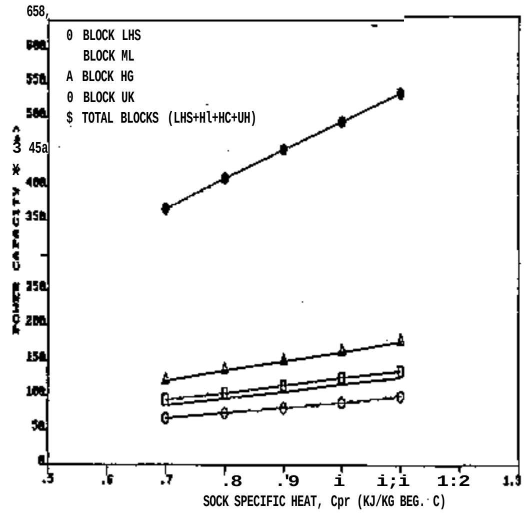


Figure 6. Sensitivity of MWe vs Lf.

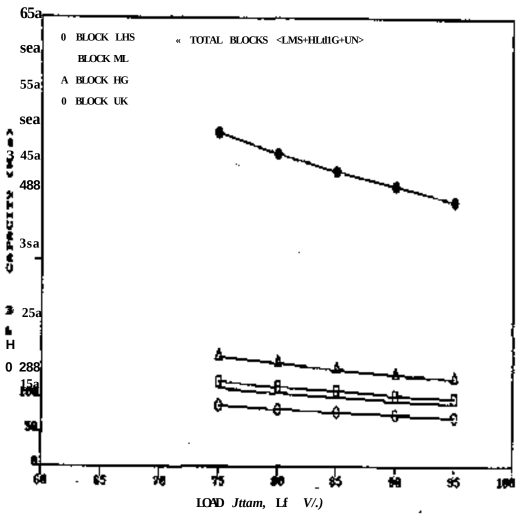
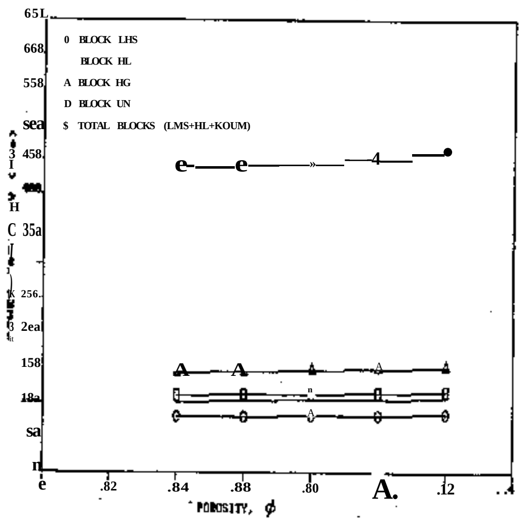


Figure 9. Sensitivity of MWe vs ϕ.



A relative and subjective scale was devised to show the degree of sensitivity and to best highlight the extent to which power capacity estimate varies with each input parameter. This is summarized in Table 4.

Table 4. Sunmary of the Sensitivity of Greater Tongonan Field Assessed Power Capacity to Rf, CEf, Lf, Cpr, /Or and *f*.

PARAMETER	RANGE OF PARAMETER	INCREMENT CHANGE	AVE. MUe CHANGE PER INCREMENT CHANGE	TOTAL MWe CHANGE OVER PARAMATER RANGE	DEGREE OF MUe SENSITIVITY
RECOVERY FACTOR Rf	15-35%	5%	91 (+24%)	362 (+133%)	HIGH
CONVERSION EFFICIENCY CEf	9-13%	1%	45 (+9%)	181 (+44%)	MODERATE
LOAD FACTOR Lf	75-95%	5%	25 (-6%)	102 <-21%?	SLIGHT
ROCK DENSITY /Or	2500-2700 kg/cu, m.	50 kg/cu. m.	7 (+1.6%)	29 (+7%)	NEGLIGIBLE
ROCK SPECIFIC HEAT Cpr	0.7-1.1 kj/k-g. °C	0.1 kJ/kg. °C	42 (+10%)	170 (+46%)	MODERATE
POROSITY ⌀	0.04-0.12	0.02	6 (+ 1%)	22 (+5%)	NEGLIGIBLE

HIGH = > 25% MWe CHANGE PER PARAMETER INCREMENTAL CHANGE
MODERATE = 24-10% MWe CHANGE PER PARAMETER INCREMENTAL CHANGE
SLIGHT = 9- 5% MWe CHANGE PER PARAMETER INCREMENTAL CHANGE
NEGLIGIBLE = < 5% MWe CHANGE PER PARAMETER INCREMENTAL CHANGE

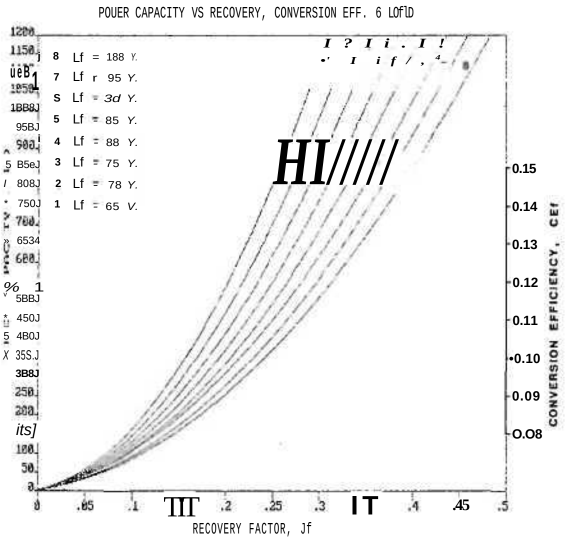
From the results of the sensitivity analysis, the following conclusions are drawn:

1. The power capacity responds variably to the various parameters for each specified parameter increment. Power estimate is most sensitive to variations in Rf, moderately sensitive to increments in CEf and Cpr, and slightly to almost insignificantly, to changes in *Lf,/Or* and *f*.

2. The power potential of the Greater Tongonan resource is estimated at a range of from about 270 MWe, representing the most reasonable pessimistic assumptions, to about 635 MWe which considers the more optimistic deductions.

The relationship between the parameters CEf, Lf and Rf wherein the sensitivity of power capacity is significant, is graphically illustrated in Figure 10 which provides for direct estimation of power capacity at any given value of CEf, Lf and Rf.

Figure 10. Power Capacity vs Recovery Factor (Rf), Conversion Efficiency <CEf) and Load Factor <Lf>.



HOH TO USE THE ERAPH:

1. 60 HORIZONTALLY FROK ANY GIVEN VALUE OF CONVERSION EFFICIENCY HITKIN THE CEI RANGE INDICATED.
2. LOCATE INTERSECTION OF CEf WITH THAT OF THE LINE PLOT CORRESPONDING TO THE EIVEN PLANT LOAD FACTOR. Lf.
3. DRAH A STAIGHT LINE FRON THE ORIGIN PASSING THROUGH THE CEf vs Lf INTERCEPT.
4. READ FRON THIS LINE THE POWER CAPACITY Mile) FOR ANY CHOSEN RECOVERY FACTOR.

CONCLUSIONS

Our stored heat calculation indicated a total power generating potential of about 530 MWe for 25 years for the Greater Tongonan field. This includes identified resource capacity of 104 MWe for the currently producing field in Mahiao-Sambaloran, 122 MWe in Malitbog and 138 MWe in Upper Mahiao. Both the Upper Mahiao and Malitbog areas, the northern and southern extensions of Mahiao-Sambaloran field, have been allocated as future development areas for power expansion. The optimum power plant capacity for each of the proposed Upper Mahiao (Tongonan IV) and Malitbog (Tongonan II) production field, therefore, is 110 MWe. This capacity is based on our conservative but reasonable assumptions for the various input parameters used in the resource assessment. A probable resource with a stored heat power potential of about 165 MWe exists in Mahanagdong, a separate system further south. Mahanagdong covers an area of almost 8 sq. km., based on a development reach of 1400 m. from existing pads. This area, however, would still require further well delineation and testing.

The total power capacity estimated for Greater Tongonan has been subjected to a sensitivity analysis. The power capacity responds variably to the different assumed values of the various input parameters and is most sensitive to Rf, less sensitive to values of CEf and Cpr and almost negligibly to Lf, /Or and *f*. Other power capacity estimates of lower (270 MWe) and higher (635 MWe) figures were also calculated which were dependent on the values of the input parameters representing either pessimistic or otherwise optimistic assumptions.

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