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FITTING THE POWER STATION TO THE GEOTHERMAL FIELD

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ABSTRACT

After the initial wells have been drilled in a new geothermal field there may be sufficient information to develop a prelimary mathematical model of the field. If the model includes formulae giving well output as a function of wellhead pressure and the total fluid draw-off then calculations of station performance over a period of say 30 years can be made for different power station configurations or separator pressure conditions. This paper presents the results of two exercises done to look at the feasibility of this type of analysis. One is based on a preliminary model of the Wairakei field and the other on a partial model of the Ngawha field.

It is concluded that the analysis is feasible and that it could be of assistance in determining the preferred station configuration and pattern of development.

INTRODUCTION

Unless stated otherwise the following text refers to the exercise based on the preliminary Wairakei field model. In the initial sections the basic concepts used will be described. Then follows a typical output from the program and some graphed results and finally some conclusions drawn as to the usefulness of the type of analysis presented.

ASSUMED STATION CONFIGURATION

It was assumed that the station would comprise high pressure (HP), intermediate pressure (IP) and low pressure (LP) sets. The inlet pressures for these would be in the range of 8 to 15 bar abs., 3 to 6 bar abs. and approximately 1 bar abs. respectively.

As indicated in Fig 1 geothermal fluid is assumed to be fed direct to both HP and IP separators. The LP separator is supplied with fluid from the IP Separator and the fluid discharged from the HP Separator forms part of the supply to the IP separator.

The initial development of the station assumes HP, IP and LP sets with a further development after 7 years of the operation in which the IP and LP sets are duplicated. The period of time between the two developments allows for a reassessment of the field capacity after the firsf-stage is commissioned.

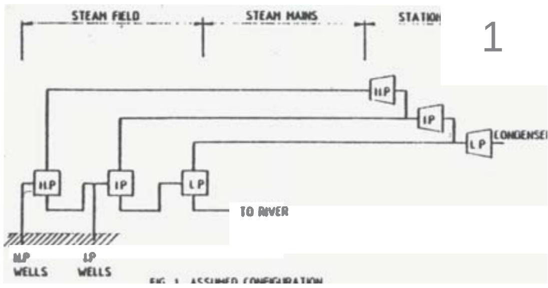

FIG 1 ASSUMED CONFIGURATION

BASIC OBJECTIVES AND OPTIMISATION PHILOSOPHY

The basic objective of the work presented in this paper is to develop a method of analysis that will help in making the best use of a geothermal resource. In terra of resource depletion the significant figure is the rate of fluid withdrawal. (This assumes a liquid dominated field.) The cost of obtaining a given flaw of geothermal fluid is dependent on the HP and IP wellhead pressures and the proportion of flow feeding each type of separator.

Prom the separators onward the plant should be optimised to rake the best use of the steam and gas flaw delivered from the separators. The program therefore includes a routine that optimises the diameter of each steam line and its insulation thickness. It is interesting to note the remarkably law figures for insulation thickness required, from economic considerations only, on the LP pipework. A calculation providing for the minimum insulation thickness necessary for personnel protection has not yet been included in the program.

The pipework optimising calculations and the other sections of the program use a sub-routine that calculates the total turbo-generator output. The steam pipe optimising calculations maximise the net value given by subtracting pipe costs from the value of the power generated.

Alterations in the diameter and insulation of the pipework cause variations in steam pressure and quantity at the turbine stop valve. The value of power generated should be adjusted to allow for consequent changes in the cost of turbo-generators and other equipment. Unless this is done the validity of the pipe optimisation my be questioned.

However, since pressure drop varies as the 5th power of diameter and cost approximately as the 2nd power an error in the actual value assigned to a kW of output does not affect the pipeline diameters or velocities very strongly. This can be seen from the pipework optimisation data given in Table 1 where the value placed on a kW of power is 75% of that for the optimisation in Table 2. In Table 1 the % figures show the change relative to the data in Table 2.

An economic comparison between different development options is made using the concept of net value which is the value of power generated less the cost of wells and pipework. However, as defined above it is only a very rough indication and could be misleading. It would be more useful it it allowed for changes in the cost of turbo-generators, the cooling system, transformers etc, and for changes in auxiliary power

TABLE 1

PIPE OPTIHISATION WITH VALUATION ON POWER AT 75% OF THAT ASSUMED FOR TABLE 2

TOTAL INSULATION COST	($M)	11.18 (-8.4%)
TOTAL PIPE COST EXCL INSULATION.	($M)	61.15 (-5.8%)
COST OF PIPE (EXCL. INSULATION)	($/KG)	6.08
COST OF INSULATION (EXCL. CLADD.)	($/CUB M)	1020.00
COST OF CLADDING	($/SQ M)	73.00

		MAIN LINES HP	IP	LP
NUMBER		1	4	4
LENGTH	(M)	3288.8	3200.0	3200.0
DIAMETER	(M)	1.21 (-4.0%)	1.01 (-4.0%)	1.00 (-3.0%)
MEAN VEL.	(M/S)	26.8 (+9.0%)	29.2 (+8.4%)	42.6 (+8.3%)
PRESS DROP	(MBAR)	736 (+23.2%)	586 (+20.8%)	345 (+18.3%)
INSULATION	(MM)	78 (-14.3%)	61 (-14.6%)	21 (-24.6%)
PIPE COST	($M)	8.01 (-6.6%)	23.21 (-5.8%)	22.64 (-5.7%)

TABLE 2
TYPICAL OUTPUT FROM PROGRAM

GEOTHERMAL FLUID FLOW		
AFTER COMMISSIONING STAGE 2	(TONNES/HR)	5949.30
WELLHEAD ENTHALPY	(KJ/KG)	1100.00
DISCOUNT RATE FOR ECONOMIC CALCNS	(%)	5.00
VALUATION ON POWER	($/(KW-YR))	242.00
FLUID DRAU-OFF OVER 30 YEARS	(MEGATONNES)	1382.61
TOTAL GENERATION OVER 38 YEARS	(GWH)	40703.23

PRESENT WORTH VALUE OF GENERATION	($M)	618.75
" COST OF WELLS	($M)	52.20
" COST OF STEAM PIPES	($M)	60.60
" COST OF INSULATION	($M)	11.38
NET VALUE (VALUE OF NET GENERATION LESS COST OF WELLS,PIPES AND INSULATION	($M)	486.57

***** SEPARATOR DATA AFTER COMMISSIONING STAGE 2 *****

HP SEPARATOR	PRESSURE	(BAR)	9.00
	TEMPERATURE	(DEG C)	173.95
	STEAW FLOW	(KG/S)	134.21
IP SEPARATOR	PRESSURE	(BAR)	5.00
	TEMPERATURE	(DEG C)	151.39
	STEAW FLW	(KG/S)	238.67
LP SEPARATOR	PRESSURE	(BAR)	1.43
	TEMPERATURE	(DEG C)	110.00
	STEAM FLOW	(KG/S)	99.25

***** TURBINE DATA AFTER COMMISSIONING STAGE 2 *****

TURBOGENERATOR OUTPUT TOTAL (DES)	(MW)	200.e3
EXHAUST TEHPERATURE OF TURBINE	(DEG C)	31.00
************** HP TURBINE ************		
ELECTRICAL OUTPUT	(MW)	12.38
STOP VALVE PRESSURE	(BAR)	8.40
STOP VALVE STEAM FLOW(EXCL GAS)	(KG/SEC)	133.51
STOP VALVE GAS FLOW	(KG/SEC)	1Q.36
************** IP TURBINES ************		
ELECTRICAL OUTPUT	(MW)	67.43
STOP VALVE PRESSURE	(BAR)	4.66
STOP VALVE STEAM FLOW(EXCL GAS)	(KG/SEC)	357.64
STOP VALVE GAS FLOW	(KG/SEC)	23.14
************** LP TURBINES ************		
ELECTRICAL OUTPUT	(MW)	120.30
STOP VALVE PRESSURE	(BAR)	1.12
STOP VALVE STEAM FLOW(EXCL GAS)	(KG/SEC)	432.45
STOP VALVE GAS FLOW	(KG/SEC)	23.14
THEORETICAL WETNESS AT EXHAUST	(%)	10.58

**** PIPE DATA - NO. OF PIPES IS FOR BOTH STATIONS ****
(PIPES ARE DESIGNED FOR VACWH CONDITIONS)

CONDUCTIVITY OF INSULATION	(W/M DEG C)	8.86
TOTAL INSULATION COST	($M)	12.21
TOTAL PIPE COST EXCL INSULATION.	($M)	64.94
TOTAL PIPE COST INCL INSULATION.	($M)	77.16
COST OF PIPE (EXCL. INSULATION)	($/KG)	6.00
COST OF INSULATION (EXCL. CLADD.)	($/CUB M)	1020.00
COST OF CLADDING	($/SQ M)	73.08

		FEEDERS HP	FEEDERS IP	FEEDERS LP	MAIN LINES HP	MAIN LINES IP	MAIN LINES LP
NUMBER		4	8	8	1	4	4.00
LENGTH	(M)	350.0	350.e	350.0	3200.0	3200.0	3200.0
DIAHETER	(M)	0.69	0.78	8.77	1.26	1.05	1.e3
MEAN VEL.	(M/S)	19.9	23.5	32.4	24.6	26.9	39.3
PRESS DROP	(MBAR)	78	54	31	598	486	292
MASS FLQU	(KG/S)	36.1	30.4	12.4	144.4	68.8	24.6
WALL THK.	(MM)	9.2	9.9	9.9	14.3	12.4	12.2
DES PRESS	(BAR)	19.7	20.3	21.7	19.7	20.3	21.7
INSULATION	(MM)	05	70	21	91	71	28
INS. COST	($M)	8.48	0.81	Q.68	1.64	4.97	3.80
PIPE COST	($M)	1.33	3.21	3.17	8.58	24.65	24.00

TABLE 2 CONTD.

YEAR	GEOTHERMAL FIELD							TURBINE						
	AQUIF PRESS DROP	TOTAL WELLS	SEPARATOR PRESSURES			GEOTH FLUID FLOW		STEAM FLOW			PRESSURES			MW OUTPUT
			HP	IP	LP	HP	IP	HP	IP	LP	HP	IP	LP	
	BAR		BAR	BAR	BAR	KG/S	KG/S	KG/S	KG/S	KG/S	BAR	BAR	BAR	MW
1	5.29	12	9.88	5.00	1.43	740.00	100.00	133.51	178.82	217.45	8.49	4.66	1.12	106.77
2	8.50	14	9.88	5.88	1.43	749.90	100.00	133.51	178.82	48.98	8.49	4.66	1.12	186.77
3	10.44	15	9.00	5.00	1.43	748.89	188.88	133.51	178.82	48.98	8.49	4.66	1.12	196.77
4	11.62	16	9.00	5.98	1.43	740.00	100.00	133.51	178.82	40.98	8.40	4.66	1.12	106.77
5	12.34	17	9.00	5.00	1.43	740.00	100.00	133.51	178.82	48.98	8.49	4.66	1.12	106.77
6	12.77	18	9.00	5.00	1.43	740.00	189.88	133.51	178.82	48.98	8.49	4.66	1.12	106.77
7	13.03	18	9.89	5.88	1.43	748.00	100.00	133.51	178.82	48.98	8.40	4.66	1.12	106.77
8	i8.31	31	9.88	5.80	1.43	748.88	912.58	133.51	357.64	432.45	8.49	4.51	1.12	200.02
9	21.51	37	9.88	5.98	1.43	740.00	912.58	133.51	357.64	432.45	8.40	4.51	1.12	200.02
10	23.45	43	9.00	5.00	1.43	740.00	912.58	133.51	357.64	432.45	8.40	4.51	1.12	200.82
11	24.63	49	9.00	5.00	1.43	749.88	912.58	133.51	357.64	432.45	8.48	4.51	1.12	200.02
12	25.34	53	9.00	5.89	1.43	740.00	912.58	133.51	357.64	432.45	8.49	4.51	1.12	200.02
13	25.77	57	9.00	5.00	1.43	748.88	912.58	133.51	357.64	432.45	8.48	4.51	1.12	200.02
14	26.94	68	9.00	5.88	1.43	740.00	912.50	133.51	357.64	432.45	8.40	4.51	1.12	200.02
15	26.22	61	8.98	5.08	1.43	728.46	928.81	132.83	357.64	432.82	8.31	4.51	1.12	199.65
16	26.31	62	8.81	5.00	1.43	718.84	934.99	139.71	357.64	432.52	8.22	4.51	1.12	199.27
17	26.36	63	8.73	5.00	1.43	709.64	943.02	129.63	357.64	432.58	8.15	4.51	1.12	198.98
18	26.39	64	8.66	5.00	1.43	701.96	949.83	120.64	357.64	432.45	8.89	4.51	1.12	198.71
19	26.48	65	8.60	5.88	1.43	694.83	956.34	127.71	357.64	432.41	8.03	4.51	1.42	198.46
20	26.48	66	8.54	5.00	1.43	687.99	962.62	126.82	357.64	432.38	7.97	4.51	1.12	198.22
21	26.49	67	8.48	5.00	1.43	681.30	968.76	f25.95	357.64	432.35	7.91	4.51	1.12	197.90
22	26.40	68	8.42	5.00	1.43	674.74	974.82	125.09	357.64	432.32	7.86	4.51	1.12	197.75
23	26.39	69	8.36	5.00	1.43	668.22	980.84	124.23	357.64	432.29	7.89	4.51	1.12	i97.52
24	26.39	70	8.30	5.88	1.43	661.74	986.84	123.37	357.64	432.26	7.75	4.51	1.12	197.29
25	26.38	71	0.24	5.08	1.43	655.28	992.81	122.51	357.64	432.24	7.69	4.51	1.12	197.06
26	26.37	72	8.18	5.00	1.43	648.83	998.76	121.64	357.64	432.21	7.64	4.51	1.12	196.83
27	26.37	73	8.12	5.00	1.43	642.38	1884.74	128.78	357.64	432.18	7.58	4.51	1.12	196.68
28	26.36	74	8.06	5.00	1.43	635.94	1010.68	119.91	357.64	432.15	7.52	4.51	1.12	196.37
29	26.35	75	8.00	5.00	1.43	629.51	1816.63	119.04	357.64	432.13	7.47	4.51	1.12	196.14
30	26.34	76	7.94	5.88	1.43	623.18	1822.56	118.16	357.64	432.10	7.41	4.51	1.12	195.91

NOTE - THE AQUIFER PRESSURE DROP IS AN INPUT TO THE FIELD DERATING FACTOR

consumption. It is possible to establish an adjustment of this sort which would apply for a given station configuration. The net value would then give a better Indication of *the* economic value of an increase in geothermal fluid flaw or of a change in separator pressure conditions.

Where a comparison is being made between developments having different configurations the basic cost difference due to the change in configuration would have to be considered (i.e. added or subtracted as appropriate from the difference in net value).

The investigation shown in Fig 4 for instance covers the range of outputs from 180 to *260* MW. From 180 MW to about 210 MW it is reasonable to consider a station configuration comprising 1 HP unit and 4 double flow IP/LP units. Above this output the extra cost of an additional IP/LP unit would need to be considered.

The pipe size optimising routine is a major contributor to the computer time required for the investigation. A separate investigation into optimum pipe sizes should yield a suitable formula for pipe size.

DETERMINATION OF WELL OUTPUT

In considering the Wairakei field it was evident that the spread of well characteristics had to be allowed for. A cumulative distribution function (CDF) of the maximum discharge pressures (MDP's) of the wells drilled prior to commissioning (excluding relatively shallow exploratory wells) was determined as shown in Fig 2.

In the program an iterative calculation is used to establish the proportion of wells feeding the HP separators. The flow *of* geothermal fluid from each well is obtained using a formula for well output in terms of MDP, wellhead pressure (WHP) and the field derating factor which is a function of the fluid withdrawal history. As already mentioned the field model is preliminary. It does not in fact represent the well characteristics in the early years *very* well.

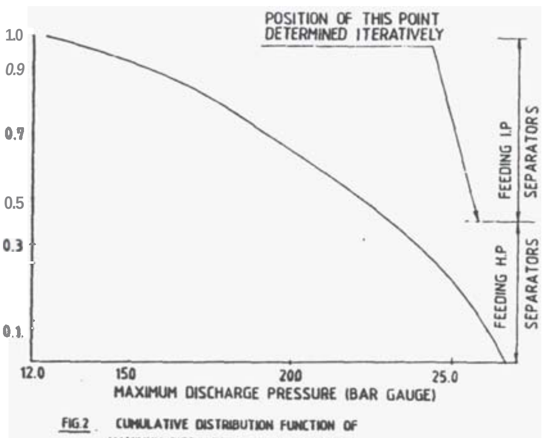

FIG 2 . CUMULATIVE DISTRIBUTION FUNCTION OF MAXIMUM DISCHARGE PRESSURE OF DEEP WELLS DRILLED AT WAIRAKEI UP TO 1959

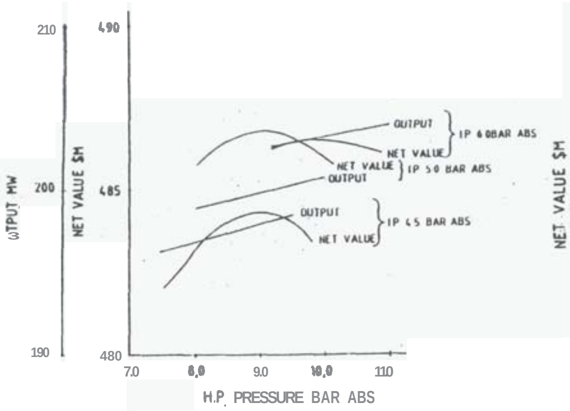

FIG 3 VARIATION IN OUTPUT (MW) & IN NET VALUE $M FOR VARIOUS COMBINATIONS OF H.P & I.P SEPARATOR PRESSURE

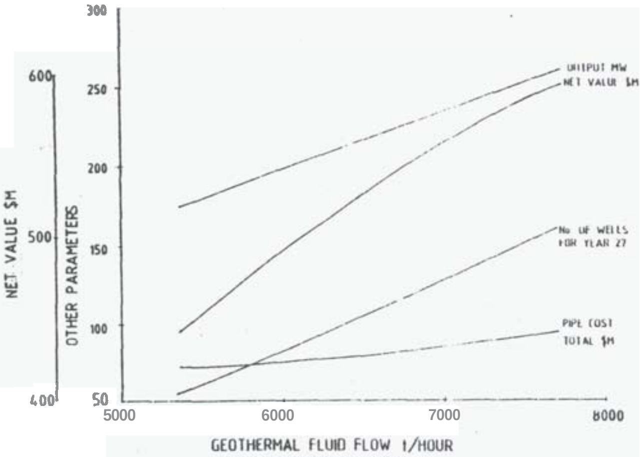

FIG 4 OUTPUT DATA FOR VARIOUS GEOTHERMAL FLUID FLOWS (H.P SEPARATOR 9.0 BAR ABS I.P SEPARATOR 5.0 BAR ABS L.P SEPARATOR 1.43 BAR ABS)

As well performance falls with depletion of the resource, the proportion of HP wells was limited on the basis that the lowest producing HP well must generate enough power to pay 50% of the amortisation annuity for a new well. From year *20* onwards, *to* avoid the calculations getting into a permanent loop, the minimum HP well flow was not recalculated.

This basis for derating HP wells is not ideal. A better system would be, for a given proportion of HP wells, to determine the total number of wells needed in a year and then to see whether a greater power output would be achieved by derating one HP well. If the answer is yes the derating of a second well would be tried and so on. Each step would require a reassessment of the total number of wells to maintain the IP steam flow. This calculation is not inherently difficult to program but the use of computer time on it was not considered as justified at this stage.

With a more realistic HP derating system it is considered that the HP sets would be decommissioned before year 25 which would allow the program to be amended to calculate the viability of wells drilled near the end of the station 'life' of 30 years. Clearly wells 'drilled' for the last year of operation are not viable. Even if the station lasted in practice for more than 30 years it is desirable in doing assessments involving comparative economics for all decisions within each set of calculations to be economically consistent.

GAS DISCHARGE

The gas present is assumed to be carbon dioxide. Its presence is accurately allowed for in calculating separator conditions, pipeline conditions and power output. The power required to extract gas from the condenser is not yet included. The formulae for specific volume, enthalpy and entropy of CO_2 were developed from references (1), (2) and (3). The analysis can therefore be used on fields having a high gas content.

RESULTS

The results as presented should be considered only as typical of the sort of output this type of analysis can provide.

Table 2 gives a typical output from the program. The HP and IP separator pressures of 9 bar abs and 5 bar abs have been selected as from Fig 3. it can be seen that these pressures give a higher net Value.

Fig 4 shows the net value, and other data graphed against geothermal fluid flow for stations based on 9 bar abs HP and *5* bar abs IP separator pressures. It can be seen that there is a strong incentive to use a high geothermal fluid flow. If the field has a high horizontal permeability a large number of wells may be acceptable.

The relatively small size of the HP set would suggest that a configuration omitting it altogether should be investigated.

THE NGAWHA INVESTIGATION

In the *case* of the Ngawha investigation the well output formulae related to reservoir level. Because there is little variation between Ngawha wells the use of a CDF of well characteristics was not required. The use *of* a reservoir level based model together with a lowest proven reservoir level gave a fixed volume of geothermal fluid, the use of which was to be optimised. This therefore was a simpler task. However, *the* confined dome of gas/steam over the Ngawha fluid makes the total analysis complex. The gas/steam will be discharged when the falling reservoir level allows the gas/steam access to the wells. Modelling the Ngawha field fully therefote awaits a model of the field which will simulate the operation of the gas/steam phase as well as the liquid phase. This could be of value when the further development of this field is contemplated.

CONCLUSIONS

Provided a mathematical model of a geothermal field can be developed, including well output as a function of wellhead pressure and the total fluid withdrawal it is possible to calculate station performance over a period of say 30 years. For these calculations it is important to establish the costs of wells, of piping and insulation on a rate basis, and the value of a kW of output. It is also important to establish any external limitations on for instance total fluid withdrawal or the maximum number of wells. The results of this analysis could help in determining the preferred pattern of development.

The concept of net value would he enhanced if it allowed for variations in costs downstream of the turbo-generator stop valves.

The scientist or engineer who develops the field model needs to work closely with the field development analysis so that due weight is given to the more significant aspects of the model. Because this was a preliminary investigation to prove a method the Wairakei model used was not refined.

ACKNOWLEDGEMENT

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