OPTIMISING NET TURBINE POWER FOR GAS CONTENT OF GEOTHERMAL STEAM

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ABSTRACT

The gas content of geothermal steam varies over a wide range and consists mostly of carbon dioxide. For equal weights, this gas is half as effective as steam when expanded through a turbine for power. Hence, its elimination from the entry steam - by chemical or other means - can reduce the electric energy generated by turbines which discharge to the atmosphere.

But for the more efficient ccndensing turbine (with vacuum exhaust), the reverse is true; this is because of the large amount of power required to pump the gases fran the ccndenser. If the gas cannot be economically removed to increase net power, then optimising leads to a specific condenser pressure required for any particular gas concentration in the steam. Graphed results present the relationship and permit ease of selection of the condenser vacuum pressure.

INTRODUCTION

Geothermal steam contains gas with a range fran virtually none up to all-gas; of this, most is carbon dioxide with only a small proportion making up the remainder of hydrogen sulphide, ammonia, methane etc. (typically less than 5 wt% of the gas), Ellis and Mahon (1977).

From the view-point of power station design, fields with steam of less than 10 wt% gas is of interest for large sized projects using turbo-generators-condensers although the less efficient atmospheric-exhaust turbine can be employed on high-gas fields, usually as a temporary expedient, until the gas declines below 10%.

To calculate turbine power the gas is, considered wholly carbon dioxide although for other purposes such as corrosion, McAdams et al. (1981), and condenser design, Hart (1980), the other gases would have to be taken into account.

The power potential of even gas-free steam is not easy to calculate and requires an iterative procedure developed by turbine designers who trace the locus of steam pressure and wetness through the machine fran entrance to exit, Wood (1960); for general purposes, a method of sufficient accuracy has been presented by James and Meidav (1977). This is adequate for gas contents of no more than several percent as applies to many geothermal fields (e.g. Wairakei and The Geysers).

For fields with higher gas content, its effect on power has to be accounted; an example of this was the U.N. assisted investigation of the Kizildere field in South-West Turkey where a typical value of 15% was analysed in separated steam at 6 bars pressure. Calculations of the power potential of this gas indicated that it was half as effective as an equal weight of steam when passed through a turbine, James (1972), and this was confirmed by Zancani (1975) on the Italian fields. More recently, a detailed fundamental study has been accomplished by Khalifa and Michaelides (1978) with the same result.

It has always been thought that the gas makes some positive contribution to geothermal power as it is possible to envisage a flow of all-gas passing through a turbine fran the inlet pressure to atmospheric exhaust - in effect, a kind of low-temperature gas turbine. In the case of the more efficient condensing set, however, a large amount of auxiliary power would be required to pump the non-condensible gas from the condenser (where it accumulates) to the atmosphere; this may reduce the net power to an uneconomic fraction of the gross, especially when the cooling water pumping power is also deducted.

As the ultimate purpose of a geothermal project is the employment of condensing sets, we shall attempt to satisfy the requirements of design engineers by estimating the net power, over a range of gas concentrations, inlet pressures and condensing (outlet) pressures.

Fortunately the power-life of geothermal systems is dependent on the value of turbine entrace pressure, James (1967), who advocated a pressure of 50 psig (4.46 bars) over a wide range of field fluid enthalpies. Here we shall take this value as a bottom limit and will consider also two other turbine inlet pressures of 100 psig (7.91 bars) and 150 psig (11.36 bars); pressures greater than 150 psig are definitely not recanmended other than for temporary expedients.

NET POWER OUTPUT FOR CONDENSING SETS

This is the difference between the gross power output and the total of auxiliary power;

the latter being mainly the sum of the gas and water pumping power. The gas has to be pumped out of the condenser against the vacuum and up to atmospheric pressure otherwise it will accumulate and raise the condenser pressure and reduce the gross power generated. Water pumps have to extract warm water from the base of the barometric condenser and discharge it at the spray zone within the natural draught tower for cooling. Once cooled, it usually does not require pumping into the spray zone of the condenser as the vacuum is sufficient to overcome the head as long as this is not excessive. Figures 1, 2 and 3 are plotted and the results given in both English and S.I. units for widest familiarity to engineers. It is clear from the figures that an optimum condenser pressure exists for each specific gas content of the turbine steam and that both these factors increase together so that, for example, a high gas of 30 wt% leads to a high condenser pressure of about 4 psia. Of course, one would have to be fairly confident of the stability of the gas content before investing considerable capital in the high cost of condensing sets which would necessarily be designed for a precise value. It is noticeable that a relatively greater power change with back-pressure is obtained at lower gas contents and a scrutiny of the figures inclines one against condensing sets at gas contents which exceed 10 to 15 wt% (which confirms the experience at Larderello). Over this gas range - up to 15 wt% - one value of condenser pressure at 100 millibars (1.45 psia or roughly 3 inches mercury) would be satisfactory for all three figures where inlet pressures are from 64.7 to 164.7 psia (4.46 to 11.36 bars), and is here recommended for geothermal systems where optimisation of net power is the criterion.

ECONOMICS

Economic aspects have already been studied, James (1970), both for separated steam transmission and for two-phase, steam-water transmission with the costs of wells, pipelines, power house etc. all taken into account. Optimising for minimum generating costs resulted in recommending a condensing pressure of about 5 inches mercury (2.45 psia, 169 millibars) over the range of gas contents examined, up to 25 wt%. This is still valid and will give the lowest cost for each unit of electric energy (kWh) generated, but of course, with a reduction in net power. The choice of which is the best condensing pressure obviously depends on which of these two competing factors dominates design criteria. And this depends, of course, on the cost of make-up energy, as has been mentioned. An increase in price of the latter shifts the optimisation to net power, whereas high inflation increases annual charges (loan payments and maintenance) and moves the optimisation towards minimising costs. Both these external factors of increasing costs (fuel or nuclear or other) are coupled to and often a reaction against high inflation with some kind of time-lag asymmetry operating; because of the complexities involved and the uncertainties in predicting the economic climate, it is probably best to 'boldly' take a condenser vacuum pressure of about 4 inches mercury (1.96 psia, 135 millibars) intermediate between the optima.

MERITS OF GAS REMOVAL

Is there any advantage in removing the gas (by chemical or other means) from the steamgas mixture entering the turbine. Aside from reduction-in corrosion potential, the power output of condensing turbines would increase when gas is removed. For example, if 100 KPH of steamgas flow containing 30 wt% gas enters a turbine at 64.7 psia, Figure 1 gives a net power of 2.9 MW(e) at the optimum condenser pressure of 3 psia. If the gas is now reduced to 0.5 wt% and the steamgas flow to 100 - (30 -0.5) = 70.5 KPH, the new power output

$$= \frac{70.5}{100.0} (5.12) = 3.61 \text{ MW(e)};$$ a power increase.

(where 5.12 MW(e) is the power for 100 KPH at 0.5 wt% gas at the new optimum condenser pressure of 1.0 psia).
Hence the net power is increased from 2.9 to 3.61 MW(e) due to the reduction in gas (approximately 24% increase in net power).

Because of this significant augmentation in net power from condensing sets, the reduction of high gas concentrations in geothermal steam should be actively pursued if gas stability is considered constant in the long-term and will not fall of its own accord under production.

High gas concentration is not, however, necessarily an adverse feature of geothermal steam as it can enhance the flow of low-enthalpy wells above that expected, by means of the gas-lift principle, James (1981).

CONCLUSIONS

Practical net power outputs of turbines operating on geothermal steam at various gas contents can be obtained fran Figures 1, 2 and 3 for condensing sets. Results are in good agreement with the fundamental study of Khalifa and Michaelides (1978) although their account ignored the requirements of water re-circulating pumping power and can be too high by roughly 15%.

Optimising for power output (maximum net power) or for economics (minimum generating cost) are both important when the strategy of geothermal power is being considered within an electric grid. Both these approaches are sensitive to the choice of condenser pressure selected, which is fundamental to such studies. In round terms, a condenser pressure of about 3 inches mercury will give close to maximum net power for gas contents up to about 15 wt%, while 5 inches mercury will minimise costs (101 and 169 millibars respectively. which alternative is adopted depends on the local view of the relative advantages of the competing factors, power and money (or which is in critical short-supply). A greater coverage of this subject is to be published in Geothermal Energy Magazine.

ILLUSTRATIVE EXAMPLE

If a million pounds per hour of geothermal steam containing 10 wt% of non-condensible gas, enters turbines at 100 psig (sea level installation), what is the best condenser pressure to maximise the net power?

According to Figure 2, the maximum power obtainable from 100 KPH is 4.57 MW(e) at a condenser pressure of 2 psia (138 millibars). Hence, for a million pounds/hour, the power would be 10 times as much, namely 45.7 MW(e).

REFERENCES

Ellis, A.J. and Mahon, W.A.J. (1977): Chemistry and Geothermal Systems. Academic Press, U.S.A.

Hart, W. (1980): Control of gas absorption in a geothermal-steam direct-contact condenser. Geothermics, 9, 3/4, 271.

James, R. (1967): Optimum wellhead pressure for geothermal power. New Zealand Engineering, 22, 6, 221.

James, R. (1970): Power station strategy. U.N. Symp. Development and Utilisation of Geothermal Resources, Pisa, Italy.

James, R. (1972): Further tests on the Kizildere geothermal field and a pre-feasibility study. U.N.D.P. Ankara, Turkey.

James, R. and Meidav, T. (1977): Thermal efficiency of geothermal power. Geothermal Energy Magazine, 5, 4, 8.

James, R. (1981): Large flows of low-enthalpy geothermal wells can be due to non-condensible gas-lift. Geothermal Energy Magazine (in Press).

Khalifa, H.E. and Michaelides, E. (1978): The effect of non-condensible gases on the performance of geothermal power systems. Report No. CATMEC/28, Brown Univ., Providence, R.I., U.S.A.

McAdams, G.D., Lichti, K.A. and Soylemezoglu, S. (1981): Hydrogen in steel exposed to geothermal fluids. Geothermics (in Press).

Wood, B. (1960): Wetness in steam cycles. Proc. Inst. Mech. Engrs. 1 Birdcage Walk, Westminster, London, 174, 14, 491.

Zancani, C.F.A. (1975): Summary of thirty years' experiencein selecting thermal cycles for geothermal power plants. Proc. Sec. U.N. Sympos. on the Develop. and use of Geo. Resources, Lawrence Berkeley Laboratory, Univ. of California, U.S.A.

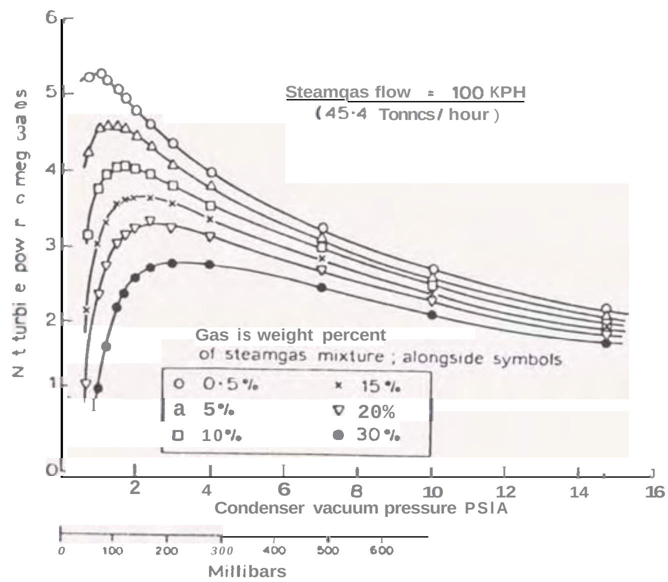

Figure 1. Net power from condensing turbine at various gas contents of steam. Entry pressure = 64·7 PSIA (4·46 bars).

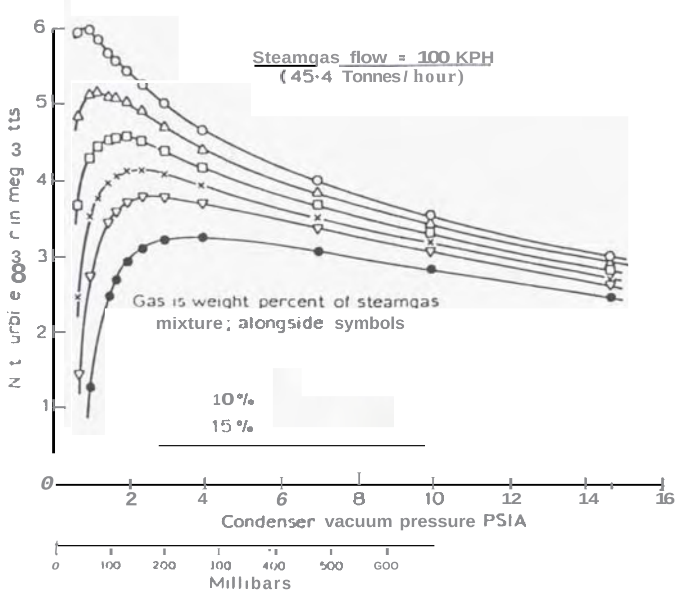

Figure 2. Net power from condensing turbine at various gas contents of steam.
Entry pressure = 114·7 PSIA (7·91 bars).

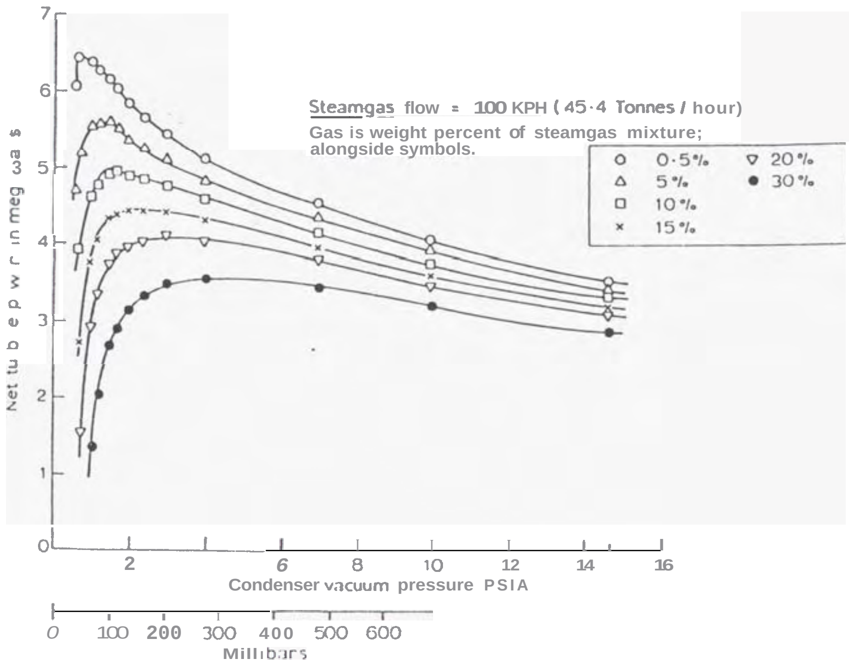

Figure 3. Net power from condensing turbine at various gas contents of steam,
Entry pressure = 164·7 PSIA (11·36 bars).