PERFORMANCE ENHANCEMENT OF HURGHADA GAS TURBINE PLANT USING Li-Br ABSORPTION COOLING SYSTEM

تحسين أداء محطة القوى الغازية بالغردقة باستخدام نظام تبريد بالامتصاص يعمل بمحلول بروميد الليثيوم

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خلاصة :

نتيجة لارتفاع درجة حرارة الجو في فصل الصيف في منطقة الغردقة بجمهورية مصر العربية ، فإن ذلك يؤدي الى خفض القدرة المولدة من محطات القوى الغازية المستخدمة في الحصول على الطاقة اللازمة خلال تلك الفترة . ونظرا لزيادة احتياجات الطاقة نتيجة لازدياد النشاط السياحي في هذه المنطقة مما يعني ضرورة تعويض الخفض في القدرة المولدة خلال شهور الصيف ، يتناول هذا البحث عرض تصور لتبريد الهواء المستخدم في التشغيل عند دخوله لضاغط المحطة الغازية باستخدام نظام تبريد بالامتصاص يعمل بمحلول بروميد - الليثيوم بهدف تحسين أداء المحطة . ويتم تشغيل نظام التبريد المقترح عن طريق الاستفادة من حرارة غازات عادم التوربين الغازي . وقد تم عرض وتحليل النموذج الرياضي المستخدم في هذه الدراسة والنتائج التي تم التوصل إليها ، وأيضا تم عمل مقارنة للقدرة المولدة من المحطة باستخدام نظام التبريد المقترح وتلك التي يتم الحصول عليها بدون تطبيق هذا النظام طوال شهور السنة . كما يتناول البحث عرض تأثير درجات حرارة الطقس المختلفة على أداء وحدة التبريد بالامتصاص المقترحة . وقد أوضحت النتائج مدى اعتماد الزيادة في القدرة المولدة على ظروف الطقس .

ABSTRACT

During the hot months of the year, high atmospheric temperatures cause reductions in net power output of gas turbine power plants . Because peak electric demand for many utilities occurs in the hot summer months, a traditional combustion turbine installation is at a disadvantage for summer peaking operation. When a utility needs electric generating capacity most, the combustion turbine's capacity is at its lowest level.

In the present work, description and analysis of the use of absorption Li-Br cooling cycle to enhance the performance of the Hurghada gas turbine plant through the improvement of inlet parameter are carried out. The plant consists of four General Electric gas turbines, each of them has a rated power of 25 MW In the proposed system, the cooling cycle is activated by heat recovered from the turbine exhaust.

A computer simulation that provides calculation of the performance of the plant is presented. Monthly values of the net power output, percetage increase in power output as well as performance of the cooling system are given with the corresponding weather conditions. Results of tha simulation model show that the percentage enhancement of the net power output depends on the weather conditions The results of tha present analysis validated the advantages of gas turbine cogeneration with absorption air cooling.

KEYWORDS

Gas turbine power enhancement, Li-Br absorption cooling cycle, ambient conditions.

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INTRODUCTION

Due to rapid increase in the world population and consequent energy demand, the power industry has recently been installing a large percentage of its new generation capacity in the form of gas turbines. They are relatively inexpensive and can be procured, designed and installed in less than two years. Since gas turbines consume air which is taken from the environment, their performance is strongly affected by the weather conditions. And because of gas turbines are constant-volume engines for which shaft horsepower is proportional to the combustion air mass flow, so the gas turbines output improves if the air temperature is depressed at the compressor inlet and air density increases.

One way of restoring, or even improving operating conditions is to add an air cooler at the compressor inlet. The air cooling system services to raise turbine performance to peak power levels during the months when the high atmospheric temperature causes the gas turbines to work at off-design conditions, with reduced power output plant.

There are many attempts carried out for using inlet air chilling in gas turbine power augmentation. Ondrays and Wilson [1] have made options in gas turbine power augmentation include absorption chiller, mechanical (electric driven) chillers and thermal energy storage. Lucia and Broncon [2] described the technical and economic advanteges of providing inlet air cooling system to increase the gas turbine's power rating and reduce its heat rate. The comparison study of cogeneration gas turbines with and without compressor inlet air cooling proves that, the power output may be increased by (18-19) percent when using an absorption unit to cool the compressor inlet air by (10 °C). Also the energy saving increases by (10-11) percent, with an increase in the efficiency of 5 percent. Hall and Stover [3] have studied an inlet air chilling systems, three types of inlet air chilling were considered: direct mechanical refrigeration, absorption refrigeration and thermal energy storage. The overall effect of net power produced for each scheme is 36.5, 36.3 and 37.8 MW respectively, which means that the thermal energy storage system may be considered as a mean to maximize chilled inlet air performance. The application of thermal (ice) energy storage for inlet air cooling of a combustion turbine is studied by Ebeling et. al. [4].

Because of the location of Hurghada is in the hot summer region in Egypt and as the electricity demand increases in this time of the year due to rapid increasing of the tourist activities, the study of performance enhancement of Hurghada gas turbine power plant, specially in the hot summer months, is more important.

CLIMATE DATA OF HURGHADA

The climatic data of Hurghada are given in Table 1. As shown, the maximum value of the dry bulb temperature (DBT) of about 34 °C can be reached during the month of August Where the minimum DBT of ambient atmosphere in this region occurs in January and it's value is 9.7 °C. Also, it can be observed that the temperature during the summer months from May to August is usually higher than 30 °C. On the other hand, values of the relative humidity (R.H.) are usually higher in cold months.

Maximum value of R.H of 59% is expected in Jan.. However, the values of R.H and DBT will determine the monthly values of the dew point temperature which will be considered as the minimum temperature of air, after cooling, at the compressor inlet.

Table 1 Climate data of Hurghada

Months	Jan.	Feb.	Mar.	Apr.	May	Jun.	July	Aug	Sep.	Oct.	Nov.	Dec.
T_{max}	21.5	22.5	24.6	27.5	30.5	32.2	33.5	33.9	22.0	29.6	26.5	23.9
T_{min}	9.7	10.3	12.8	16.4	20.1	23.8	25.0	25.2	23.0	19.8	15.8	11.1
RH	59	49	49	47	44	43	47	47	51	55	55	54

GAS TURBINE PLANT

The electric power station in Hurghada shown in Fig.1 consists of five General Electric (GE) frame gas turbine units with the data given in table 2, [5].

Table 2. Data of the Hurghada gas turbine unit

<table>
<tr><th colspan="2">Construction features</th><th>Gas turbine rating</th></tr>
<tr><td colspan="2">PG 55341
Generator drive
Simple cycle
one shaft</td><td>Base / Peak 23.45 / 25.25 MW
Inlet temperature 15 °C
Exhaust temperature 482 / 510 °C
Inlet pressure 1 atm.
Exhaust pressure 1 atm.</td></tr>
<tr><th>Compressor</th><th>Turbine</th><th>Combustion chamber</th></tr>
<tr><td>17 stages
Axial flow
5100 rpm</td><td>2 stages (single shaft)
rpm</td><td>10 chambers</td></tr>
<tr><th colspan="2">Fuel system</th><th>Generator</th></tr>
<tr><td colspan="2">Distillate No 2 oil
51 gpm</td><td>Air - cooled
28.9 / 31.2 kVA (Base / Peak)
3000 rpm
11000 kV
50 Hz</td></tr>
</table>

The aim of the present work is to study the annual performance of the Hurghada gas turbine unit when an absorption cooling system is applied to reduce the inlet air temperature of the cycle In the theoretical model, ambient air cooling up to the dew point temperature will be considered

DESCRIPTION OF THE PROPOSED SYSTEM

Figure 2 shows a schematic diagram of the proposed system, which contains the gas turbine power plant augmented by the absorption cooling cycle that uses lithium bromide-water solution As shown in the figure, the heat required for the generator of the cooling unit is taken from the heat recovery steam generator (HRSG) installed at the outlet of the gas turbine Steam is generated as a result of heat transfer between the exhaust gasses and water coming out from water tank in a closed cycle.

The absorption cycle consists of four main elements: generator, condenser, evaporator and absorber, water vapor is the working fluid and lithium bromide solution is the absorbent. The generator and the absorber which work at two different pressures are connected to each other through a solution pump and a pressure reduction valve. An expansion valve controls the flow of the refrigerant from the condenser to the evaporator.

The air flow cooled due to the heat transfer between the ambient air and the chilled water coming from the evaporator of the cooling unit through the heat exchanger installed at the compressor inlet. A cooling tower is used to dissipate the heat from the hot water coming from the condenser and the absorber of the cooling unit.

ANALYSIS OF THE PROPOSED SYSTEM

The performance curves of the gas turbine unit which are given in the manual [5] are used to estimate the changes of the output power with ambient conditions. In order to use these curves in the computer model, a curve fitting is applied to get the performance data in the polynomial forms.

Ambient air is cooled to the dew point temperature which is expressed as a function of dry bulb temperature and relative humidity [6] as :

$$t_{dp} = 16.5621 \ln(\varphi) + t_{db}, \ {}^{\circ}C \tag{1}$$

Where t_{dp} is the dew point temperature (C), φ is the relative humidity and t_{db} is the dry bulb temperature.

The extracted heat from air when it is being cooled can be evaluated from the following equation:

$$q = h_1 - h_2 \quad (kJ/kg) \tag{2}$$

Where h_1 and h_2 are the enthalpies of air before and after cooling respectively, h_1 and h_2 can be evaluated as follows:

$$h_1 = 1.006\ t_{db} + \omega_1\ (2501 + 1.87\ t_{db}) \tag{3}$$

$$h_2 = 1.006\ t_{db} + \omega_2\ (2501 + 1.87\ t_{db}) \tag{4}$$

Where ω is the specific humidity of air, it can be evaluated at saturation condition as a function of temperature as given in the following formula, [6]:

$$\omega = a * EXP(b * t_s) \tag{5}$$

Where: $t_s = t_{dp} / 25$

$a = 0.00431815, \qquad b = 1.5097$

The operating conditions and detailed analysis of the Li-Br cycle is given by Hamed [7]. Performance of an absorption refrigeration cycle using water-lithium bromide as refrigerant-absorbent combination depends mostly on the existing initial conditions. For example, The temperature of the evaporator is an initial parameter which specified by the system designer and as a result the low-side pressure of the cycle could be determined. Two other parameters depend on the ambient conditions, (dry cooling) are the condenser and absorber temperatures . In systems using a water cooled condenser and absorber these two temperatures are dependent on the temperature of the available cooling water. After the identification of the evaporator, condenser and absorber temperatures, the generator temperature can be determined.

Analysis of the thermodynamic cycle of the Li-Br absorption system shows that the minimum temperature required for generation in the cycle can be expressed as follows:

$$t_{g,min} = 183.3\, x^3_{min} + 25.05\, x^2_{min} - 14.35\, x_{min} + 1.2\,(t_c - 20) + 20.04,\ ^\circ C \qquad (6)$$

Where x_{min} (the minimum solution concentration) is given as:

$$x_{min} = 0.4 + 75 \times 10^{-4}\,(20 - t_e) + 0.006\,(t_{ab} - 30) \qquad (7)$$

Where t_c, t_e and t_{ab} are the condenser, evaporator and absorber temperatures, respectively.

The maximum temperature of the generator is calculated such that the solution concentration cannot exceed 0.6 to avoid crystallization of salt in the generator. On the other hand, the minimum temperature is determined to insure adequate heat transfer to the generator to start the separation of water vapor

If the cooling ratio of the Li-Br absorption cycle is considered against the operating temperatures of the cycle, the following approximate relation could be written as:

$$COP_{Li\text{-}Br} = 0.6\,[\,3.6631\{(t_c + t_g + t_{ab}) / 25\} - 0.05 + 0.1\,\{(t_c - 5) / 25\} - 2.49628\,] \qquad (8)$$

Where t_g is the generator maximum temperature which is given as

$$t_g = 52 + 1.116(\,t_C - 10\,),\ ^\circ C \qquad (9)$$

RESULTS AND DISCUSSION

The absorption cooling cycle performance is presented in Figs. 3 and 4, where the coefficient of performance which is the ratio between the cooling effect and heat added to generator is calculated at different temperatures. Fig. 3 shows the effect of absorber temperature on the COP at different evaporator temperatures It can be observed that, for a constant evaporator temperature, the value of COP decreases with increase in the absorber temperature However, in the condition of dry cooling, the absorber temperature depends on the ambient temperature Evaporator temperature must be selected to maximize the performance of the overall power plant, where the reduction of the evaporator temperature must increase the capacity of the power plant, but in the same time the COP of the cooling unit decreases. Therefore, the operating cooling temperature must be selected through the overall analysis of the gas turbine augmented by the cooling system. Also, the effect of the generator temperature on the performance of the cooling cycle is presented in Fig. 4 It can be noticed that the COP increases to a certain maximum value and then slightly decreases. However, a temperature control can be applied to lower the temperature of heat extracted from flue gasses through low pressure steam generator (Fig. 2). Theoretical results of the values of COP of the Li-Br absorption cooling cycle show that COP in the range of 0.6 up to 0.8 can be attained according to the operating temperatures. However, actual values of about 0.65 can be realized in this conditions.

Figure. 5 illustrates the annual variation of both the dry bulb temperature (DBT) and dew point temperature (DPT) of the weather condition of Hurghada. According to the assumption, air will be cooled from the (DBT) to the corresponding (DPT). Therefore, the cooling load of tha absorption cycle will vary through the year according to the difference between (DBT) and (DPT). The cooling load and the net power of the gas turbine, with and without cooling of ambient atmosphere is shown in Fig. 6

Power enhancement of gas turbine unit can be observed with application of inlet air cooling. It must be noted that the increase in power in hot months is limited because the drop in ambient air temperature is also restricted by the weather condition specially the relative humidity. However an increase in power output of about 10 % can be realized in June as shown in Fig. 7 which indicates the percentage increase in the power in the different months of the year.

The loads of the different elements of the absorption cycle (generator, condenser, absorber and evaporator) are presented in Fig. 8. As shown, the curves are nearly parallel because the performance of the absorption cycle in the given range of ambient temperature has a small changes, where the values of COP varies of only about 5% (Figs. 3, 4).

CONCLUSIONS

Power enhancement of Hurghada gas turbine using Li-Br absorption cooling cycle is described and analyzed. Theoretical calculations are based on inlet air cooling from the dry bulb temperature (DBT) up-to the corresponding dew point tamperature (DPT) The percentage increase in the power output of the gas turbine unit is shown to be highly dependent on the weather conditions (ambient temperature and relative humidity) Analysis of the monthly percentage increase in power output shows that a maximum value of enhancement of about 10 % can be realized in June. Also, the performance analysis of the absorption cooling cycle demonstrates the effects of different temperatures of the units of the absorption cooling system.

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NOMENCLATURE

a : constant given in eqn. (5)
b : constant given in eqn (5)
h enthalpy of air, (kJ/kg)
q heat extracted from air, (kJ/ kg)
t : temperature, (°C)
x solution Concentration.

SUBSCRIPTS

ab absorber
c condenser
db : dry bulb
dp dew point
e : evaporator
g generator
max : maximum
min minimum

ABBREVIATIONS

COP coefficient of performance
DBT dry bulb temperature
DPT dew point temperature

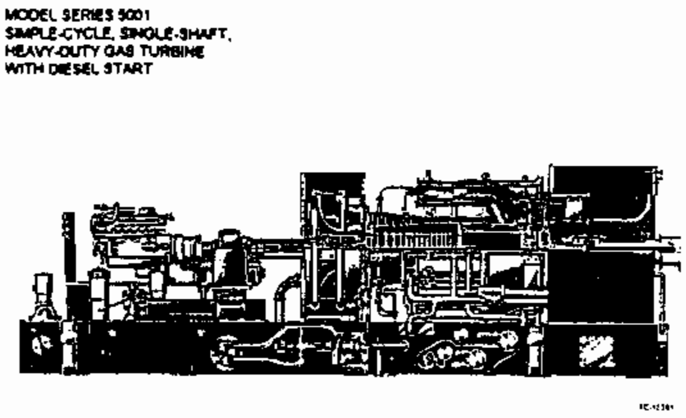

Fig.1 The Hurghada GE 25 MW gas turbine

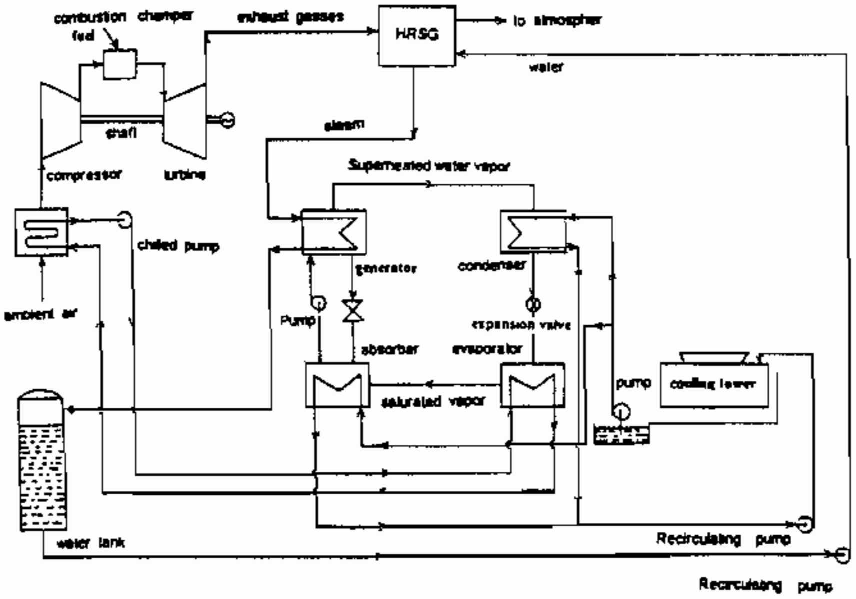

Fig.2 Schematic diagram of gas turbine plant augmented by the absorption cooling cycle

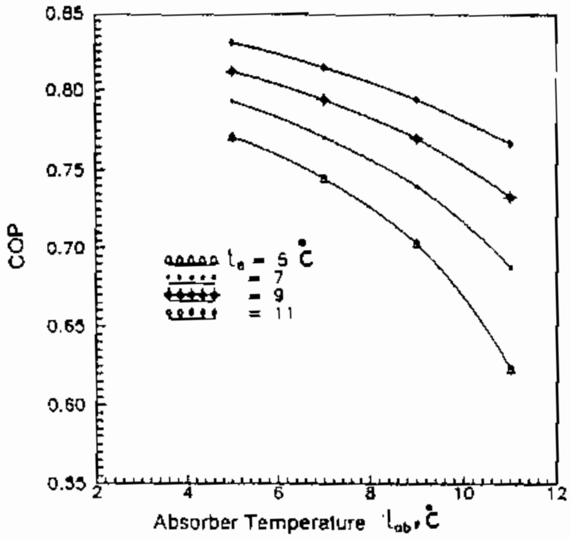

Fig. 3 The effect of absorber temperature on COP at different evaporator temperatures

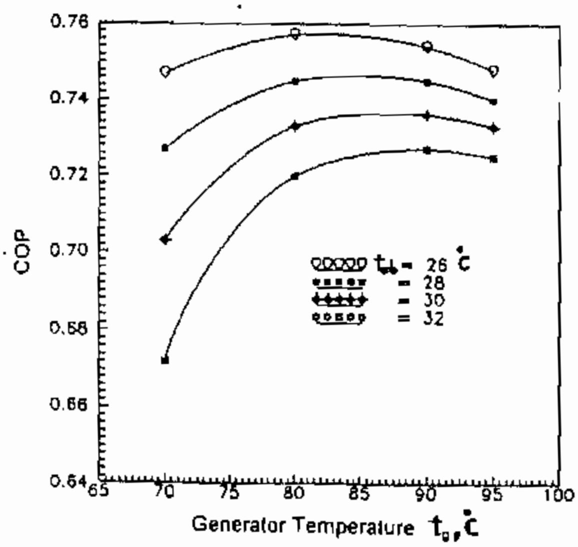

Fig. 4 The effect of generator temperature on COP with varying of absorber temperature

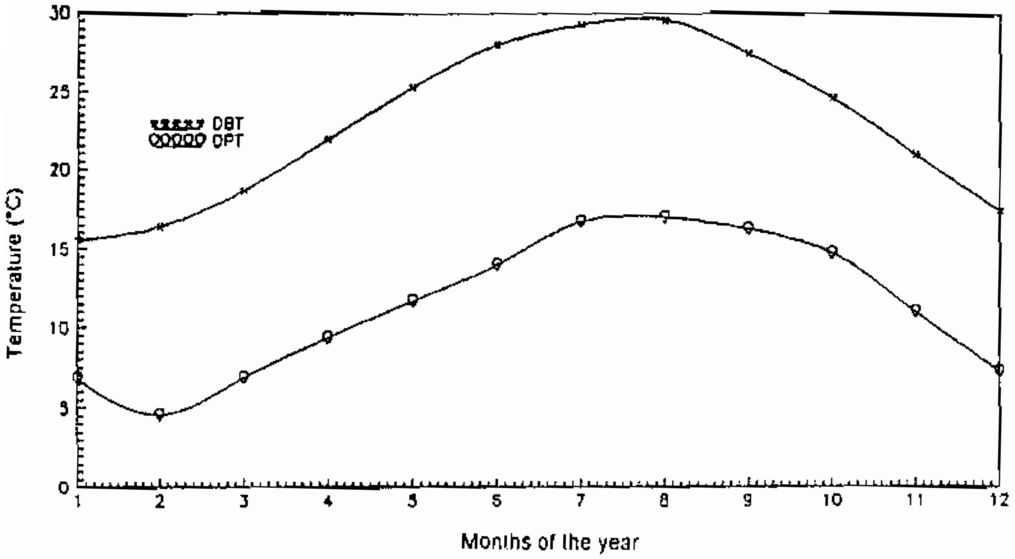

Fig. 5 Ambient conditions of Hurghada during the year

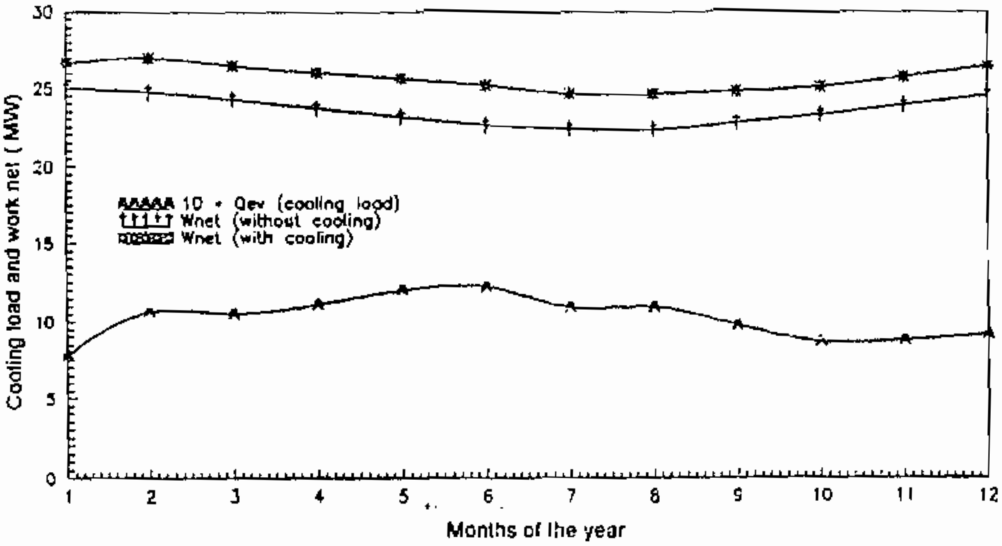

Fig. 6 Power plant performance with compressor inlet air cooling to corresponding dew point temperature

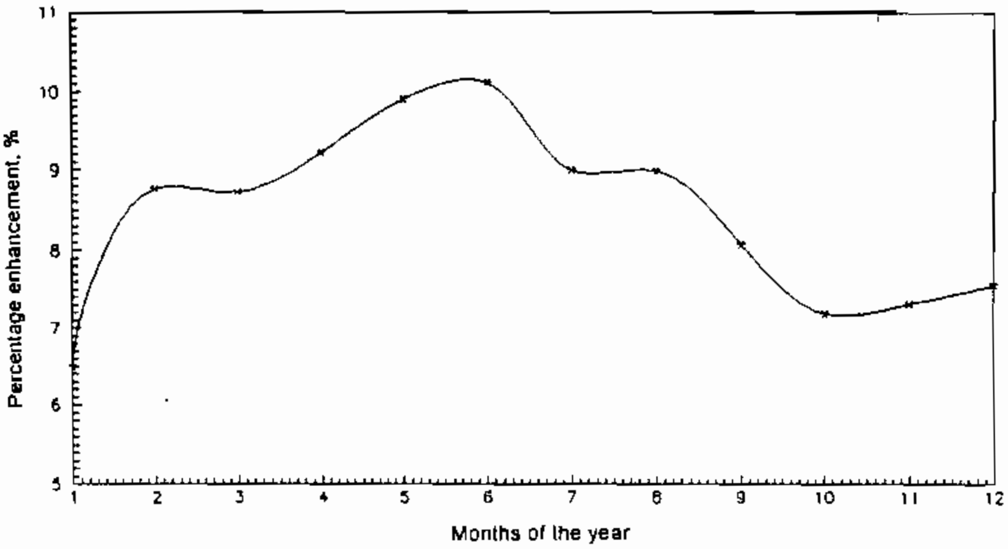

Fig.7 The percentage increase in power output when air is cooled to corresponding dew point temperature

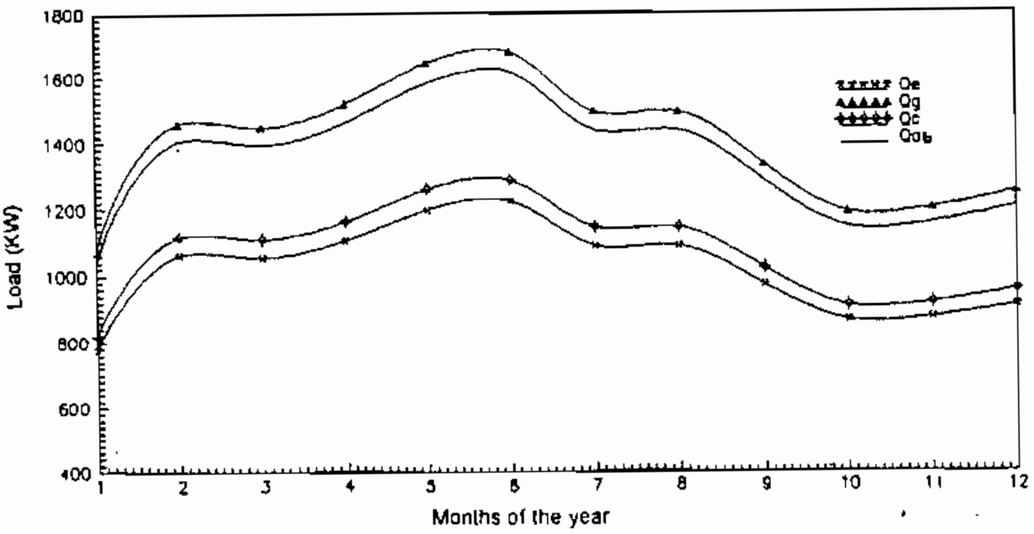

Fig.8 Generator, Absorber, Condenser and Evaporator loads during the year when air is cooled to the corresponding dew point temperature.