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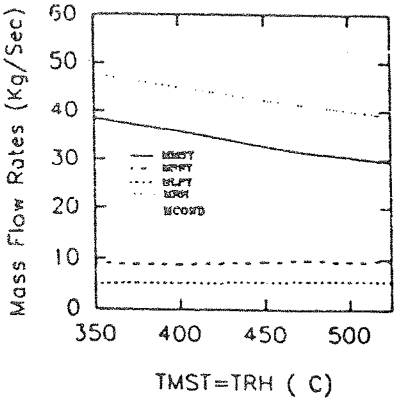

Fig.12

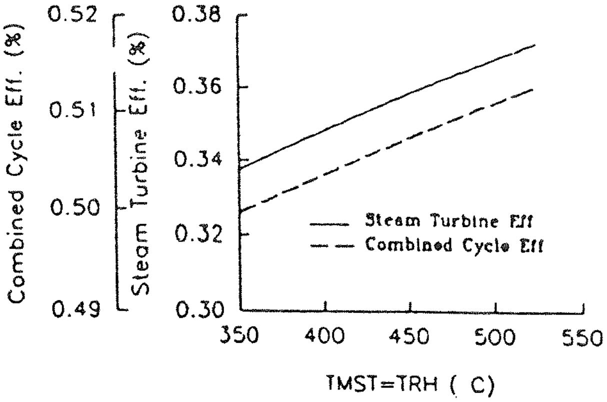

Fig.15

RESULTS FOR DUAL–PRESSURE BOTTOMING CYCLE

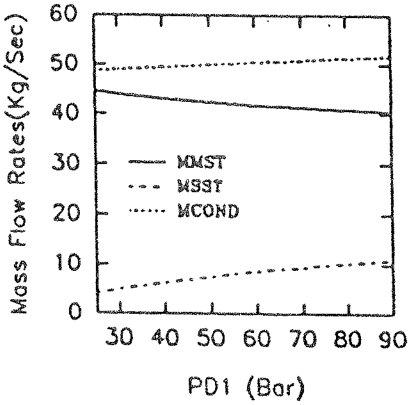

Fig.13

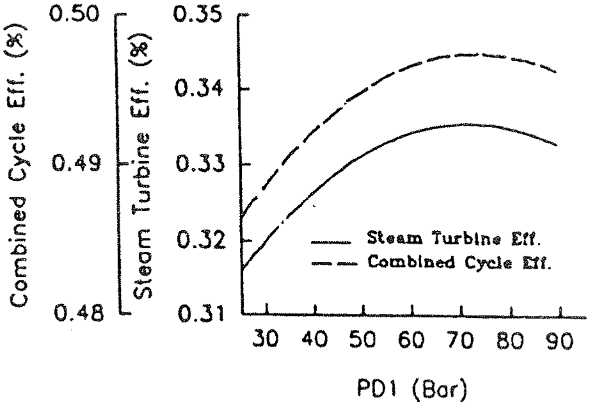

Fig.16

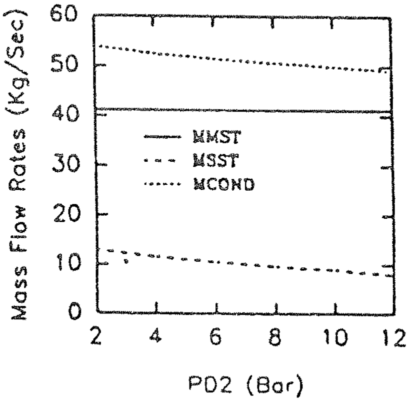

Fig.14

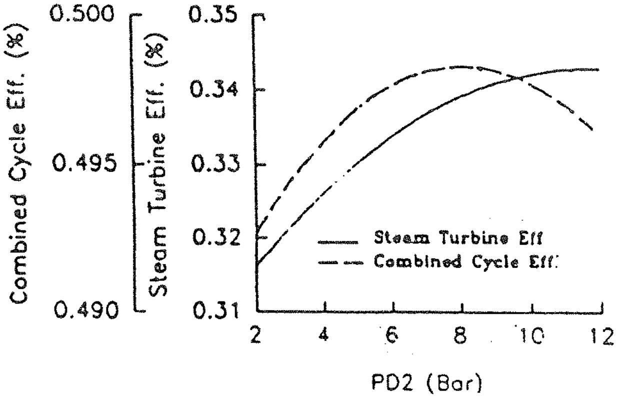

Fig 17.

RESULTS FOR TRIPLE - PRESSURE REHEAT BOTTOMING CYCLE

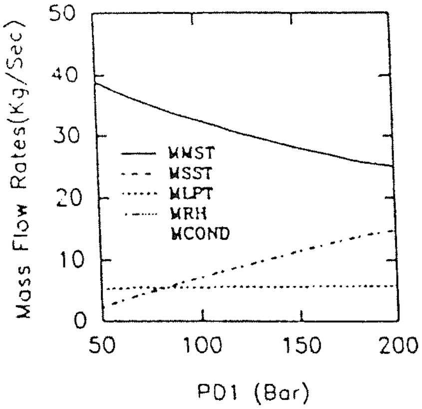

Fig.6

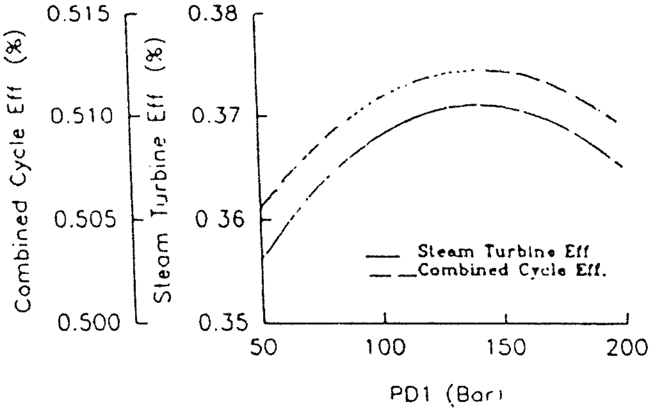

Fig.9

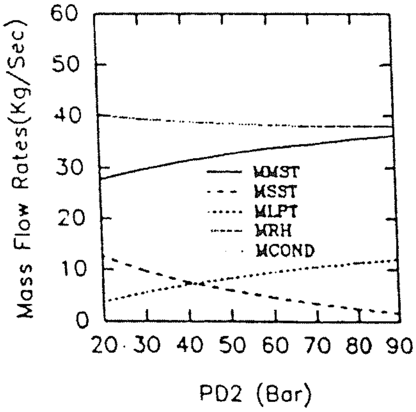

Fig.7

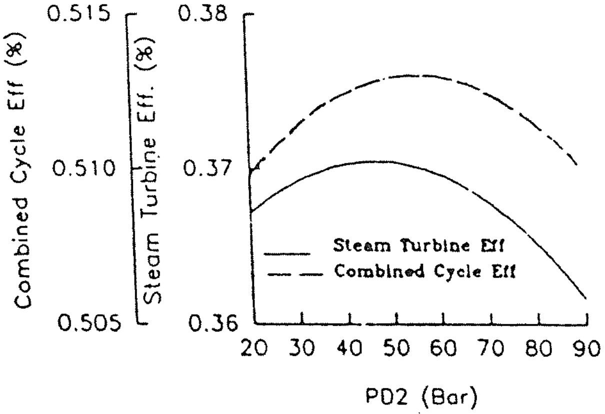

Fig.10

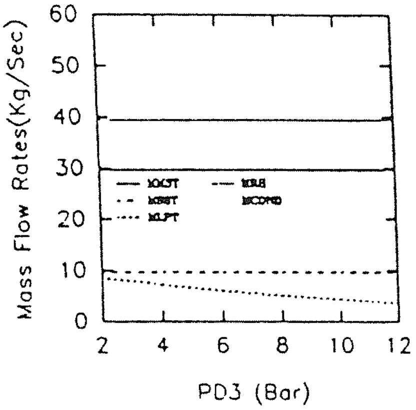

Fig.8

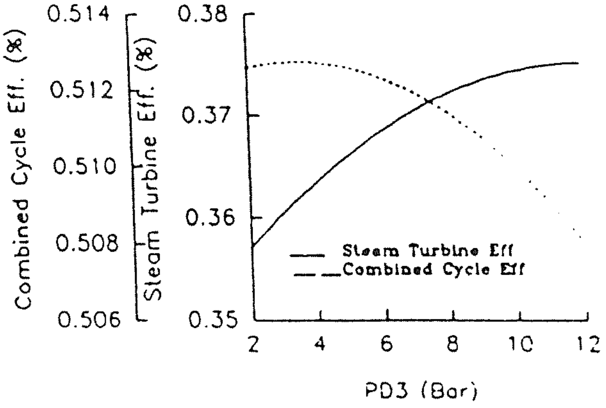

Fig.11

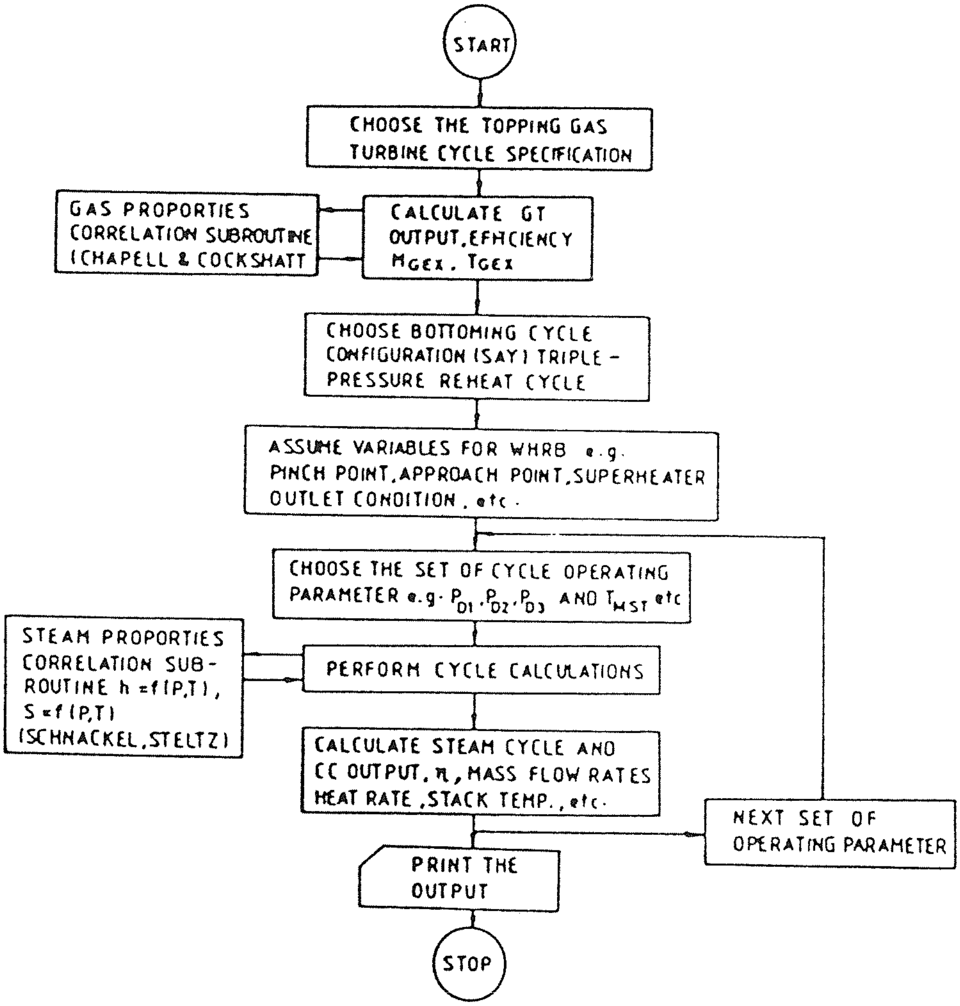

Fig.5 Flow diagram of computer programme used for parameter analysis

W = Work, KW

Subscripts

C, COND = Condenser

CR = Cooled reheat

D = Drum

FC = Saturated liquid

FLD = Flue gas discharge

GEX = Exhaust gases

HPEO = HP-economizer outlet

HPEX = HP-turbine exhaust

LPEO = LP-economizer outlet

LPEX = LP-turbine exhaust

LPIN = LP-turbine inlet

LST = Low Steam turbine

MST = Main steam turbine

PC = Condensate pump

P3 = HP and IP pump

RH = Reheat

SPEO = IP-economizer outlet

SPEX = IP-turbine exhaust

SST = Intermediate Steam Turbine

1,2,3 = 1st, 2nd and 3rd level in *Fig*.3 & 4

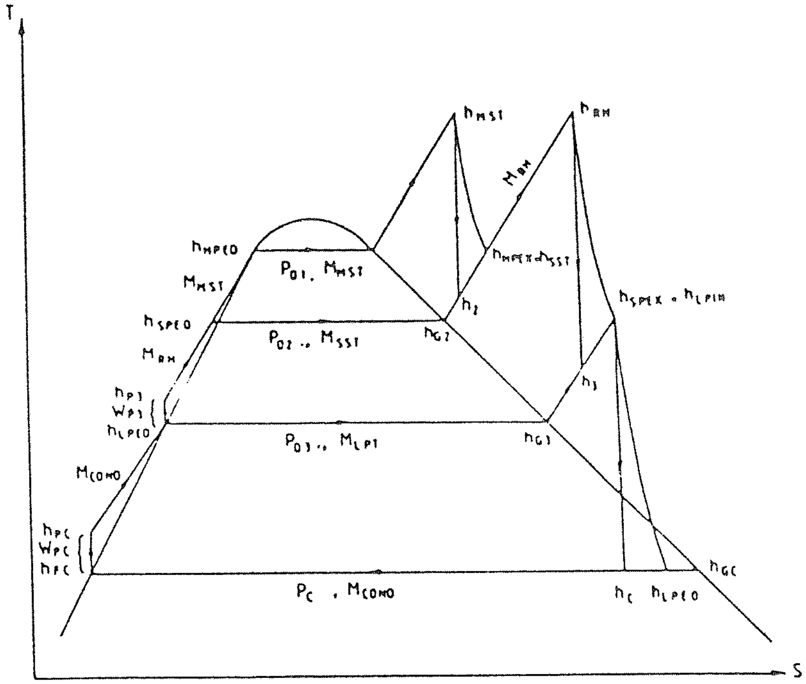

Fig 3. Schematk Expansion Line for Triple - Pressure Reheat Cycle

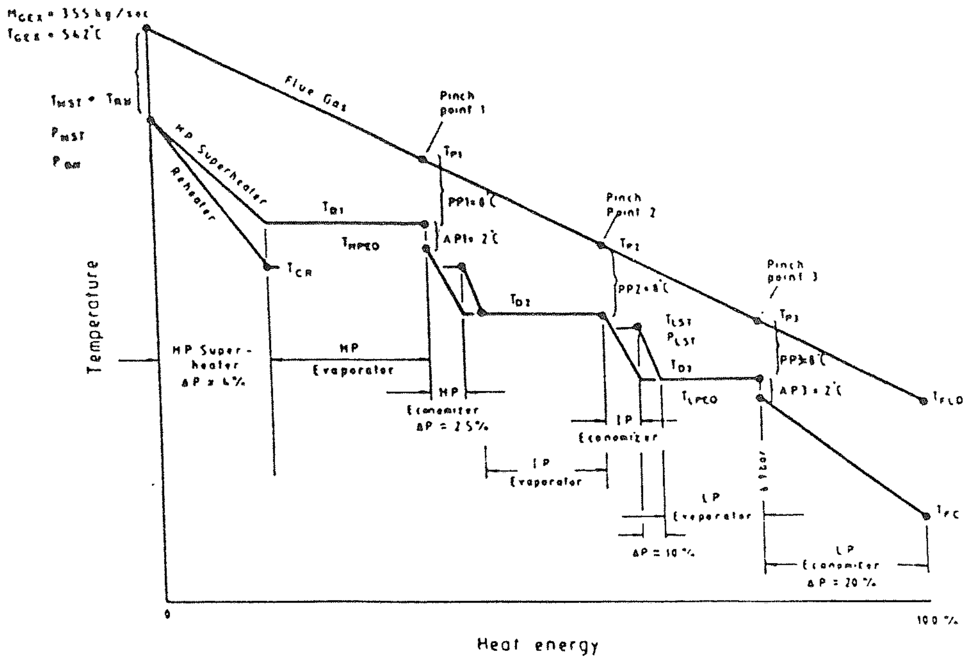

Fig 4. Temperature / Heat Energy Diagram

heat energy from GT at pinch point 1,2 and 3 and mass flow rates at different section are given below.

$$Q_{HP} = M_{GEX} (h_{GEX} - h_{p1}) \tag{1}$$

$$Q_{IP} = M_{GEX}(h_{p1} - h_{p2}) \tag{2}$$

$$m_{MST} = \frac{O_{HP} - \dfrac{Q_{IP}(h_{RH} - h_{CR})}{(h_{CR} - h_{SPEO})}}{(h_{MST}-h_{HPEO})+(h_{RH}-h_{CR})- \dfrac{(h_{HPEO}-h_{SPEO})}{(h_{CR}-h_{SPEO})} (h_{RH}-h_{CR})} \tag{3}$$

$$m_{SST} = \frac{Q_{IP}-m_{MST}(h_{HPEO}-h_{SPEO})}{(h_{CR}-h_{SPEO})} \tag{4}$$

$$m_{LPT} = \frac{Q_{IP}-(m_{MST}+m_{SST})(h_{SPEO}-h_{LPEO})}{(h_{LST}-h_{LPEO})} \tag{5}$$

A Suitable computer program has been prepared for this analysis incorporating correlations for calculation of steam properties [10,11] and gas properties [12]. the same programme can be used for different configurations given. The flow diagram given in fig. 5 indicates the calculation procedure for the above configurations.

Results and Discussion

As already mentioned parametric studies were conducted for CC constituted with a given GT configuration, coupled with a single-pressure, dual-pressure and triple-pressure reheat steam cycles configuration as shown in Fig.1. The WHRB steam output and efficiency is calculated for various steam generatoin pressure assuming fixed values of pinch point, approach point and superheater outlet temperature.

Typical results of the study showing the variation of mass flow rates, ST cycle efficiency and CC efficiency for change in various parameters such as P_{D1}, P_{D2}, P_{D3}, and T_{MST}, ect are given in Fig.6-17.

Fig 6,7 and 8 show variation in steam/condensate mass flow in various sections of boiler with change in HP, IP and LP circuits respectively.

Figs. 9,10 and 11 indicate variation in steam turbine cycle efficiency and total CC efficiency upon variation of pressure in HP, IP and LP circuits. It is seen from Fig. 9 that CC efficiency increases with rise in HP-drum pressure and then reduces. The optimum value for HP-drum pressure is in the range of 120-130 bar. Similarly Fig.10 given pattern of change in efficiency with change of intermediate circuit pressure, while Fig. 11 shows that same for LP-circuit. It is seen from Fig. 11 that though ST efficiency improves with higher LP-drum pressures, the best CC efficiency is obtained at pressure of approximately 4 bar.

Figs. 12 and 13 indicate variation in boiler flows and ST/CC efficiencies for various main steam/reheat steam temperatures. As expected the CC efficiency improves with higher steam temperatures.

Figs. 14-17 show similar results for a dual-pressure cycle. It is seen that best CC efficiency is obtained with HP-drum pressure of about 75 bar and LP-drum pressure of 7-5 bar.

Nomenclature

AP = Approach point °C
CC = Combined cycle
C_P = Specific heat, kJ/kgk
E = efficiency
GT = Gas turbine
h = Enthalpy, kJ/kg
HP = High pressure
IP = Intermediate pressure
LP = Low pressure
m = Mass flow, kg/s
P = pressure, bar
PP = Pinch point °C
Q = Heat energy, kj/s
S = Entropy, kJ/kg
ST = Steam turbine
T = Temperature, °C

Naturally, each of the above situations would require a different design and optimization strategy. In general, knowing the necessary input data pertaining to ambient conditions, the fuel used, component data, and the desired output requirements, the design point calculations can be performed by making suitable assumptions about component choice etc and following an iterative procedure [8,9]. For parametric optimization, however, computer simulation enabling performance prediction at design point as well as part load conditions is necessary. These require more detailed information about individual component characteristics and a suitable simulation procedure. An overview of the parametric investigations for some salient practical CC power plants has been given in this paper.

Waste Heat Recovery Boiler (WHRB)

The WHRB is the key component in the CC power plant, coupling the GT and steam turbine (ST) cycles, the design of which is crucial to performance of the CC.Obviously, this component is required to affect maximum heat recovery from GT exhaust bringing the stack temperature as close as possible to the acid dew point of exhaust gases, while keeping the pressure drop as well as the size of boiler within desirable limits. The factors which affect the cost and effectiveness of any WHRB are classified as, pinch point, approach point, allowable back pressure, stack temperature and steam pressure and temperature. The minimum temperature difference for heat transfer,which is known as pinch point plays an important role in identifying the optimum heat recovery and arrangement of heat exchangers. Approach point is the difference between saturation temperature of the fluid and water leaving economizer. Lowering approach point will increase probability of steaming in the economizer which may cause hammering and blanketing in economizer side. The allowable gas pressure drop through the heat recovery system can influence the design and cost of unit. As the back pressure is increased the boiler size is reduced. Also increase in back pressure decreases gas turbine expansion range, which inturn reduces power output of GT.

In the optimization of thermal conversion systems traditional first-law analysis based upon component performance characteristion coupled with energy balance normally leads to a correct final answer.However to asses the quality of overall energy conversion for a CC, exergy analysis or second-law analysis also will be desirable.

A Simplified Parametric Study

As described the design of bottoming cycle involves assumption of suitable values of a number of thermodynamic parameters, like boiler pressure, superheater exit temperature, approach point, pinch point etc. It is therefore necessary that a sensivitity analysis be carried out to identify the parameters which influence the system design the most. Such a study is the first step towards optimization of the system.

For the present analysis the CC consisting of a simple gas turbine of 102.6 MW and 32.6% efficiency of given design has been chosen and alternative bottoming cycles from a single - pressure non reheat cycle to triple-pressure reheat cycle without supplementary firing have been considered (Fig. 1).

The paramtric variation mainly pertains to bottoming cycle. Fig.2 shows a typical arrangement of triple-pressure reheat cycle and illustrates the heat transfer system of the WHRB. Fig.3 and 4 shows the TS-diagram and temp./heat transfer pattern of the WHRB of the bottoming cycle of a triple-pressure reheat cycle. The main governing equations for calculating efficiency and better output [3]. The drawback of this cycle is the use of supplementary firing.

Isothermal gas turbine combined cycle attempts to carryout the expansion as well as part of combustion, simultaneously in the turbine. The isothermal expansion path is divided into a number of segments of equal pressure ratio [4], where sufficient O_2 is added to restore temperature to that at the inlet stage. When all the fuel has been burned, the remaining combuster-turbine segments are treated as adiabatic expansion. Isothermal gas turbine combined cycle can provide better efficiency as compared to the normal Brayton cycle. The bottoming cycle for the above GT can be any one of the normal steam cycles.

Organic compounds, employed as working fluid for low temperature heat recovery, are found to exhibit a performance better than that of steam cycles. One such successful attempt is the Kalina cycle which uses a mixture of ammonia and water [5]. This pilot plant is expected to achieve a CC efficiency of 55 percent. The efficiency of this cycle is 1.6 to 1.9 times higher than that of Rankine cycle system.

In addition to above novel concepts which are mostly in the development stage the progress made in the technique of coal-gasification facilitates the use of combined cycle using coal as fuel. Such power plants are known as integrated coal gasification combined cycle (IGCC) and also some times uses the concept of pressurized fluidized bed combustor (PFBC)[6,7].

Design of Combined Cycle Power Plants

In the design of combined cycle power plants, three different design situations may be encountered in practice, e.g.

a) Designing the complete combined cycle power plant afresh for a given set of requirements.

b) Designing a suitable bottoming cycle for an existing design of GT power plant for waste heat recovery.

c) Conversion of an existing steam power plant into a combined cycle power plant by adding a suitable topping GT cycle along with modification in the steam cycle.

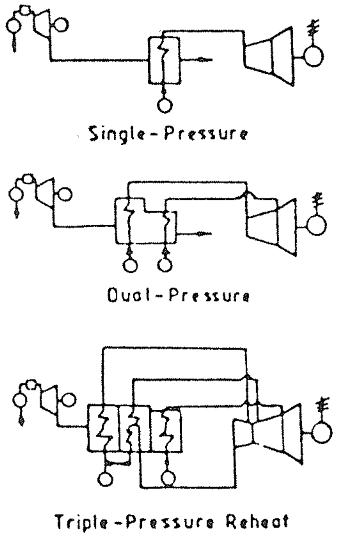

Fig 1. Combined Cycle Plant parformance with one Gas turbine

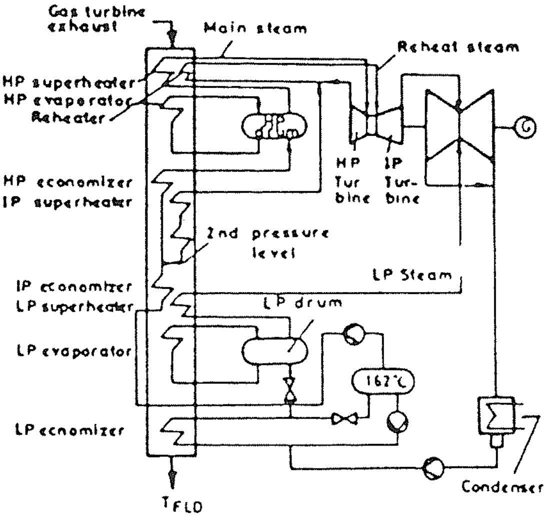

Fig 2. WHRB Diagram of Triple - Pressure Reheat Cycle

having small gestation period and low capital cost. But unfortunately, the overall efficiency of GT power plant is low and it was not possible so far to use coal in such power plants, hence these did not find wide application in the world. But with increased availability of natural gas, and also the feasibility of coal gasification it is desirable to make use of these power plants more widely. So to obtain higher overall efficiency as well as to reduce pollution it becomes essential to couple this gas-turbine cycle with a bottoming cycle using a waste heat recovery boiler (WHRB), thus yielding the combined cycle concept.

From the point of environmental pollution the combined cycle concept is very attractive. Usually the products of combustion the waste heat as well as noise are the main polluting factors affecting the environment. The exhaust gases may include. NO_x (NO, NO_2, etc.) CO, CO_2, unburned hydro-carbons, SO_2, SO_3, dust, heavy metals, chlorides, etc. The combined cycle power plant is beneficial in a number of ways, firstly because of its distinctly higher overall efficiency (45-50%), the thermal pollution (Waste heat into environment) is much lower. Also a high excess air coefficient results in more complete combustion, giving less CO or unburned gases, etc. Also, the large air flow in the system gives the advantage of diluting the pollutants. NO_x is accentuated only at high temperatures. With-high excess air flow the resulting peak cycle temperature are low, thereby reducing NO_x generation. Further, it is possible to use water/steam injection to a limited extent to cool the flame, thus reducing NO_x. The concentration of SO_2 , SO_3 depends mainly on the quality of fuel used, as GT generally uses selective clean fuels there is less problem of SO_2 and SO_3 pollution.

Alternative Combined Cycle Concept

During the last two decades a number of alternative ,Combined cycle concepts have been evolved. The simplest arrangement of course consisted of a simple GT coupled with a single-pressure bottoming Rankine cycle. However in this concept the waste heat utilization is not very effective both in terms of energy and exergy. The effectiveness can be substantially enhanced by employing a dual-pressure or a triple-pressure bottoming cycle with or without reheating. In selective cases the combined cycle using supplementary firing in a waste heat recovery boiler (WHRB)is also used with advantage. The other innovative concepts in combined cycles are

1. Cheng Cycle.
2. Aeroderivative combined Cycle.
3. Isothermal combined Cycle.
4. Kalina Cycle.

All the above systems are the combination of a simple GT coupled with new configuration of bottoming cycles, which would increase waste heat utilization and other performance features. In Cheng cycle, gases from a GT are used to generate steam in a WHRB. The steam produced may partly or totally be injected in the combustion chamber of the GT itself, which improves the power output of GT based on the increase of mass flow rate through the turbine, as well as reduces NO_x generation because of lower flame temperature, in the combustion chamber [1]. The Japanese government started a national project for energy conservation called the Moonlight Project [2] based on this cycle.

The Aeroderivative system is a combination of GT with a novel steam bottoming cycle, consisting of a steam compressor, high temperature steam turbine, high pressure steam turbine and a condensing turbine, which produces maximum steam condition at 25 bar and 800 -850°C, that ensures high thermal

UNDERSTANDING THE CHARACTERISTICS AND POTENTIAL OF COMBINDED CYCLE POWER PLANTS

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ABSTRACT

Combined cycle power plants using different configurations coupling gas turbine topping cycle and steam turbine cycle are becoming attractive as these are more efficient and less polluting to the environment. with increased availability of natural gas in India the combined cycle power plants are becoming more popular. This paper, after making a brief review of alternative combined cycle concepts presents a simplified parametric analysis of combined cycle configurations using a simple gas turbine cycle with dual-pressure and triple-pressure reheat bottoming cycles. The salient features of computer program used are given and typical results are presented, bringing out some aspects of the combined cycle characteristics.

INTRODUCTION

With the twin-crises of energy resource depletion and pollution increasingly engulfing our civilization, it has become very crucial to develop more efficient and less polluting thermal power plants, which are capable of effectively utilising fuels like coal and natural gas etc. instead of the more scarce liquid petroleum fuels. For this purpose, the concept of combined cycle power plants is very attractive and is gaining prominence. In India, coal is quite abundant and,lately, there is increased availability of natural gas as well.

A combined cycle (CC) is defined as production of power in two steps firstly a gas-turbine (GT) cycle providing part of total power and exhausting to a waste heat recovery steam cycle, which generates the rest of the output.

Gas turbines have, by now proven to be very compact and reliable type of power plants