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Performance of the Integrated Gas and Steam Cycle (IGSC) for Reheat Gas Turbines

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ABSTRACT

In 1978, the Japanese government started a national project for energy conservation called the Moonlight Project. The Engineering Research Association for Advanced Gas Turbines was selected to research and develop an advanced gas turbine for this project.

The development stages were planned as follows: First, the development of a reheat gas turbine for a pilot plant (AGTJ-100A), and second, a prototype plant (AGTJ-100B). The AGTJ-100A has been undergoing performance tests since 1984 at the Sodegaura Power Station of the Tokyo Electric Power Co., Inc. (TEPCO).

The inlet gas temperature of the high pressure turbine (HPT) of the AGTJ-100A is 1573K, while that of the AGTJ-100B is 100K higher. Therefore, various advanced technologies have to be applied to the AGTJ-100B HPT. Ceramic coating on the HPT blades is the most desirable of these technologies.

In this paper, the present situation of development, as well as future R & D plans for ceramic coating, is taken into consideration. Steam blade cooling is applied for the IGSC.

INTRODUCTION

Since 1978, The National Research and Development Program for The Energy Conservation Technology, called the Moonlight Project, has been conducted by the Ministry of International Trade and Industry (MITI) of Japan.

Under the master program, a new combined cycle plant having a target total efficiency of 55% has been under development at the Engineering Research Association for Advanced Gas Turbines. This high efficiency combined cycle plant consists of a high efficiency reheat gas turbine and a conventional steam turbine.

As the first step, the AGTJ-100A reheat gas turbine has been developed for a pilot plant whose target combined cycle efficiency is 50%. The AGTJ-100A is a twin spool reheat gas turbine with an intercooler, which is a water spray type direct heat exchanger. The high pressure system consists of the High Pressure Compressor (HPC), high pressure combustor (HC) and high pressure turbine (HPT). The intermediate turbine (IPT), reheat combustor (RH), low pressure turbine (LPT), and low pressure compressor (LPC) comprise the other spool.

In the case of the IGSC evaluation, superheated high pressure steam is injected into the front of the HC and then superheated much higher to the HPT inlet temperature. This is the key point for the IGSC to maintain high plant thermal efficiency. See references at the close of paper.

Conditions of the IGSC

The reheat gas turbine inlet temperature is 1300°C for the HPT and 1175°C for the LPT, which is the same as the level in the reheat gas turbines being developed under the Moonlight Project in Japan. The cooling blade/nozzle metal temperatures are 800°C/850°C, which are also the same as in the Moonlight Project. The HPT, IPT and LPT are all steam cooled. Furthermore, the inlet gas temperature of the RH is always kept at 800°C in order to protect it from high temperature damage.

Cycle Pressure and Thermal Efficiency of the IGSC

When the temperature conditions of the IGSC are decided on, the next question is how to choose the cycle pressure and the distribution of the pressure ratio between the LPC and HPC.

Fig. 1 shows the plant thermal efficiency characteristics of the IGSC by the two parameters of cycle pressure and LPC/HPC pressure ratio. The efficiency increases as the cycle pressure increases and the LPC pressure ratio decreases.

This means that the plant thermal efficiency increases as the cycle pressure decreases, if the LPC pressure ratio decreases even further. However, the LPT outlet temperature increases as the cycle pressure decreases and the influence of the LPC pressure ratio on the LPT outlet temperature is very small. The characteristics of the LPT outlet temperature according to the cycle pressure are shown in Fig. 4. Hence, the minimum cycle pressure depends on the maximum temperature selected for the LPT outlet.

The assumed efficiency and pressure loss is shown in items (1) - (23) below. The efficiency of the turbines and compressors is defined in terms of polytropic efficiency in order to prevent the influence of pressure ratio deviation.

The steam and air cooling flow to the blades and nozzles is calculated based on the model of cooling

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effectiveness shown in Fig. 2.

(1)	LPC efficiency (Polytropic)	91%
(2)	HPC efficiency (Polytropic)	90%
(3)	HPT efficiency (Polytropic)	85%
(4)	IPT efficiency (Polytropic)	86%
(5)	LPT efficiency (Polytropic)	89%
(6)	LPC inlet press loss	100 mmAq
(7)	LPT outlet press loss	400 mmAq
(8)	Inter Cooler press loss	2.0%
(9)	High press combustor press loss	3.5%
(10)	Reheater press loss	2.5%
(11)	HP shaft mechanical loss	1.7%
(12)	LP shaft mechanical loss	1.0%
(13)	Generator loss	1.5%
(14)	Leakage air for seal	2.5%
(15)	LPC inlet air temperature	15°C
(16)	Inlet air relative humidity	60%
(17)	LHV of fuel (NG)	11,701 kcal/kg
(18)	Theoretical combustion air/fuel ratio..	16.9
(19)	Steam Turbine efficiency (adiabatic) ..	85%
(20)	Steam Turbine condenser press	0.05 ata
(21)	Maximum steam temperature of S/T	566°C
(22)	Maximum steam press of S/T	169 ata
(23)	Pinch point of HRSG	20°C deg

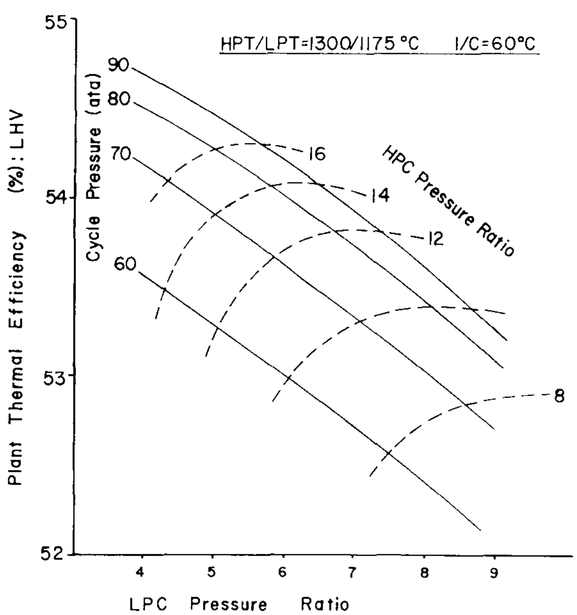

Fig. 1 THE PLANT THERMAL EFFICIENCY OF IGSC

<u>The Inter Cooler Outlet Temperature and Thermal Efficiency of the IGSC</u>

Although the thermal efficiency of reheat gas turbines is affected by the inter cooler outlet temperature, the IGSC is not affected in this way, as shown in Fig. 3. Consequently, the design temperature of the inter cooler outlet depends on the choice of maximum temperature of the HPC outlet and the materials of the HPC blade.

<u>Heat Recovery Steam Generator</u>

The temperature characteristics of the HRSG inlet gas according to the pressure of the IGSC are shown in Fig. 4. The temperature decreases if the cycle pressure is increased. Fig. 5 shows the temperature diagram of the HRSG.

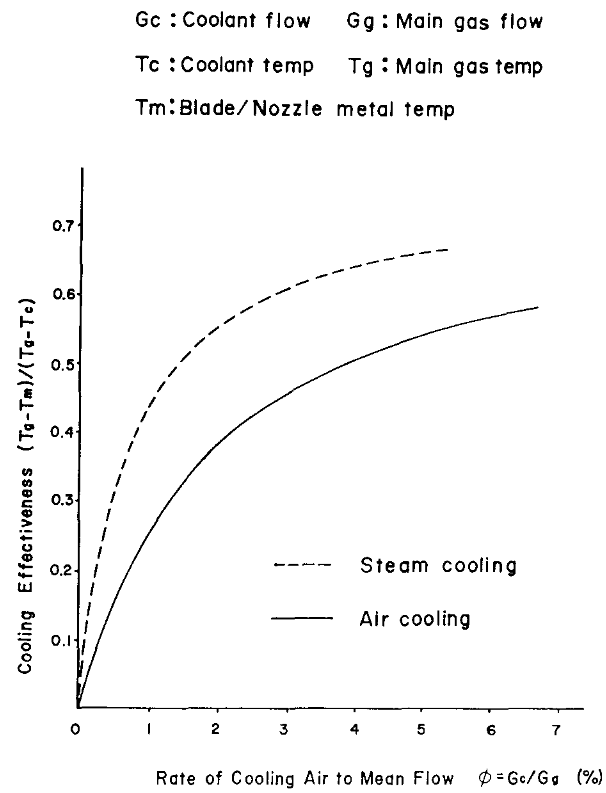

Fig. 2 COOLING EFFECTIVENESS BY STEAM AND AIR COOLING BLADES/NOZZLES

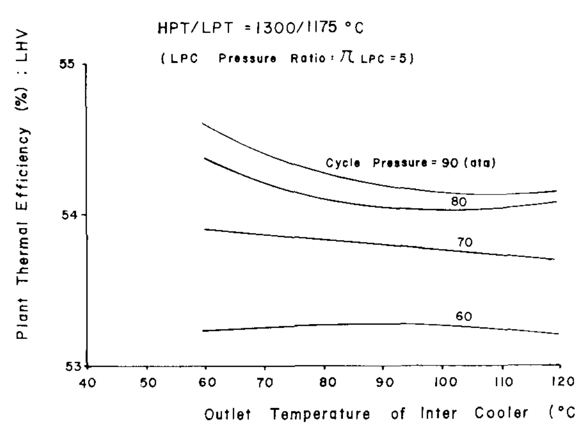

Fig. 3 THE THERMAL EFFICIENCY INFLUENCE BY INTER COOLER TEMPERATURE

In this case, the minimum limited outlet gas temperature of the HRSG is set at 80°C and clean fuel is used, to protect against corrosion from the acid dew point.

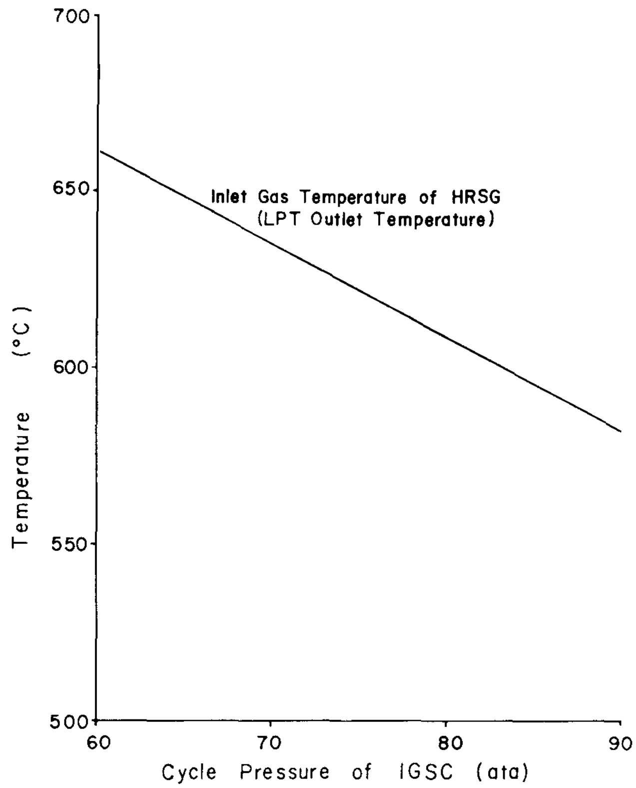

Fig. 4 THE GAS TEMPERATURE OF HRSG BY CYCLE PRESSURE OF IGSC

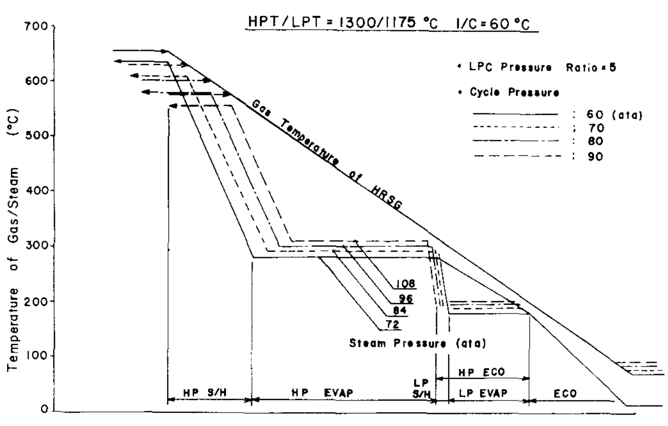

Fig. 5 THE TEMPERATURE CHARACTERISTICS OF HRSG FOR IGSC

Oxygen Concentration in the Inlet Gas of the Reheater

Significantly more oxygen is consumed in the high pressure combustor in order to superheat the injected steam. Furthermore, the cooling steam of the blade/nozzle is mixed into the main gas flow, so the oxygen concentration in the inlet gas of the reheater is quite lean. The characteristics of oxygen concentration are shown in Fig. 6. It must be demonstrated whether stable burning can be achieved with only 9 wt% oxygen. In our experience from development tests on the reheater in the Moonlight Project, the stability of burning mainly depends on the temperature of the inlet gas at a low concentration of oxygen. Hence, stable burning can be maintained at an inlet gas temperature at the reheater as high as 800°C.

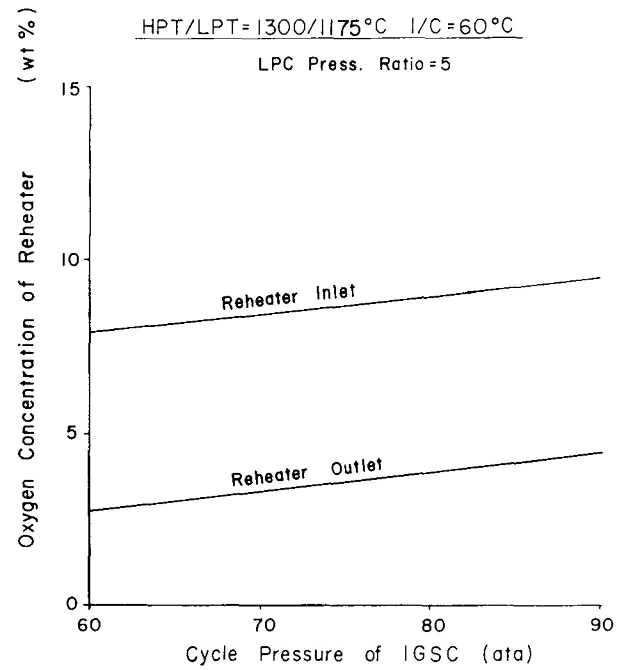

Fig. 6 THE OXYGEN CONCENTRATION OF REHEATER

Heat Balance of the IGSC

An example of one case is shown in Fig. 7. The conditions of heat balance were a HPT inlet temperature of 1300°C, a LPT inlet temperature of 1175°C, a Cycle Pressure of 80 ata and a LPC Pressure ratio of 5 in this example.

The calculated plant thermal efficiency was 54.3% at the LHV. In this case, the output capacity of the reheat gas turbine was 400 MW, the LPC inlet air flow was 335 kg/s, and the LPT exhaust gas flow was 438 kg/s. The value of flow was within the range of recent high capacity conventional gas turbines, which means that the machine size of the rotating parts can be designed to the same level as in conventional gas turbines, allowing an output capacity as high as 400 MW to be realized from the aspects of fluid dynamics and structural strength.

Fig. 8 shows the influence on performance of raising the reheater outlet temperature from 1150°C to 1200°C under the same pressure conditions. The plant thermal efficiency does not increase in proportion to the increase in reheater outlet temperature.

The main requirement for overcoming the lack of increase in plant thermal efficiency is an increase in the steam cooling flow to the LPT blades and nozzles.

COMBINED CYCLE OF REHEAT GAS TURBINES

Combined Cycle Systems

In this paper, one definition of the combined cycle is the replacement of combustor steam injection in the IGSC by a steam turbine generator and the cooling blades/nozzles of HPT, IPT and LPT are air cooled by extracting air from the HPC instead of the steam.

In the combined cycle, the condition of the steam from the HRSG is limited to 566°C, 169 ata, even if the inlet gas temperature of the HRSG is sufficiently high.

The steam turbine is composed of a high pressure turbine and reheat turbine, with the induction of superheated low pressure steam to the intermediate stage of the reheat turbine. The reheated steam temperature is controlled to keep the steam dry ratio of outlet steam at more than 93%.

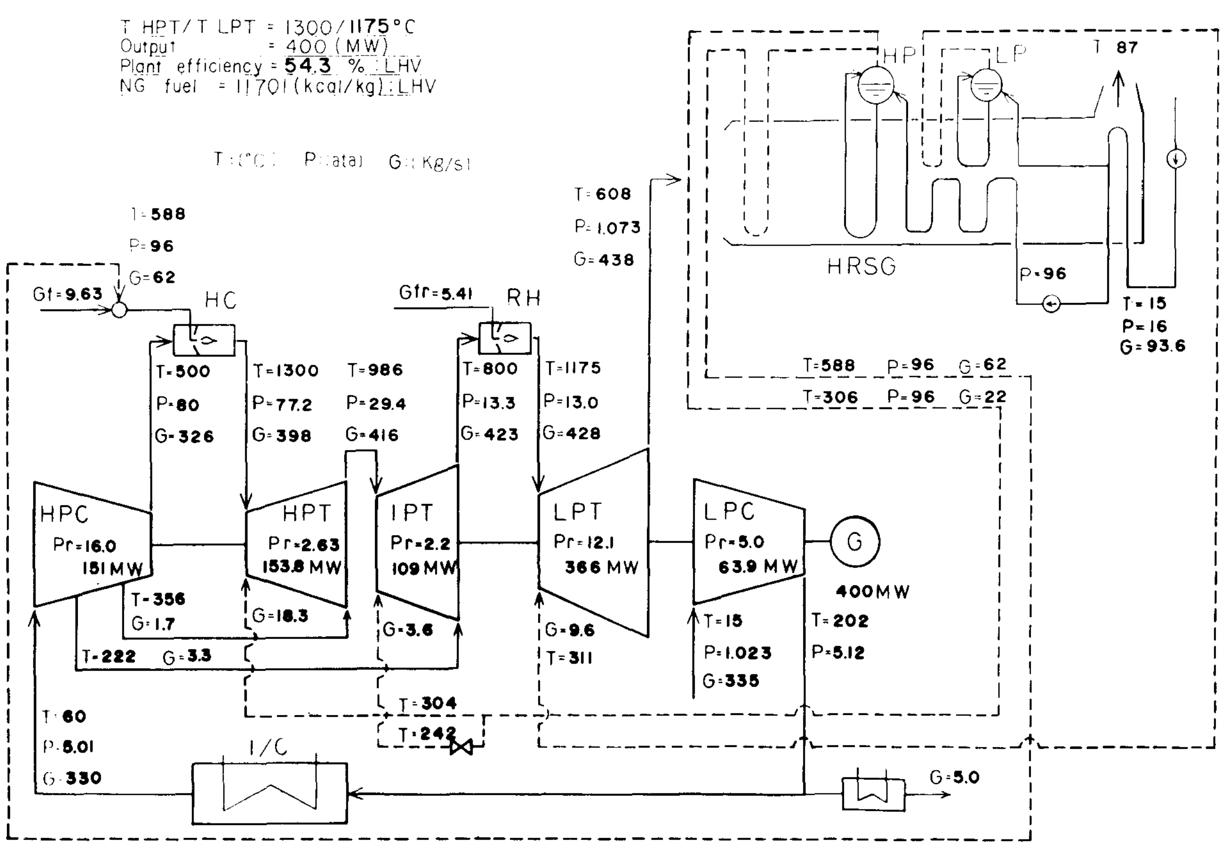

Fig. 7 HEAT BALANCE OF IGSC

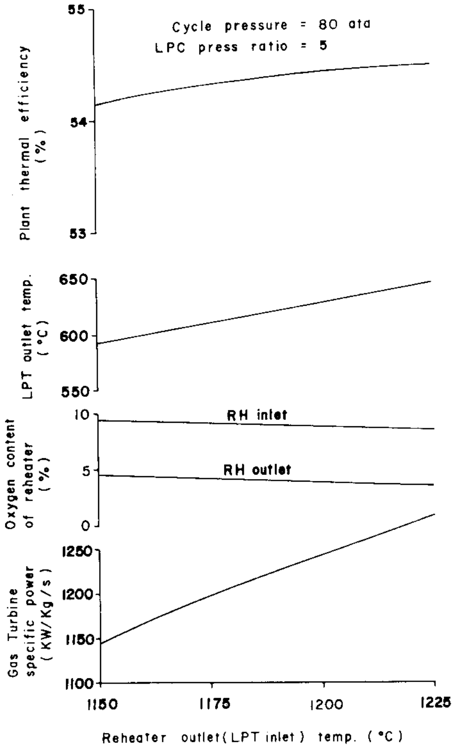

Fig. 8 THE INFLUENCE OF PERFORMANCE BY REHEATER OUTLET TEMPERATURE OF IGSC

Performance of the Combined Cycle

In order to compare the performance of the combined cycle, the conditions of the reheat gas turbines were kept the same as in the IGSC. The heat balance of the combined cycle is shown in Fig. 9. The pressure conditions chosen were a cycle pressure of 60 ata and a LPC pressure ratio of 5, which are the optimum values for performance. The inlet air flow of the LPC was 542 kg/s at 400 MW output, this output being comprised of 300 MW from the reheat gas turbines, and the remaining 100 MW from the steam turbine.

The temperature characteristics of the HRSG are shown in Fig. 10.

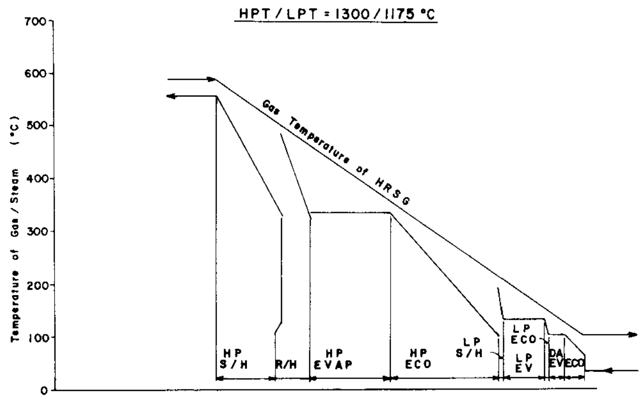

Fig. 10 THE TEMPERATURE CHARACTERISTICS OF HRSG FOR COMBINED CYCLE

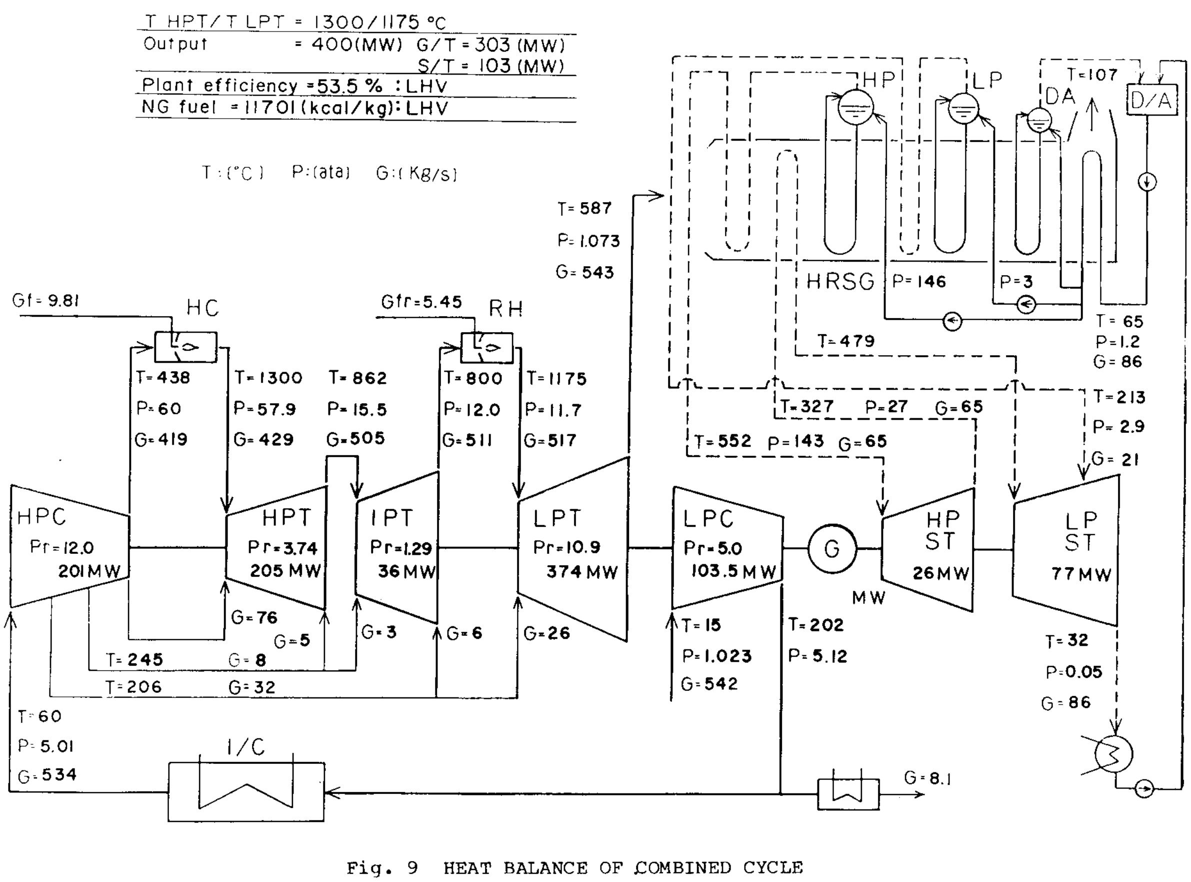

Fig. 9 HEAT BALANCE OF COMBINED CYCLE

CONCLUSIONS

The plant thermal efficiency of the IGSC can be expected to be 54% which is comparable to the conventional combined cycle. In Fig. 11, the heat loss ratios of the systems are shown.

Fig. 12 shows the influence on plant thermal efficiency of the combined cycle systems. At the combined cycle system of the reheat gas turbines, the cycle pressure does not influence the plant thermal efficiency as much as the IGSC.

As described above, since the IGSC has a plant thermal efficiency equivalent to or higher than that of conventional combined cycles, it has the advantage that no steam turbine systems are required, resulting in a reduction in product costs.

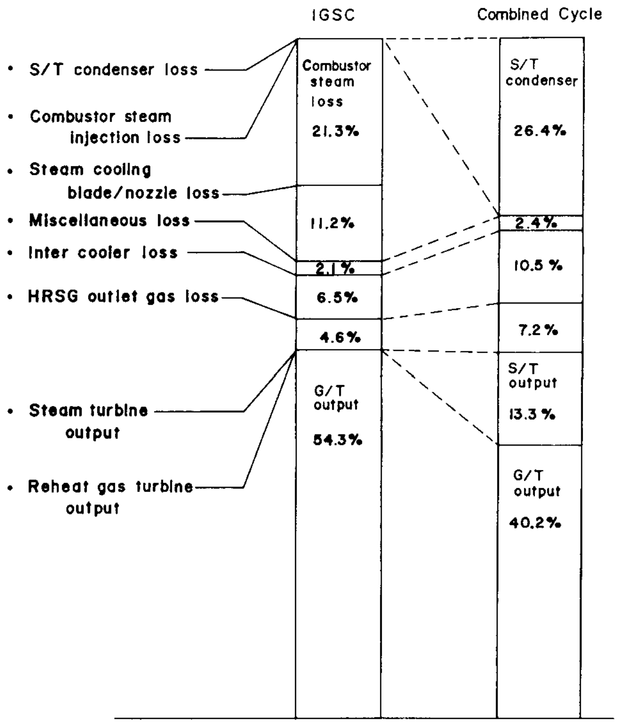

Fig. 11 BAR CHART OF HEAT ENERGY FLOW

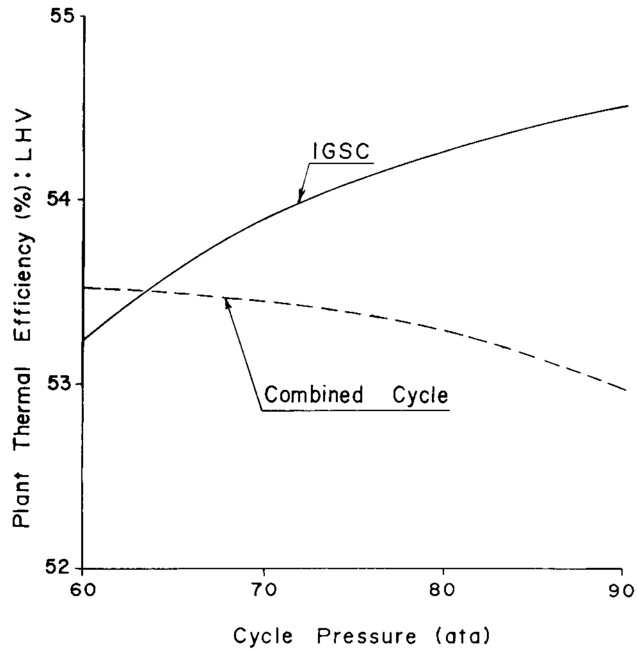

Fig. 12 THE INFLUENCE OF PLANT THERMAL EFFICIENCY BY THE COMBINED CYCLE SYSTEM

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