KAWASAKI STEEL TECHNICAL REPORT
No.13 (September 1985)

High Efficiency Blast Furnace Gas Firing Power Plant

Fuyuki Soma, Hideki Takano, Tokujiro Fujikawa, Kenzo Yamaguchi

Synopsis :

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High Efficiency Blast Furnace Gas Firing Power Plant*

Fuyuki Soma
Assistant Manager,
Power Sec., Energy
Dept., Chiba Works

Hideki Takano
Staff Manager,
Energy Technology
Sec., Chiba Works

Tokujiro Fujikawa
Staff Manager,
Energy Technology
Sec., Chiba Works

Kenzo Yamaguchi
Staff Assistant
Manager, Energy
Technology Sec.,
Chiba Works

Synopsis:

Conservation of energy is one of the most important problems which we are confronted with. We have so far accomplished remarkable records in devising measures for a power generating plant to save energy. A huge power generating plant geared to product 125 000 kW of electricity from blast-furnace gas (BFG) was put on stream at Chiba Works. The details of this new plant are described by referring to No. 3 power generating plant which was installed at West Power Plant at Chiba Works. Achievement of the highest efficiency level in the world at a BFG firing power generating plant was made possible by implementation of the BFG heater, forced draft system and others. By the adoption of these systems, plant net efficiency can attain a high value equivalent to those at advanced supercritical pressure heavy oil firing power plants. With this in-plant power generating unit, Chiba Works is now 75% selfsufficient in electricity.

1 Introduction

The No. 3 power generating plant of the West Power Plant at Chiba Works is a blast-furnace-gas (BFG)-firing high-efficiency plant designed to raise Chiba Works' electric power self-sufficiency rate by a high-efficiency conversion of rising levels of power-potential by-product gases reflecting an advancing energy saving program within the steelworks.

In the planning stage, various studies were carried out on measures to enhance the operational efficiency of the plant. As a result, a number of unconventional techniques have been implemented, including use of a steel-pipe gas heat exchanger, in which the sensible heat content of the boiler exhaust gas is used to raise the temperature of the main fuel, BFG, and a forced draft system, in which the induced draft fan for boiler exhaust gas was eliminated. Construction of the No. 3 power generating plant was started in July 1982, and the facility passed inspection by the Regional Bureau of International Trade and Industry in March 1984. The plant has been operating smoothly to date. Through use of the above-mentioned basic engineering techniques of the Company, the power plant has demonstrated a level of efficiency among the highest in the world for BFG-firing power plants.

For boiler tubes, ERW pipes specially approved by the Ministry of International Trade and Industry and rifle tubes are used. Both types of pipe were developed by Kawasaki Steel. These and other Kawasaki products account for as much as 95% of all boiler tubes used. In addition, products made by the Company are used for the turbine and generator rotor, the cores of the genera-

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tor and transformer.

Main specifications of the No. 3 power generating plant of the West Power Plant and items for improving efficiency are explained below.

2 Main Specifications of Plant

A general view of the No. 3 power generating plant at the West Power Plant is shown in **Photo 1**. A side view of the boiler plant and a diagram of steam flow in the No. 3 power plant are shown in **Figs. 1** and **2** respectively. The West Power Plant also includes two identical generating units, No. 1 and No. 2. **Table 1** shows the main specifications of the No. 3 plant in comparison with those of the two earlier plants. Compared with the earlier plants, Nos. 1 and 2, each with an output of 75 000 kW, No. 3 plant has an output of 125 000 kW. The No. 3 plant uses a forced draft system in its boiler plant and a 720-kW back-pressure turbine in its process steam line.

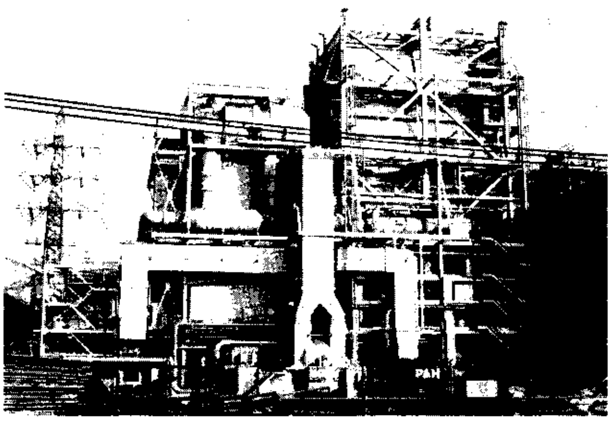

Photo 1 View of No. 3 power generating plant

3 Items for Enhancing Efficiency

3.1 Boiler Plant

3.1.1 BFG heater

Since BFG is a low-calorie fuel, the amount of its combustion air is only about 35% that of exhaust gas. As the ratio of BFG in mixed firing increases, the ratio of exhaust gas to combustion air increases. This indicates that there is a limit to the recovery of waste energy if it is solely by use of the air heater.

To cope with this problem, a method of recovering waste energy using BFG was devised. The BFG heater was of a two stage device which combines a steam-heater, using steam extracted from the turbine, and a second type, which utilize boiler exhaust gas. The BFG steam-heater uses steam extracted from the turbine to recover heat lost by the condenser, thereby enhancing plant thermal efficiency by about 1%. Further, the steam-heater raises the temperature of the BFG to about 70°C, thereby preventing low-temperature corrosion of tubes in the succeeding BFG exhaust-gas-heater.[1,2]

Since the conventional BFG-firing boiler recovers heat only at its air heater, there is a tendency toward a severe lowering of boiler efficiency with increases in the mixed firing ratio of BFG. In the present plant, equipped with the BFG heater, however, this tendency is minimized, thereby allowing high operating efficiency at any mixed firing ratio. The relation between the mixed firing ratio and boiler efficiency is shown in **Fig. 3**.[3,4] A conceptual diagram of the BFG exhaust-gas-

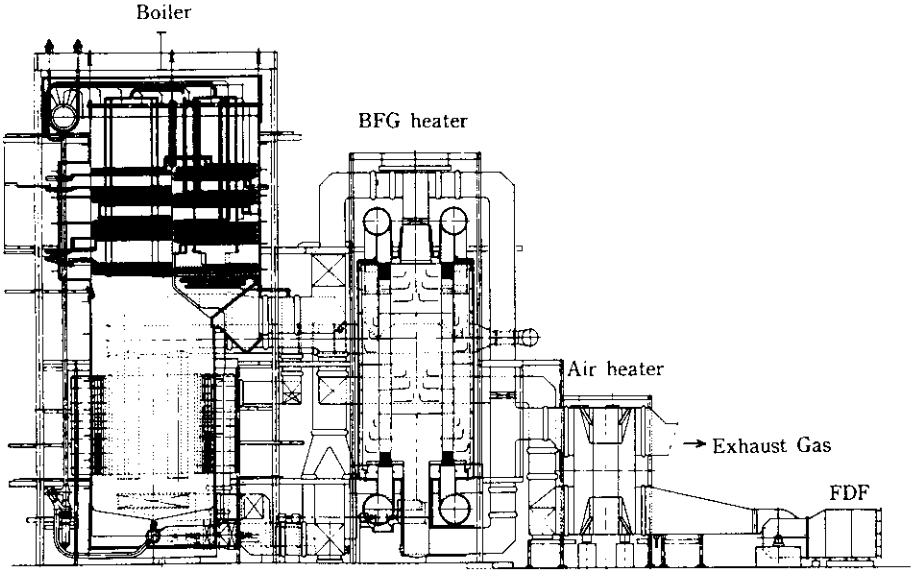

Fig. 1 Side view of boiler plant

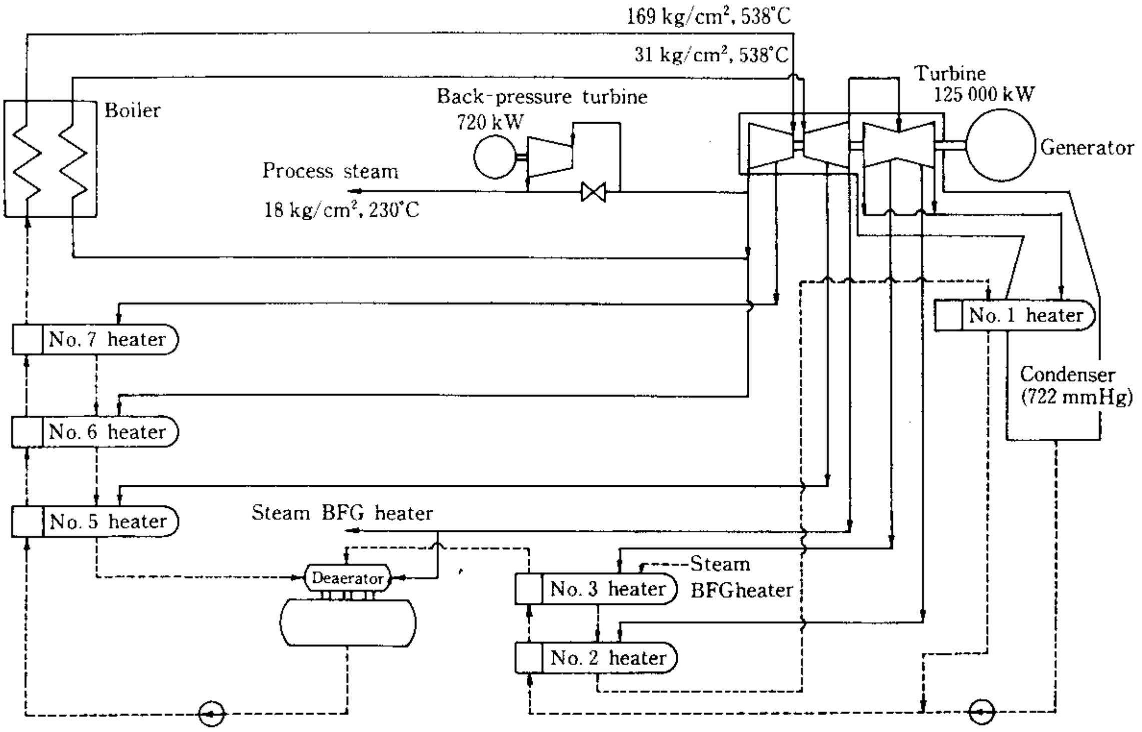

Fig. 2 Steam flow of No. 3 power plant

Table 1 Main specifications

	No. 3 Power Plant	Nos. 1 & 2 Power Plant
Capacity (kW)	125 000	75 000
Amount of evaporation (kg/h)	430 000	260 000
Pressure of steam (kg/cm²)	169	126
Temperature of steam (°C)	538	538
Combustion system	Forced draft system	Balance draft system
Fuel	BFG[1], COG[2], LDG[3], LPG[4]	BFG, COG, LDG, LPG
Process steam (kg/h)	55 000 max.	30 000 max.
Back-pressure turbine (kW)	720	—
Efficiency (power generation end) (%)	42	36

[1] BFG: Blast furnace gas

[2] COG: Coke oven gas

[3] LDG: Linz-Donawitz converter gas

[4] LPG: Liquefied petroleum gas (Butane)

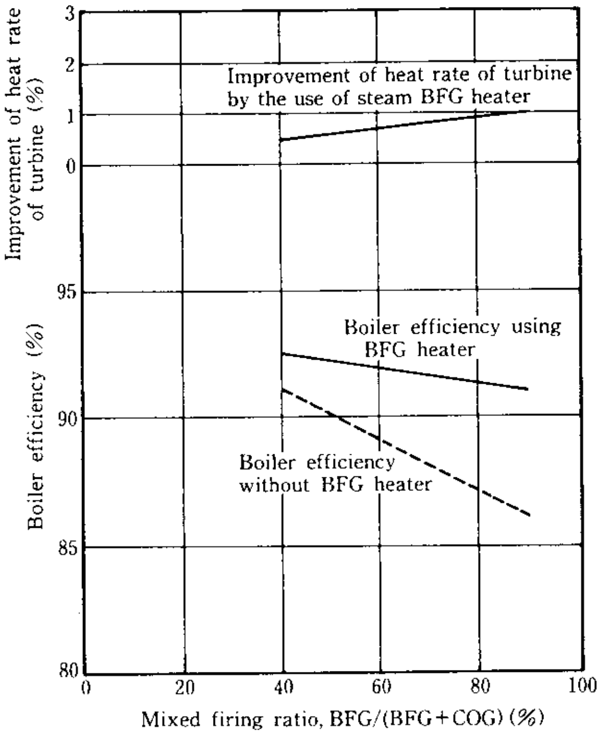

Fig. 3 Steam flow of No. 3 power plant

heater is shown in **Fig. 4**; the relation between gas flow and temperature under typical operating conditions is shown in **Fig. 5**.

Through installation of the BFG heater, the boiler exhaust gas temperature, which exceeded 200°C in the conventional-type boiler, has been reduced to about 112°C, an improvement of about 5% in boiler efficiency, which has been accompanied by an increase in generating output at the No. 3 power plant of about 9 000 kW.

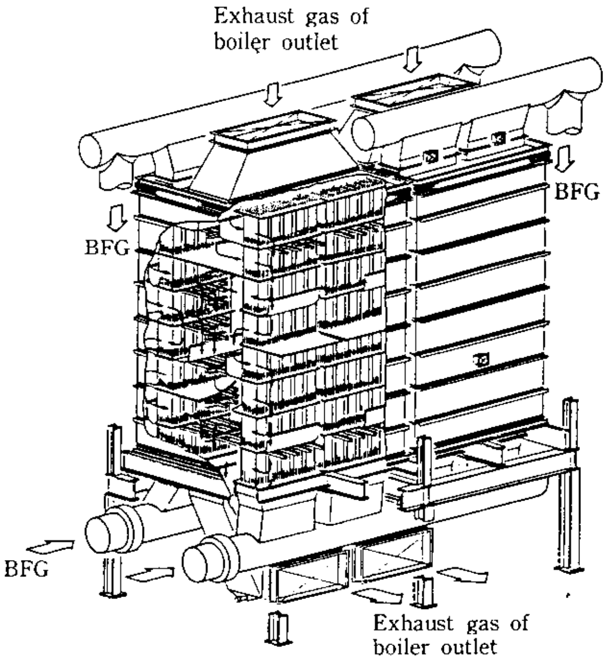

Fig. 4 View of BFG heater

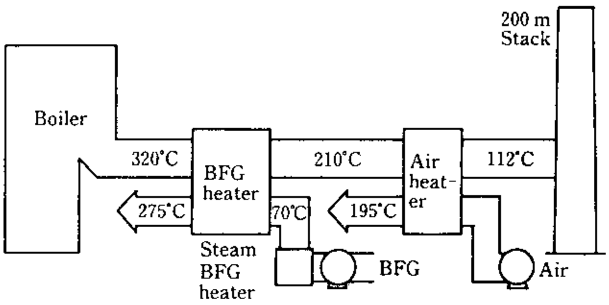

Fig. 5 Temperature of boiler exhaust gas, BFG, and combustion air

3.1.2 Forced draft system

The conventional BFG-firing boiler used a balance draft system, in which negative boiler furnace pressure is maintained to prevent gas leakage from the furnace, thereby avoiding contamination by harmful ingredients in the BFG. In this system, fuel and air are driven to the boiler furnace by pressure of the fuel gas and the forced draft fan, while the boiler exhaust gas, on the other hand, is drawn by an induced draft fan, in order to maintain a negative boiler furnace pressure. The induced exhaust gas has expanded in volume due to its high temperature, requiring use of a larger fan, with the resulting disadvantage of increased power consumption.

By contrast, in the forced draft system used in the No. 3 power plant, BFG gas and combustion air are forced into the boiler furnace by respective fans. This system requires a fan for the BFG, but since the temperature of the BFG is close to atmospheric temperature, the BFG fan may be much smaller than the exhaust-gas induced draft fan, allowing a very advantageous reduction in power consumption.

Table 2 Comparison of electric motor output between forced draft and balance draft (kW)

	Forced draft	Balance draft
Forced draft fan	730	330
Induced draft fan	—	2 020
BFG booster fan	1 040	—
Total	1 770	2 350

The forced draft system owes its feasibility to recent improvements in boiler furnace sealing techniques. Specifically in the past, heat insulators surrounding the boiler tubes were simply sealed by casing material (skin casing construction), while in the new boiler, tubes are welded (fusion-welded wall construction) to achieve air-tightness and ensure safety.

Although the new system requires a fan for BFG, the BFG fan is smaller than the exhaust-gas induced draft fan, which has been eliminated. This has resulted in a net power saving of 580 kW, about a 25% reduction. A comparison in motor output between the forced draft and balance draft systems is shown in **Table 2**.[3,4] Compared also in **Fig. 6** are changes in pressure between forced draft and balance draft systems covering stages of fuel gas, combustion air, and the combustion exhaust gas from the BFG main pipe to the stack.

3.1.3 Control of fan revolution speed

The No. 3 power plant uses a mixed firing of BFG, COG (Coke oven gas), LD gas, and LPG (Butane). Since the mixed firing ratio changes and load fluctuates, the volume of draft also shows wide variations. For this reason, fan speed is controlled to maintain higher fan efficiency under varying draft conditions. Variable voltage/variable frequency (VVVF) was considered for the control system, but ultimately fluid coupling was adopted, in consideration of ① countermeasures against electric accidents, ② panel installation space and ③ actual records of use for power generating boilers. Fluid couplings are installed on four large fans, i.e., the forced draft fan, BFG booster fan, gas recycling fan, and gas mixing fan.

Effects of control of fan revolution speed by fluid coupling, compared with that by conventional damper control, are shown in **Fig. 7**, which indicates that the effectiveness of the fluid coupling is greatest at partial loads.[3,4]

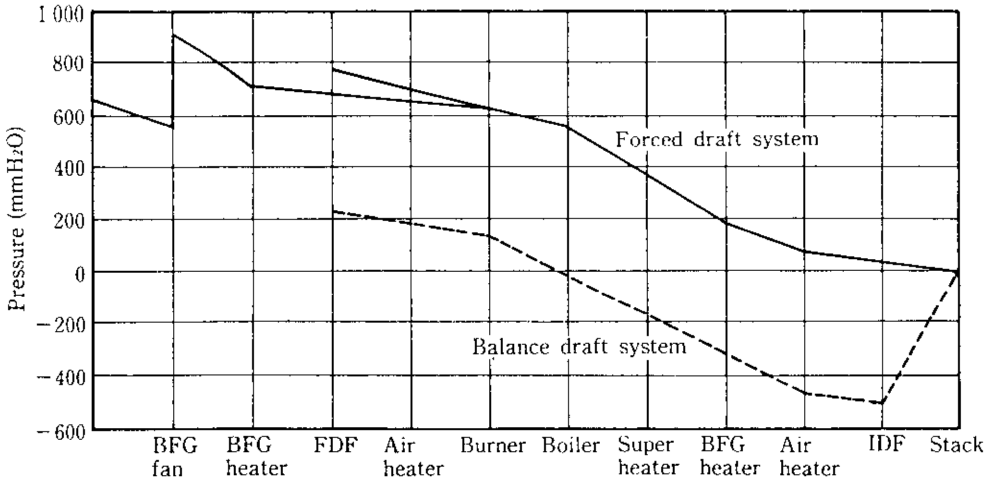

Fig. 6 Comparison of pressure between forced draft and balance draft

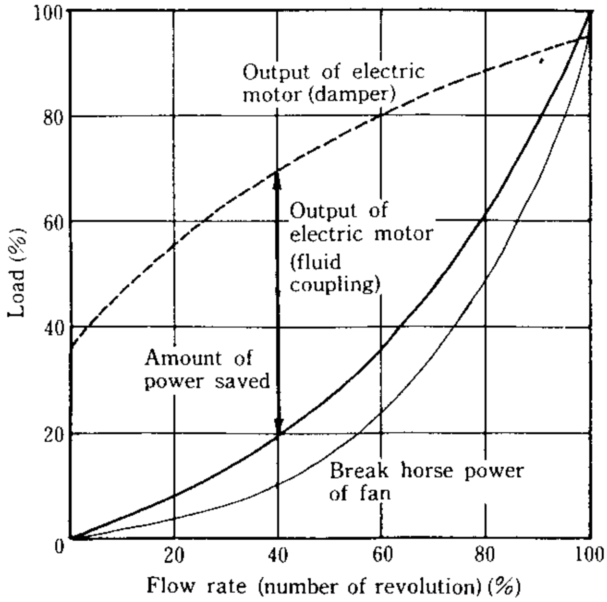

Fig. 7 Effect of control by fluid coupling on speed of revolution

3.1.4 Rifle tube

The boiler of the No. 3 power plant is equipped with three boiler water recycling pumps, as it uses a forced recycling system. To reduce the power consumption of these pumps, rifle tubes are used extensively for boiler tubes. Rifle tubes, which were first manufactured by Kawasaki's Chita Works, have a greater heat transfer coefficient than in smooth tubes, and the volume of recycled water can be reduced accordingly. They make possible a 50% saving on pump power consumption.[3~6)]

The cross section of a rifle tube and a view of the evaporation tubes in the boiler furnace where rifle tube is used are shown in **Photos 2** and **3** respectively.

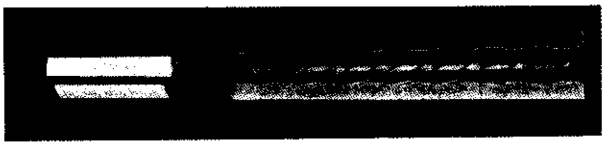

Photo 2 Rifle tube

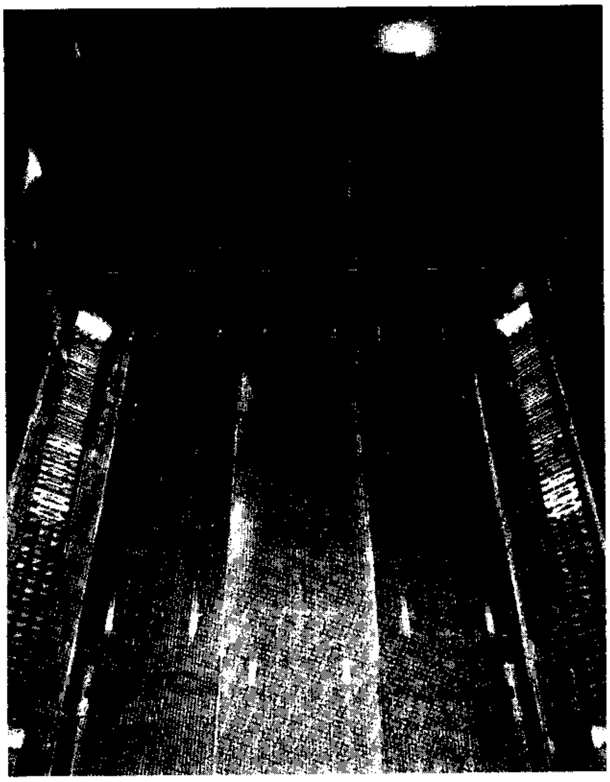

Photo 3 View of boiler tubes in No. 3 boiler

3.2 Turbine

3.2.1 High-pressure steam conditions

One of the most effective measures for enhancing the efficiency of the steam plant boiler and turbine is to increase the temperature and pressure of steam, which is particularly effective on internal turbine efficiency. An appropriate steam pressure in a 125 000 kW-class plant such as the No. 3 power generating plant of the West Power Plant was formerly considered to be 1 800 psi (127 kg/cm^2), but a value of 2 400 psi (169 kg/cm^2) was adopted for the No. 3 plant. This value corresponds to the pressure conditions conventionally considered applicable to a plant of the 350 000-kW class.

On the other hand, corrosion of boiler tubes at high-temperatures is a cause of concern, due to the inclusion of corrosive elements in BFG. To ensure safety, a steam temperature of 1 000°F (538°C) is used in the No. 3 plant, as in the existing Nos. 1 and 2 plants.

Since steam pressure has been increased from the conventional 127 kg/cm^2 to 169 kg/cm^2 in the No. 3 plant, the thermal efficiency of the turbine exhibited an improvement of about 2%.

3.2.2 Optimization of cycle

Optimizing the steam cycle is an important problem in improving the thermal efficiency of a turbine plant. At the No. 3 plant, steam from the low-pressure turbine is used as a heat source for the No. 1 to No. 3 low-presure heaters; steam from the medium pressure turbine, for the deaerator and No. 5 high-pressure heater; and steam from the high-pressure turbine, for the No. 6 and No. 7 heaters. Steam from the medium-pressure turbine is also used as a heat source for the previously mentioned BFG steam-heater, and the drain after heat-exchange is recovered by the No. 3 low-pressure heater. In addition a portion of the steam extracted from the high-pressure turbine is decompressed, cooled, and used as process steam for the factory. To effectively use energy released at the time of decompression and cooling, a back-pressure turbine has been installed. This turbine has a maximum output of 720 kW.

3.2.3 Modification of blade shape

Final turbine blades 23 inches in height have generally been used for conventional plants in the 125 000-kW class. The No. 3 plant, however, uses a turbine blade 26 inches in height. This has the advantage of reducing the exhaust loss, in comparison with that of conventional plants. A new turbine nozzle shape has also been developed to improve performance in the high Mach-number region. These two innovations contribute to improvement in turbine efficiency.

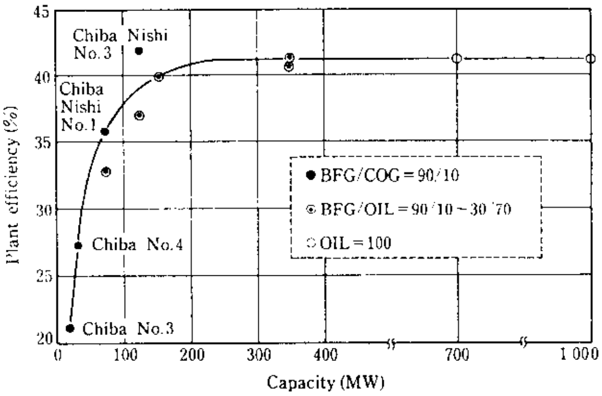

Fig. 8 Comparison of plant efficiency

3.3 Plant Efficiency

After adoption of the efficiency measures for the boiler and turbine, as described above, a plant performance test was conducted. The results indicated plant efficiency of about 42%, slightly higher than originally planned. As shown in **Fig. 8**, this plant efficiency figure was obtained by comparing the No. 3 power plant with a large-scale commercial power plant in the 350 000 to 1 000 000-kW class. The No. 3 plant shows better plant efficiency than conventional plants. This result was partly made possible by use of BFG with low sulphur content (relative to heavy oil) as the main fuel in order to lower the boiler exhaust gas temperature to about 112°C. As a result, the electricity self-sufficiency ratio of the Chiba Works has risen from the previous approximate 50% to about 75%.

4 Using Conditions of Kawasaki Steel Products

Construction of the No. 3 power generating plant of the West Power Plant was carried out under a policy of using Kawasaki Steel products whenever possible.

Table 3 Application of the products of Kawasaki Steel (t)

Boiler	Boiler tube	1 130
	Pipe	620
	Steel frame	910
	Casing	765
Turbine & generator	Rotor	130
	Core	135
	Casing	120
	Condenser	70
	Heater	105
	Pipe	65
Total		4 050

Major Kawasaki Steel products used for the No. 3 power plant are summarized in **Table 3**, and include the following recently developed items:

(1) Boiler tubes made from STBA 22 ERW pipes, manufactured by Chita Works and given special approval by the Ministry of International Trade and Industry (about 10 tons)
(2) STB 42 rifle tubes manufactured by Chita Works (about 60 tons)
(3) Turbine and generator rotor manufactured by Mizushima Works (about 130 tons)
(4) RG-6H transformer core manufactured by the Hanshin Works (about 57 tons)

5 Concluding Remarks

Construction of the No. 3 power generating plant at the West Power Plant at Chiba Works was started in July 1982. The plant successfuly passed governmental inspection at the end of March 1984, and has been operating smoothly to date.

The plant incorporates new techniques for attaining higher efficiency, and demonstrates a plant efficiency of about 42%, much higher than that of large commercial power plants.

Through the construction of the No. 3 power plant, the electric self-sufficiency ratio of Chiba Works has risen from its previous 50% or thereabout to some 75%. The No. 3 plant has already made a great contribution to energy savings efforts and indicates the future direction of BFG-firing power generating plants.

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