NIPPON STEEL TECHNICAL REPORT No. 123 MARCH 2020

Technical Report

UDC 662 . 741

SCOPE21 Cokemaking Process

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Abstract

SCOPE21 is a revolutionary cokemaking process developed under a national project; the process comprises a fluidized bed coal dryer, a pneumatic preheater for rapid heating of coal to 330–380°C, and a hot briquetting machine for coal fine. Commercial plants using the process were built at Oita and Nagoya Works in 2008 and 2013, respectively, and have been in steady operation ever since. The process enables use of a markedly larger amount of non- or slightly-caking coal for coke production than by the conventional process and attains far higher plant productivity.

1. Introduction

Coke is indispensable for iron and steel production by a blast furnace, and cokemaking facilities, or coke ovens, constitute an important part of an integrated steel works. Whereas blast furnaces are relined every 20 years or so, coke ovens operate far longer; actually many coke ovens were built in Japan in the high economic growth period in the 1960s and 70s, and many of them are still working more than 50 years later. Such ovens are super-aged and have to be replaced with new ones, and super aging of coke ovens has been strongly regarded as a serious problem in Japan since the 1990s. While a variety of methods for oven repair have been developed and put into actual practice, studies for the development of a next-generation cokemaking process have been carried out in view of the replacement of super-aged ovens.

Coke ovens are expensive to build, and higher productivity and lower construction costs are required for newly built ovens. To produce high-strength coke adequate for charging into blast furnaces, coal excellent in caking properties is required as the raw material, but since the resources of such good caking coal are limited, technologies that allow increased use of non- or slightly-caking coal have been sought to cut the coke production costs and use coal resources more effectively. Since cokemaking is a high-temperature process, a new cokemaking process is also required to be more energy saving and environment friendly.

Against this background, a development project of an innovative coke producing process for the next generation, named the super coke oven for productivity and environmental enhancement toward the 21st century (SCOPE21), was conducted from 1994 to 2003 as a national project in which the member companies of the JAPAN Iron and Steel Federation (JISF) participated.[1] Based on the results of the development, Nippon Steel Corporation realized the SCOPE21 process by constructing new coke ovens at Oita and Nagoya Works. This paper explains the development of the SCOPE21 process, and reports the operation of Nippon Steel's commercial SCOPE21 plants.

2. Outlines of SCOPE21 Process

Facing the need for building new coke ovens in Japan in the not-too-distant future, the development of the SCOPE21 technology was launched aiming at devising a revolutionary coke producing method for the next generation capable of significantly enhancing oven productivity, using coal resources more efficiently (increased use of non- or slightly-caking coal), and improving energy efficiency and environmental protection.

Figure 1[2] shows the outlines of the SCOPE21 process introduced to Oita and Nagoya Works. It is characterized mainly by coal pretreatment methods more advanced than those of conventional coke oven plants. Here, before being charged into the coking chambers of the coke oven, coal is dried and rapidly heated through pretreatment facilities. First, coal is blended and crushed as by the conventional process, and then it is fed to a fluidized-bed dryer to be preheated, dried, and classified into coarse and fine coal. While the

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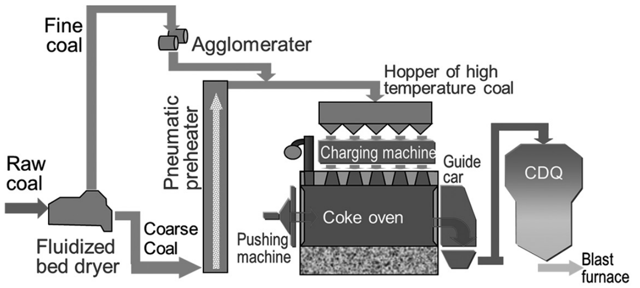

Fig. 1 Schematic diagram of SCOPE21 process flow in Oita/Nagoya[2)]

coarse grains are rapidly heated to roughly 330 to 380°C through a pneumatic preheater, the fine grains are agglomerated in heat, then mixed with the heated coarse grains, and charged into coking chambers at high temperature.

During these pretreatment steps, especially the rapid preheating, the coal is modified and its coking properties are improved. As a result, it is possible to produce coke of a sufficient strength even at markedly high blending ratios of non- or slightly-caking coal, which is inadequate as the feedstock for the conventional cokemaking process. For the SCOPE21 development, the target blending ratio of the non- or slightly-caking coal was raised from 20% of the conventional wet coal charging process to 50%.

Charging of hot and dry coal dramatically shortens the carbonizing time in coking chambers enhancing the plant productivity, and as a result greatly decreases the energy consumption. In addition, the agglomeration of the coal fine is advantageous for increasing the bulk density of charging coal, as is coal drying. The agglomeration serves also as a measure to prevent adverse effects of coal fine on oven operation. Owing to the above pretreatment, SCOPE21 is a high-efficiency process requiring a significantly shorter carbonizing time and a smaller number of coking chambers.

3. Development of Element Technologies and Verification Tests on Pilot Plant

The results of the development of principal element technologies of SCOPE21 under the national project are described in this Section.

(1) Rapid heating of coal and coke quality improvement effects

Rapid coal heating is an important part of the SCOPE21 process because the properties of low-grade non- or slightly-caking coal are advantageously modified through rapid heating. As an elementary study, non- or slightly-caking coal was rapidly heated through a compact pneumatic heater for 200 g of coal (all the units herein are metric), and its softening and melting characteristics were investigated by the needle penetration test. Here the heating rate was 1×10^4°C/min, and after cooling the specimen coal in a nitrogen atmosphere, the needle penetration depth was measured during heating at a rate of 3°C/min. As **Fig. 2** shows[3)] when the specimen was heated from 330 to 380°C, the needle penetration depth increased at 400°C or above, demonstrating that the softening and melting properties of coal have improved.

Actually, the content of mobile components increased through the observation of rapidly heated coal by the NMR micro-imaging method.[4)] Coal is considered to be a coagulated structure of a multi-component group of molecules bridged together by noncovalent bonds. When rapidly heated, the noncovalent bonds are presumed to weaken, the coagulation structure to relax, and the amount of mobile components to increase as a result.

At the next study stage, coal rapidly heated through a test apparatus (see **Fig. 3**)[5)] comprising cylindrical pneumatic heaters, each 65 mm in diameter and 8 m in height, was charged into a test coke oven, and the strength of the coke thus obtained was evaluated. In this test, the coal was dried, preheated to 250°C, and classified into fine coal 0.3 mm or less in size and coarse coal over 0.3 mm through a fluidized-bed dryer. Then both the fine and coarse coal were rapidly heated through pneumatic heaters at an average heating rate of 1×10^4°C/min, the fine coal was then agglomerated through a hot briquetting machine, mixed with the coarse coal, and charged into an electric-heating test coke oven, 400 mm in width, 600 mm in length, and 600 mm in height. The coke obtained was cooled in a nitrogen atmosphere and subjected to the drum test.

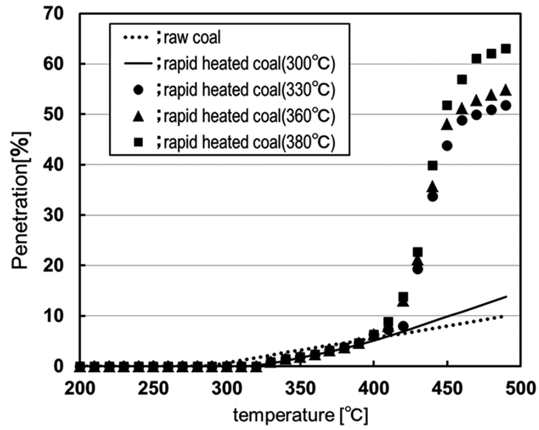

Fig. 2 Needle penetration into heated coal[3)]

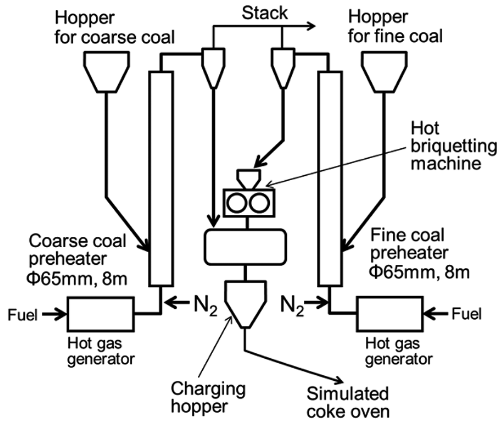

Fig. 3 Laboratory-scale coal pretreatment facilities[5)]

Figure 4 shows the drum index (DI^{150}_{15}) of the coke obtained by mixing 50% caking coal and 50% non- and slightly-caking coal, rapidly heating the mixture from 330 to 420°C and then charging into the test oven.[5)] When the coal mixture was heated to over 300°C at a slow rate of 2°C/min, the strength of the coke obtained was lower than that of the coke made from coal without preheating, and in contrast, when the coal was rapidly heated from 330 to 400°C, the coke strength was higher than the same by 3 to 6 points. In addition to the above, the coke strength decreased when the coal was heated to above 400°C, and it became clear that excessive heating was harmful.

The coke strength improvement effects of the SCOPE21 process were confirmed in through-process tests from the coal pretreatment including rapid coal heating to carbonization in the coke oven of a

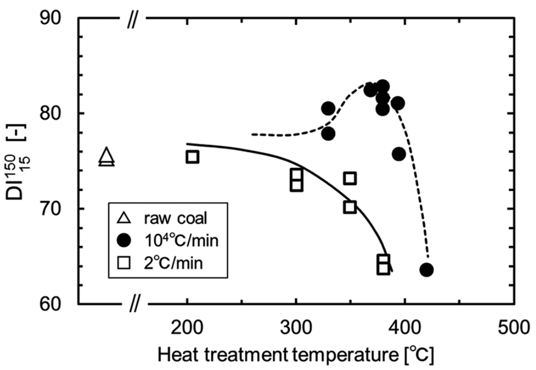

Fig. 4 Effect of coal rapid heating on coke strength[5)]

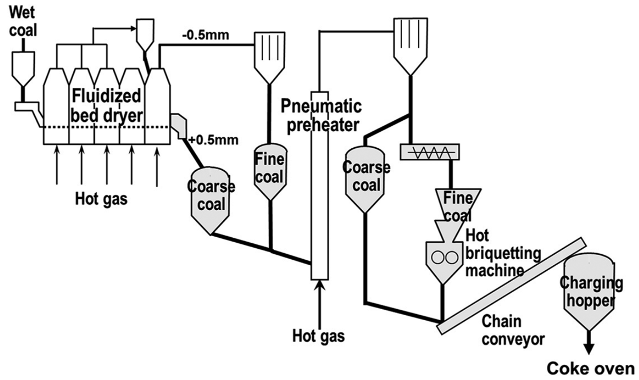

Fig. 5 Schematic flow of coal pretreatment in SCOPE21 pilot plant[6)]

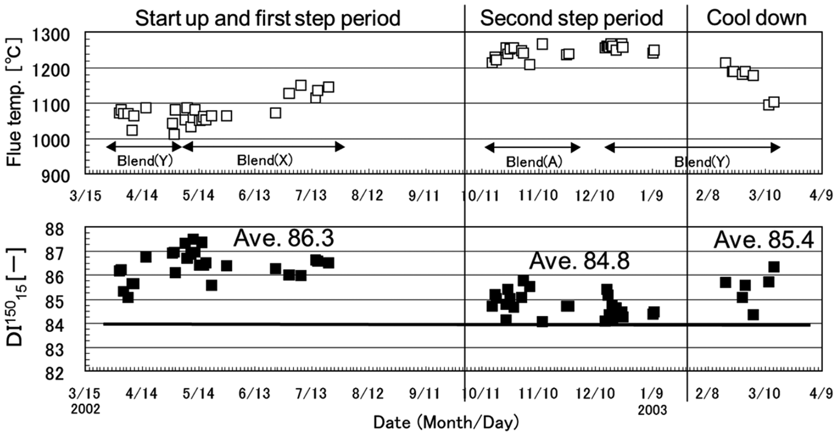

Fig. 6 Flue temperature and coke strength during pilot plant test[6)]

pilot plant.

Figure 5 schematically shows the coal pretreatment facilities of the pilot plant.[6)] The coarse coal and fine coal dried, preheated, and classified as the fluidized-bed dryer are fed separately to the pneumatic preheater and rapidly heated. After that, the fine coal is briquetted in heat, mixed with the coarse coal, and charged into the coke oven via a chain conveyer and pneumatic transfer. After carbonizing, coke is discharged into a cassette cooler, and after being cooled in nitrogen gas to below 100°C, laid in a storage yard. The samples for the coke quality test were taken there.

In the pilot plant test, the raw material contained 50% of caking coal and 50% of non- or slightly-caking coal, and the conditions of the rapid heating were set such that the calculated average temperature of the coarse coal increased within the range of 330 to 365°C, and that of the fine coal from 330 to 375°C. **Figure 6** shows the coke strength under typical operating conditions during the pilot plant test.[6)] The test period was roughly divided into the start-up and first-step period when the oven temperature was low, the second-step period when the oven temperature was raised to 1250°C, and the cool-down period. Even in the second-step period when the coke strength was comparatively low, the drum index of coke was 84.8. This corroborates that high-quality coke was produced from the raw material coal containing as much as 50% non- or slightly-caking coal.

Figure 7 compares the coke strength in the second-step period with that obtained through the conventional process with wet charging coal. The SCOPE21 process was evaluated as being capable of

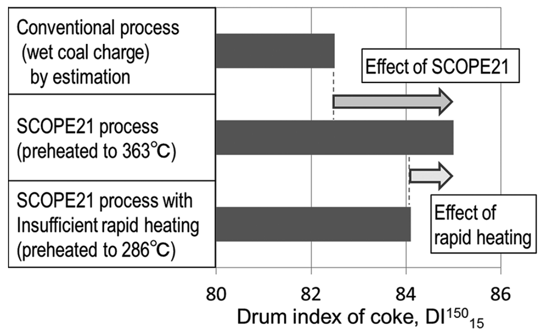

Fig. 7 Coke strength improvement by SCOPE21 process

producing coke with a strength higher by 2.5 points than that of the conventional process from charging coal of the same blend. The rapid heating of coal was considered to account for 0.9 points of the improvement;[6)] this value is the difference in coke strength between the case where the heating temperature of the pneumatic preheater was set at 286°C, lower than 330 to 380°C at which the rapid heating effect shows, and the case where the coal was heated to 363°C.

The balance improvement of 1.6 points is presumably due to the increase in the bulk density of charging coal from 0.7 (conventional wet coal) to 0.74 t/m^3 in the second-step period, and more homogeneous charging coal by making the grain size finer than by the conventional process thanks to stable operation of the pneumatic preheater.

(2) Briquetting of coal fine and its effects on stable operation

By the SCOPE21 process, the classified fine coal is formed in heat into briquettes. Appropriate operation conditions of the briquetting facilities were studied and the effects of briquetting on the coke oven operation were evaluated in the pilot plant test.

Figure 8 shows the outlines of the briquetting machine of the pilot plant,[7] and **Table 1** its specifications.[7] The best operation conditions were studied based on briquette quality evaluated in terms of briquette yield. As seen in **Fig. 9**,[7] when the pressure of the gas emitted from the material exceeded 5 kPa, the briquetting yield fell with the increase in gas pressure. The gas pressure increase was presumed to result from increased gas emission during the compaction for briquetting and consequent decrease in voids between grains. From this result, degassing was considered necessary.

When coal containing much moisture is dried, agglomerated fine grains separate from each other, which adversely affects oven operation. Since the charging coal temperature is high by the SCOPE21 process, a large amount of gas is emitted during the charging into coking chambers, and it was feared that the carry-over, or coal fine particles carried by the gas to outside the chambers, would increase.

In the pilot plant test, where the raw material coal was crushed to -6 mm and subjected to the pretreatment procedures before being charged into the chambers, the amount of the carry-over was compared between the case with the hot briquetting of coal fine and the case without.[8] Since fines carried over by the gas are mixed with the ammonia liquor and tar and captured by the tar decanter, the quinoline-insoluble (QI) component of the tar in the decanter was measured and regarded as the carry-over. As shown in **Table 2**, whereas the QI amount was 13% without the hot briquetting of coal fine, it decreased to as low as 4.6% with the briquetting, less than a half. The effect of coal fine briquetting to decrease the carry-over has thus been confirmed with an actual operation result.

In addition, the gas from the coking chambers was sampled in the ascension pipe by isokinetic sampling during the one-hour period from the beginning of charging, and the size distribution of the QI component grains in the tar was measured by laser diffraction scattering; **Fig. 10** shows the result.[8] With the briquetting of fine coal, the ratio of grains 30 to 100 μm in size is markedly lower than without it, which confirms the positive effect of the briquetting.

The decrease of fine particles in the gas is expected to serve as a means for decreasing carbon deposition on the chamber walls. The carbon deposition was evaluated during the pilot plant test by hanging bricks in the top space of the coking chambers.[9] **Figure 11** shows the carbon deposition from the beginning of coal charging to the end of the coking time measured by hanging bricks through test holes of the oven ceiling before the charging;[9] based on the structural observation of the carbon deposits through a microscope, the bars of the graph are divided into the part corresponding to coal-origin carbon and that corresponding to pyrolytic carbon. Since the pyrolytic carbon deposition changes depending on the temperature, the bars of the graph were adjusted so that they represented the deposi-

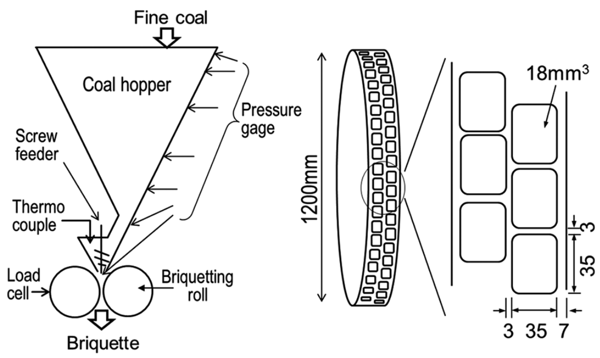

Fig. 8 Hot briquetting machine of SCOPE21 pilot plant[7]

Table 1 Specifications of briquetting machine in pilot plant[7]

Briquetting pressure	5000 kg/cm
Roll size	1200 mm ϕ × 87 mmW
Briquette size	18 cm³, 35 × 35 × 8.5 mm

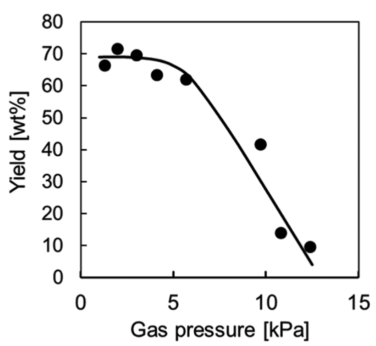

Fig. 9 Influence of gas pressure during briquetting on briquette yield[7]

Table 2 Effect of fine briquetting on carry over

Condition	QI in decanter tar
With hot briquetting	4.6%
Without hot briquetting	13%

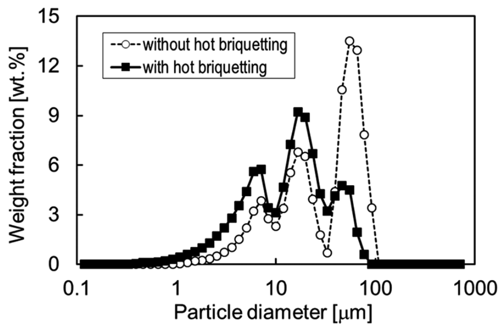

Fig. 10 Size distribution of carry over particles at ascension pipe[8]

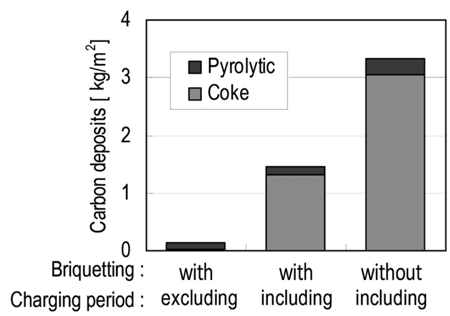

Fig. 11 Carbon deposits in SCOPE21 pilot plant operation[9]

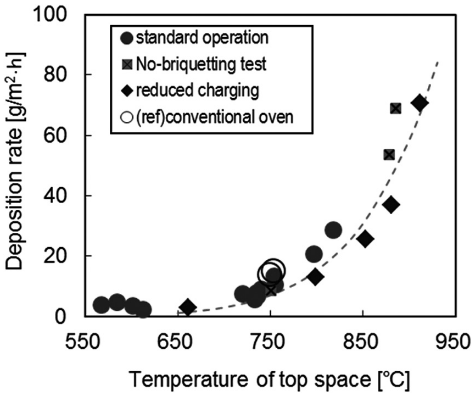

Fig. 12 Influence of top space temperature on carbon deposition during coking period (excluding coal charging period)[9]

tion at the same temperature in the top chamber space. Without the coal fine briquetting, the carbon deposit was more than twice that with the briquetting, which confirms the large carbon deposit decreasing effect of the briquetting. Most of the carbon deposit was of coal origin.

Figure 11 also shows the carbon deposit that formed during the coking time after the charging time; this was measured by hanging bricks after charging. In this case, the carbon deposit was very low, and it consisted mostly of pyrolytic carbon. This indicates that carbon deposition occurs owing mostly to coal fine flying during charging.

The rate of carbon deposition during the coking period excluding the charging period changed greatly depending on temperature (see **Fig. 12**[9]). Although the graph reflects the effects of operation conditions set for test purposes, the top chamber space temperature was usually comparatively low at 800°C or lower during the pilot plant test, and the carbon deposition by the SCOPE21 process was evaluated as being substantially equal to that by the conventional process.

(3) Low NO_x combustion

As high productivity was targeted in the development of the SCOPE21 process, it was necessary to increase the heat input for coal carbonization from the level of conventional ovens, which means that a greater amount of combustion gas has to be supplied. In most cases, when the amount of fuel gas is increased, local combustion occurs significantly, and the heating of coal tends to be uneven in the vertical direction. Moreover, the NO_x concentration in the exhaust gas increases, which is environmentally undesirable. In this situation, it was necessary to develop a combustion chamber structure capable of homogeneous combustion and low NO_x emission even when the fuel gas amount was twice that of conventional ovens.

For the development study of an optimum flue design, a combustion test oven comprising real-size flues was constructed;[10] **Table 3** shows its specifications. Instead of heat transfer to the coking chamber, the heat generated by the test oven was removed by water-cooled walls. Conventional flues and newly developed ones were provided in the oven, and the heat generation of the two was compared.

As a result of the studies of the arrangement of the flue ports at the bottom, it was clarified that, rather than by arranging the fuel gas port and the air port adjacent to each other as shown in part (a) of **Fig. 13**[10], by arranging them in a staggered way as shown in part (b), the contact of the fuel gas with the air is restricted, the local

Table 3 Specifications of combustion test oven

Oven size	H 7.5 × L 6.0 m
Flue size	H 6.6 m - twin flue type
Number	12 (6 developed, 6 conventional)
Gas inlet	Fuel: 1 stage, Air: 3 (4) stage

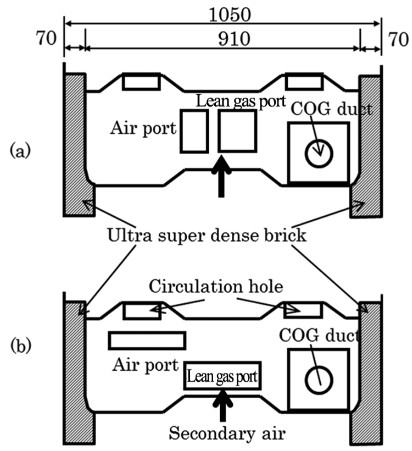

Fig. 13 Arrangement of flue ports at bottom[10]

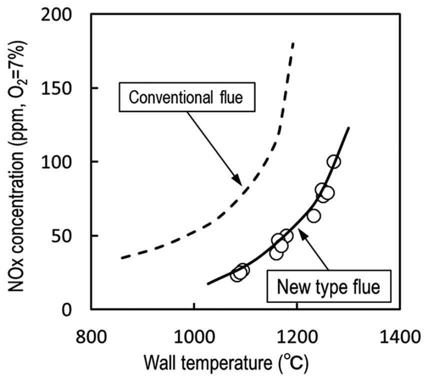

Fig. 14 Relationship between wall temperature and NO_x concentration in exhaust gas[10]

combustion in the lower part better controlled and NO_x emission greatly decreased. In addition, providing circulation holes in the bottom of the partition wall between two adjacent flues (twin flue) to allow part of the exhaust gas to circulate is effective at decreasing NO_x emission.

The developed flue structure decreased NO_x emission to far lower levels than that of conventional flues as shown in **Fig. 14**;[10] actually, the developed flue satisfied the NO_x emission standard, 170 ppm, set for newly built coke ovens. The developed flue structure was adopted for the pilot oven, and the same low NO_x emission as that of the combustion test oven was confirmed in the test operation under the condition that the heat was removed not by water cooling but by that used for coke production.

4. Commercial Plants of SCOPE21 Process

Based on the results of the national development project, the first commercial oven of the SCOPE21 process was built as the No. 5 Coke Oven of Oita Works in 2008 (see **Fig. 15**). Then, after years of commercial operation of Oita No. 5 CO, the second commercial

Fig. 15 Overview of Oita No. 5 coke plant

Fig. 16 Overview of Nagoya No. 5 coke plant

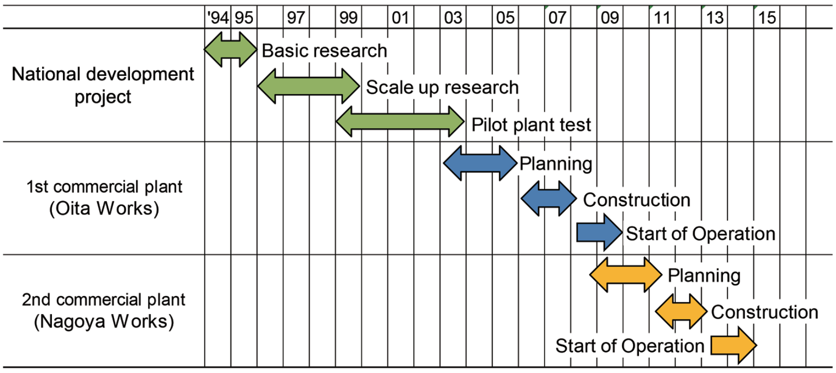

Fig. 17 Development of SCOPE21 and construction of commercial plants

oven was commissioned in 2013 as the No. 5 CO of Nagoya Works (see **Fig. 16**).

Figure 17 shows a rough time table from the commencement of the development project to the start-up of the second commercial oven. After completion of the development project, environmental assessment for Oita No. 5 CO was conducted in 2004 to 05, then the coke oven was erected from April 2006 to April 2008. The construction work of the oven proper was completed in January 2008, and coal was first charged on February 1, and the first batch of coke was ejected out of the oven on the following day. After integrated operation from the coal pretreatment facilities to the coke oven and the coke dry quenching (CDQ) equipment, the construction project of the first commercial SCOPE21 plant was concluded in May 2008.

The planning studies for the No. 5 CO of Nagoya Works started in 2008, the foundation work for the plant began in March 2011, the brick work for the oven proper was completed in September 2012, the oven was dried and heated up from December 2012, the first coal charging took place on March 1, 2013, and thus the oven entered into commercial operation. The coal pretreatment equipment was constructed in parallel, and commissioned in March 2013. Then, with the start-up of the CDQ equipment, the entire No. 5 CO Plant entered into through-process operation in May 2013.

Table 4 shows the specifications of these commercial SCOPE21 plants. Either of them comprises 64 coking chambers, each 0.45 m in width, 6.7 m in height, and 16.6 m in length (effective volume 43.7 m^3), where coal is charged into and carbonized, and has an annual coke production capacity of one million tons per year.

Since the start-up in February 2008, Oita No. 5 CO increased its operating ratio to reach 184.5% operation in January 2009. In the early days of the operation, the operating ratio was increased to 135% by gradually raising the oven temperature, then it was raised to the design maximum, and then the design coking time was attained by raising the charging coal temperature. **Figure 18** shows the actual coking time.[11] The coking time became shorter the higher the charging coal temperature as estimated by heat transfer calculation, and was shortened to 13 h (operating ratio 184.5%) when the

Table 4 Specifications of Oita/Nagoya SCOPE21 process

Fluidized bed dryer	161 t/h
Pneumatic preheater	106 t/h
Agglomerator	36 t/h × 2
Number of ovens	64
Dimensions of ovens	W 0.45 × H 6.7 × L 16.6 m
CDQ	123 t/h

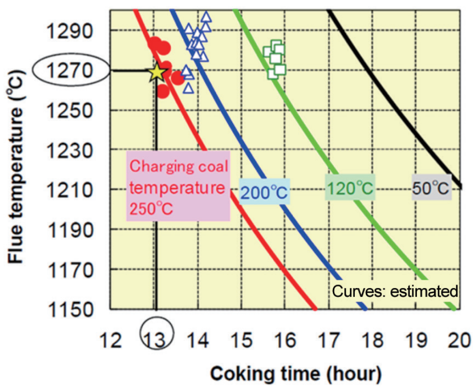

Fig. 18 Relationship between flue temperature, charging coal temperature and coking time[11]

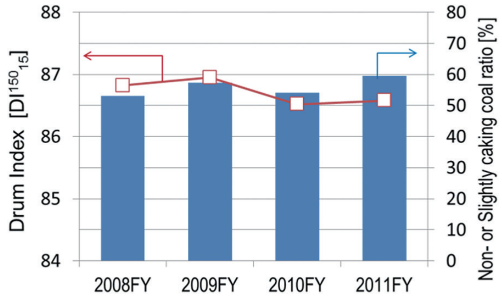

Fig. 19 Coke strength and blending ratio of non- or slightly-caking coal at Oita No. 5 CO

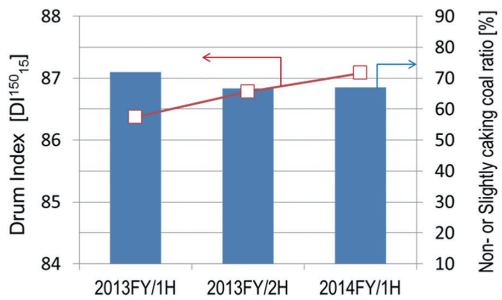

Fig. 20 Coke strength and blending ratio of non- or slightly-caking coal at Nagoya No. 5 CO[2)]

charging coal temperature was 250°C, and the oven temperature 1 270°C.

Nagoya No. 5 CO also reached the maximum operating ratio of 184.5% in November 2012, three months earlier than initially planned.

Figures 19 and **20**[2)] show coke strength (DI^{150}_{15}) and the blending ratio of non- or slightly-caking coal after the commissioning of Oita No. 5 and Nagoya No. 5 CO plants, respectively. A drum index of 86 or above has been maintained at both the plants, confirming the production of high-strength coke as initially envisaged. The blending ratio of non- or slightly-caking coal has exceeded 55% at Oita, and 60% at Nagoya. This demonstrates that the use of economical, low-quality coal has been increased significantly without sacrificing coke strength.

5. Conclusion

The SCOPE21 process was developed as a national project under a common problem consciousness among the Japanese steelmakers and coke producers, and the concept quickly brought into commercial reality at Nippon Steel's Oita and Nagoya Works. These plants continue stable and high-efficiency operation.

The process has greatly improved the operating efficiency of coke ovens by increasing the blending ratio of non- or slightly-caking coal and remarkably enhancing plant productivity owing to the introduction of innovative methods of coal pretreatment. At present, with the price of high-quality coal going up and its resources running short, the state-of-the-art SCOPE21 process is expected to be highly effective at the efficient use of coal resources and saving energy.

It has to be emphasized that the SCOPE21 process was achieved based on the results of an activity of the Coal Combustion Technology Development (Cokemaking Technology by Advanced Coal Conversion) under a subsidy for the promotion of coal production and utilization. We would like to express our sincere gratitude to all those concerned.

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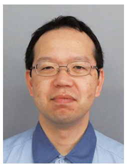
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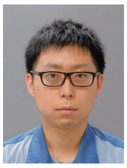
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