Ironmaking Technologies Contributing to the Steel Industry in the 21st Century

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In the 20th century, NKK's ironmaking sector sharpened its competitive edge by taking the initiative in developing innovative technologies and fulfilling social requirements. Noteworthy achievements included: extended utilization of various raw materials for ironmaking, improved productivity, and decreased energy consumption. These innovations are now being applied successfully to the expansion of NKK's environmental businesses. In the 21st century, technological breakthroughs will continue to be pursued, diversifying the areas of R&D in accordance with social needs.

1. Introduction

The technological development carried out by NKK's ironmaking division in the 1990's can be represented by the phrase: "combinating and pursuing the ultimate". Individual technologies cultivated in individual processes were combined to achieve greater objectives. Efforts were focused on enabling the true potential of technologies accumulated in NKK's steelworks to be achieved at ultimate levels. The 1990's saw the development of various new technologies worth closing the 21st century. For example, massive pulverized coal injection was achieved by combining blast furnace operation technology with that used in high quality sintered ore production as well as equipment that allowed high load blast furnace operation. The ironmaking division contributed to the development of the revolutionary Zero Slag Process[1)] in the steelmaking sector by establishing low-silicon blast furnace operations through optimizing raw material properties. These achievements are now fully utilized in NKK's expanding environmental businesses, opening up new horizons in the interaction between the steel industry and society centering on resource recycling.

In order to respond to the diversifying need for developing new ironmaking technologies in the 21st century, NKK's ironmaking sector will merge its technologies with those of its counterpart in Kawasaki Steel with which NKK is going to integrate and establish unparalleled ironmaking technologies as JFE.

2. Development of ironmaking technologies in the 1990's

2.1 Blast furnaces

Fig.1 shows the transition of major operation parameters at NKK's blast furnaces. The technological development in the 1990's was carried out conforming to local conditions at each of the Keihin and Fukuyama Works. In 1998, NKK, by starting up Fukuyama's No.2 blast furnace, established the four blast furnace system with the total annual capacity of 10 million tons. In addition, new PCI (Pulverized Coal Injection) systems were installed at each blast furnace, gradually expanding this mode of operation. While the technology for injecting large amounts of pulverized coal has been actively developed, a world-first practice of injecting waste plastics into blast furnaces has also been established. A problem common in both pulverized coal and waste plastics injection operations has been that the pressure drop tends to increase at the lower part of blast furnaces due to the accumulation of unburned char. This problem has been overcome by establishing new techniques of controlling burden distribution by fully utilizing the hot blast control valve[3)] and NEW-CFC in order to directly control the lower part of the blast furnace.

With regard to hot metal quality, efforts have long been made to reduce Si content with a view to reducing refining costs in the subsequent steelmaking process. In 1996, a new technique, FIMPIT (Fiber In Metallic tube for Pig Iron Temperature)[4)] for directly measuring hot metal temperature at a tap hole, was developed at the Fukuyama

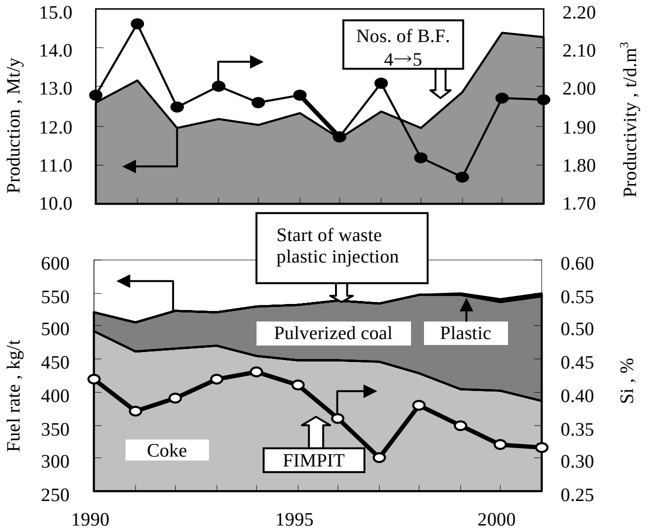

Fig.1 Transition of major operation parameters within NKK's blast furnaces

Works. It was installed at each blast furnace in order to strengthen heat level control, and as a result, stable production of low-Si hot metal became possible. In October 1997, the Fukuyama Works achieved a world record in terms of Si content (less than 0.2%) averaged across the entire hot metal produced over a month by a steelworks.

In terms of prolonging blast furnace life, refractory properties and cooling systems have steadily improved. These improvements were successively applied when blast furnaces were relined. Technical improvements have also been made in terms of repairing the shaft and bosh sections while blast furnaces are in operation. As a result, the Fukuyama No.5 blast furnace, which began operations in 1986, is still working after 17 years. This is remarkable when contrasted with those blast furnaces that began operations in the 1970's whose working life was a mere five to seven years (**Fig.2**). Some of the old blast furnaces achieved productivity levels of 1.9 t/d-m^3 and PCR (Pulverized Coal Rates) of 170 kg/t, making large contributions to productivity increase.

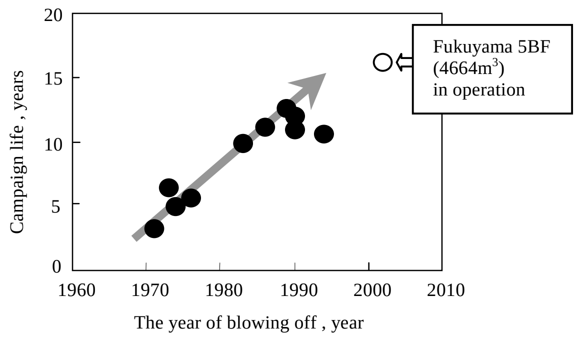

Fig.2 Transition of NKK's blast furnaces life

The furnace life prolongation technologies developed in the 1990's include the new technology for replacing the bosh cooling staves and the newly developed, long lasting copper cooling staves[5]. The latter will be described later. In 1999, all 60 cooling staves were replaced by cast copper cooling staves at the Fukuyama No.4 blast furnace. The entire replacement work was completed over a period of only 87 hours furnace shutdown, thus establishing the rapid cooling stave replacement method[6]. The operating performance immediately before and after this shutdown is shown in **Fig.3**.

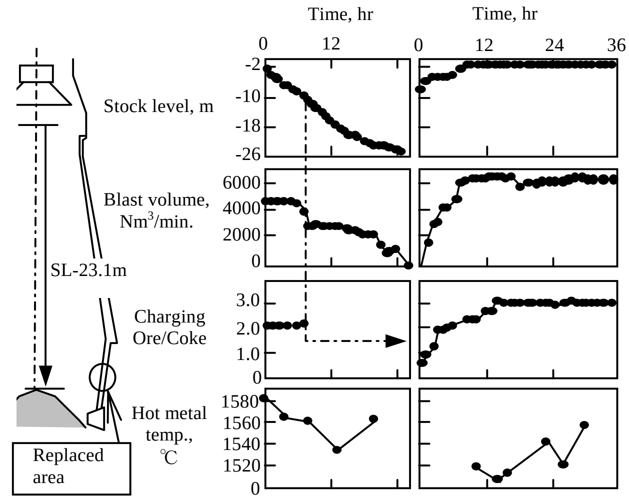

Fig.3 Operating performance before and after changing Fukuyama No.4 BF's bosh cooling staves

2.2 Sintering

As to NKK's sintering operation Keihin Works has excess sintering capacity. In contrast, the Fukuyama Works needs to operate two sintering machines at full capacity since it moved to the aforementioned four blast furnace system. Another factor is that Fukuyama's No.5 sintering machine was modified in 1988 to a HPS (Hybrid Pelletized Sintering) machine[7] for producing high-quality agglomerates using high-quality fine ore pellet feed as the main material. Based on the characteristics of these two steelworks, total economic merits were pursued. The Fukuyama Works uses mainly high-quality hematite pellet feed while the Keihin Works uses mainly iron ore with a high combined water content that significantly affects production capacity. In recent years, technological developments that allow the use of large amounts of ore with high combined water content have continued and expanded to counter the possible depletion of Australian high-quality hematite deposits. The SSW (Segregation Slit Wire)[8] was developed and put into practice in order to deal with the problem that using large amounts of ore with high combined water content tends to lower the sintering yield. **Fig.4** shows the transition of the mixing ratio of pellet feed and ore with high combined water content as well as yield expressed in terms of the return fine rate. The figure demonstrates that the use of these ore types that are difficult to use was expanded while increasing the production yield.

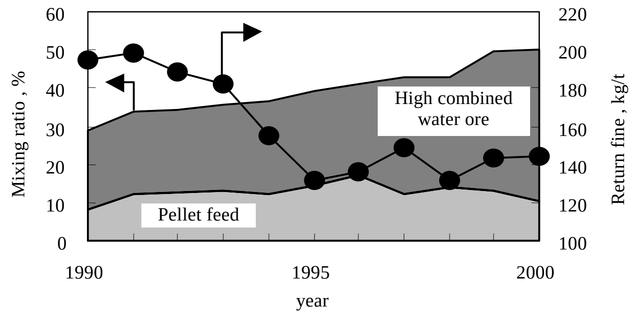

Fig.4 Transition of material type and return fine rate at NKK's sintering operations

Full automation of the Fukuyama No.4 sintering machine in February 1996 has minimized the required manpower[9]. This machine had previously been operated by 12 operators (three operators working each of four shifts). By developing and strengthening the operation control and sintering control systems (**Fig.5**), thus eliminating the manual operations, this machine is now operated without any shift operator.

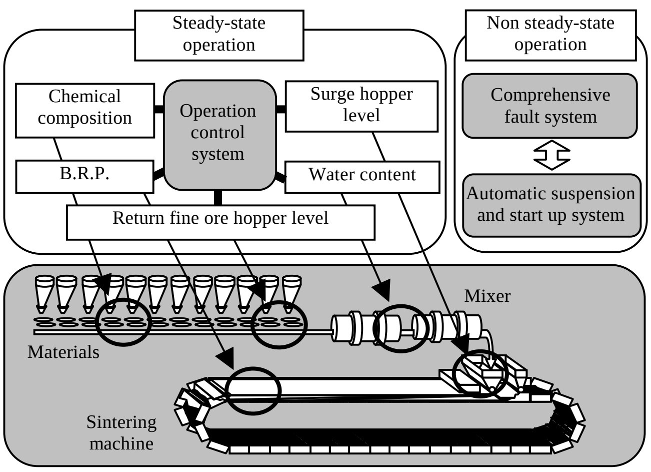

Fig.5 Operation control systems at the Fukuyama No.4 sintering plant

2.3 Cokemaking

Project SCOPE-21, currently being promoted as a Japanese national project, aims to solve various problems facing existing coke ovens such as: the need for expanded use of low-grade, non- or weak-coking coal; increasing productivity; eliminating smoke and dust generation, and energy saving. In addition to dealing with these problems, NKK has been actively engaged in wide-ranging technological development in terms of cokemaking such as the accurate control of coke quality for stabilizing blast furnace operations, and prolonging coke oven life. **Fig.6** shows the transition of the ratio with which non- or weak-coking coal was used in NKK's cokemaking operations over the last 10 years.

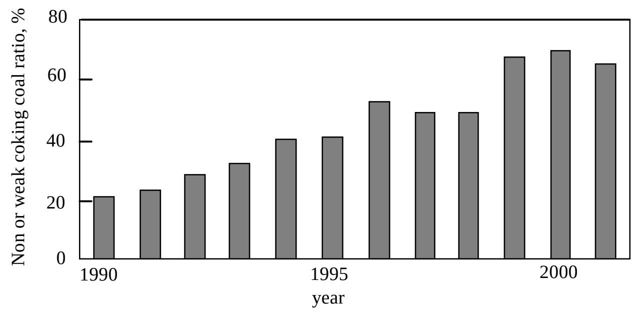

Fig.6 Transition of non- or weak-coking coal ratio (NKK)

This increase in ratio was achieved by developing the following new technologies:

(1) Increasing coke strength by improving the method of crushing coal (selective crushing) and by expanding the effect of formed coal (selective briquetting); and,

(2) Increasing the accuracy of controlling the cokemaking process by improving accuracy in estimating coke strength[10] and by automated strength measurements.

Productivity increase was promoted focusing on coke oven machine automation such as charging cars and guide cars. These machines were automated in the Fukuyama Works in 1996 and at the Keihin Works in 1998. The automated operation system[11] at the Fukuyama Works achieved the cycle time (required time for working on one oven) of 6.5 minutes, the shortest in Japan. The development and improvement of leading-edge technology have greatly increased operating efficiency. One example is the expert system[12] incorporated in the COG (Coke Oven Gas) refining process, where the computer makes the operational judgments instead of humans. Energy saving, promoted over the last 10 years, has focused on increasing energy recovery rather than on energy consumption savings. **Fig.7** shows the transition in terms of the amount of COG recovered from coke ovens, and the amount of steam recovered from the CDQ (Coke Dry Quenching) process by effective use of the sensible heat produced by coke.

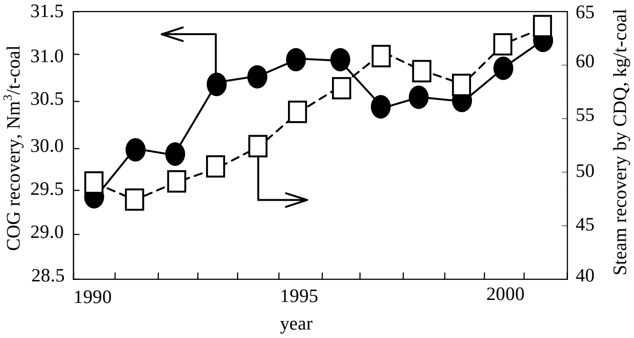

Fig.7 Transition of COG and steam recovery (Keihin)

In order to increase the amount of COG recovery, increased use of coal with a high volatile content was promoted. At the same time countermeasures were taken against carbon adhesion to the carbonization chamber walls. In CDQ steam recovery, air injection into the CDQ system was optimized by performing 3-D numerical analysis and introducing real-time models[13].

Constructing a new coke oven battery entails a huge capital investment, so it is important to prolong the life of a coke oven. This aspect has been attacked on two fronts: developing techniques for repairing coke ovens and for diagnosing oven life. Typical new technologies developed for the former are as follows:

(1) Hot repair technique for oven walls. Parts of the refractories that make up the oven wall are replaced while the oven is still hot.

(2) Large-scale thermal spray technique for smoothing refractory surfaces that have become uneven due to degradation, and for plugging small penetrating holes. (This technology was jointly developed with other companies.)

In order to diagnose oven life, various sensors have been developed and a database constructed (**Fig.8**). Based on these, it is planned to develop an optimal repair method.

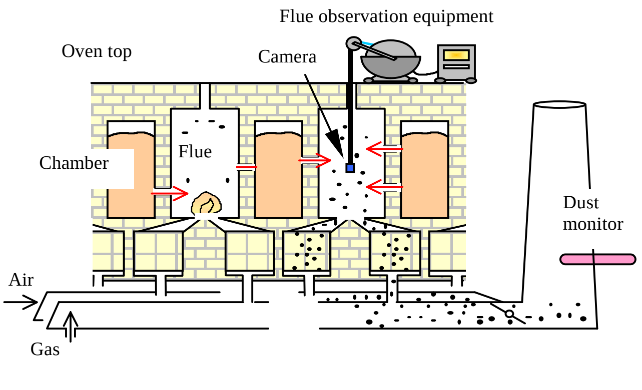

Fig.8 Sensors installed for facilitating efficient oven repair

3. Massive injection of pulverized coal into blast furnaces

Fig.9 shows the years of constructing PCI (Pulverized Coal Injection) equipment at NKK's blast furnaces and the transition of the PCR (Pulverized Coal Rate). Generally, PCI operation of a blast furnace tends to cause the following problems:

(1) Blast furnace upper zone permeability worsens with increases in ore/coke ratio.

(2) Permeability in the lower zone of the blast furnace worsens due to coke powder accumulation.

(3) Combustion efficiency of pulverized coal worsens with increasing PCR.

In order to overcome those problems that hinder stable blast furnace operation, NKK has actively promoted the development of techniques such as optimal control of burden distribution by using NEW-CFC, designing of sintered ore properties most suited to massive PCI, and highly combustion efficient pulverized coal burners.

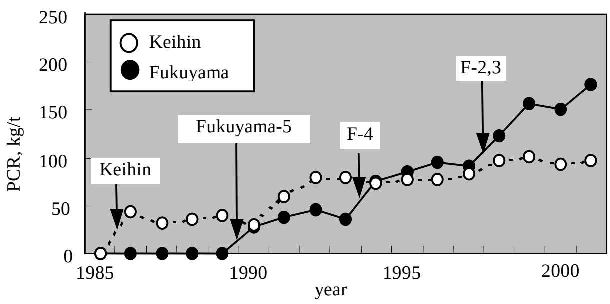

Fig.9 Years of constructing PCI equipment and transition of PCR

3.1 Pulverized coal burners with high combustibility[14]

It is important to increase the combustibility of pulverized coal at the tip of the tuyere in order to make efficient use of pulverized coal as a heat source and reducing agent in blast furnaces without wasting it as dust discharged at the top of the furnace.

Numerical models were employed for evaluating the effects of lance arrangements on the combustion behavior of pulverized coal in the blowpipe. The results are shown in **Fig.10**. In the case (c), two lances are eccentrically arranged in order to prevent the collision of pulverized coal flows, and accelerate combustion. It was estimated that this eccentric double lance arrangement increased combustion efficiency by more than 15% when compared with the conventional single lance arrangement. This lance arrangement was first adopted at the Fukuyama No.4 blast furnace in April 1994. Subsequently, all NKK's blast furnaces were equipped with it, making a large contribution to a massive PCI operation.

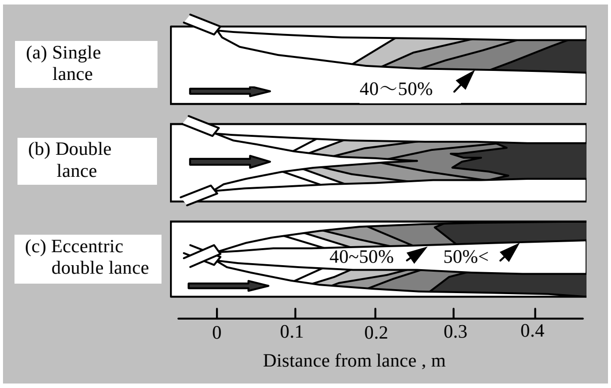

Fig.10 Effects of lance arrangements on pulverized coal flows and combustion efficiency

3.2 Sinter properties optimized to massive PCI operation

Reduction degradation of sintered ore tends to be caused in the blast furnace's upper zone due to low temperatures in this zone. As the massive PCI operation lowers the heat flux ratio, this low-temperature zone is narrowed, suggesting that the reduction degradation of sinter could be weakened by a massive PCI operation. In order to obtain sinter properties optimized to a massive PCI operation, attempts were made at the Fukuyama Works to lower the SiO_2 content of HPS ore and increase the RI of sintered ore while at the same time relaxing the RDI specifications.

The effect of SiO_2 content in sintered ore on blast furnace permeability was investigated at the Fukuyama No.4 blast furnace. The results are shown in **Fig.11**. It was found that sintered ore with low SiO_2 content (high RI, high RDI) can significantly improve lower furnace zone permeability while maintaining permeability in the upper zone. This behavior is attributable to such factors as: reduction degradation in the upper zone being weakened, despite high RDI due to the above-mentioned effect; and the reduction and meltdown properties in the cohesive zone are significantly improved due to increased RI[15].

These technological developments led to the Japanese record of 218 kg/t achieved by the Fukuyama No.4 blast furnace in October 1994, and the world record of 266 kg/t achieved by the Fukuyama No.3 blast furnace in June 1998[16]. More recently, the Fukuyama Works averaged 210 kg/t across all furnaces. This was the highest amount recorded in the world by an integrated steel mill with four large-scale blast furnaces.

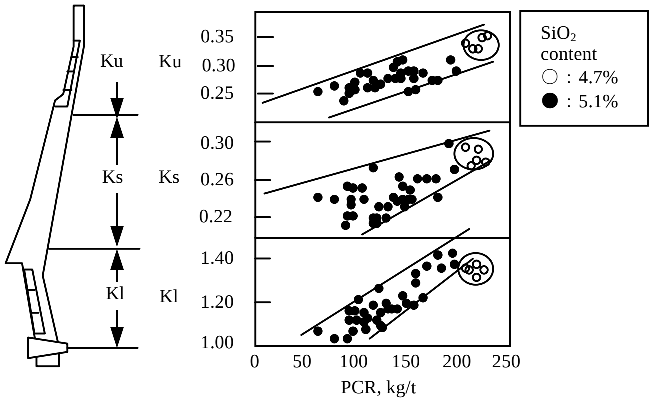

Fig.11 Effects of SiO_2 content in sintered ore on blast furnace permeability

3.3 Developing a highly durable furnace cooling system

Hot model experiments and measurement of operating blast furnaces carried out by the company indicated that the massive PCI operation tends to move the focal point of combustion (the highest temperature point in the raceway) toward the tip of the tuyere, and also that large amounts of slag originating from ash content in pulverized coal tend to accumulate at the end of the raceway, forming a layer of poor permeability. These phenomena could confine the gas flow in the lower zone of the furnace into the peripheral area of the furnace, thereby increasing the thermal load on the bosh[17].

As a countermeasure, NKK developed cast copper cooling staves with high thermal conductivity. The cast copper cooling staves provide a high level of cooling, thus preventing thermal deformation. Due to its superior cooling performance, slag forms a self-coating layer on the inner surface of the bosh, thus preventing the physical wear on the cooling stave bodies. As a result, the newly developed cast copper cooling staves offer excellent resistance to high thermal loading[5].

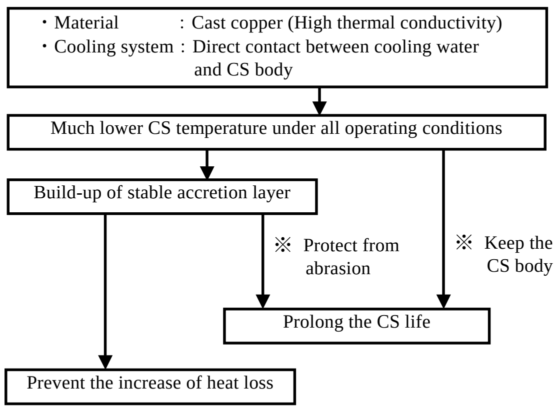

Fig.12 Effect of introducing cast copper cooling staves

4. Low-Si hot metal production technology

In recent years, further reduction of the consumption of flux materials and ferroalloys in the steelmaking process has been required, as well as the reduction of slag generation, and zero slag operation of converters is increasingly desired. In response, NKK's ironmaking division has tried to reduce the Si content in hot metal being sent on to the steelmaking process. Two approaches were tried: the first was to reduce the Si content in hot metal before tapping; the second to reduce Si content after hot metal has been tapped from the blast furnaces.

4.1 Developing FIMPIT[4)] and reducing Si content in hot metal

It is important to determine the heat level in a blast furnace accurately and in real-time in order to reduce Si content in hot metal before it is tapped. For doing so, it is necessary to be able to measure the hot metal temperature directly immediately after it has been tapped from a tap hole. However, the tap hole surroundings is a severe environment with high-temperature hot metal spouting from the blast furnace, and it has been extremely difficult to directly measure the temperature.

A new technology using optical fibers has been developed by NKK for directly measuring the temperature of hot metal immediately after it has been tapped. This new FIMPIT technology allows the direct measurement of hot metal temperatures with minimal external disturbance caused by heat dissipation into the runner and atmosphere. **Fig.13** shows a schematic representation of the measurement system using this technology.

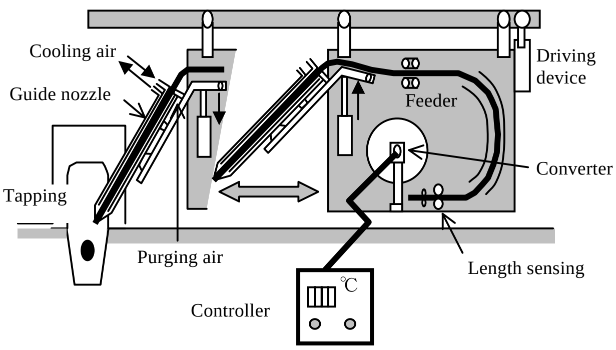

Fig.13 Schematic structural diagram of FIMPIT

Fig.14 shows the transition of hot metal temperature and Si content at the Fukuyama Works. This technology was effective at lowering the hot metal temperature by 20 degrees C and reducing the hot metal Si content by more than 0.1% when compared to conventional operations.

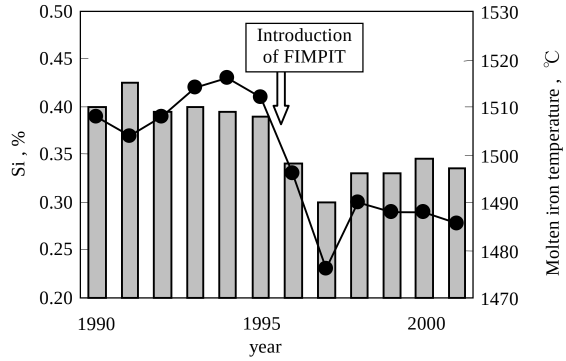

Fig.14 Operational transition before and after the introduction of FIMPIT (Fukuyama)

4.2 Raising the desiliconization treatment level in cast house floor

The desiliconization treatment in the cast house is generally performed by injecting desiliconization flux into hot metal at the tilting runner, since this provides a favorable degree of reaction efficiency. Due to reasons mentioned earlier, desiliconization levels need to be raised further.

When reducing Si content, it is essential that the charging amount of the desiliconization flux is increased. However, the method of charging flux into a hot metal ladle can result in negative results such as foaming that makes it difficult to gather the correct amount of hot metal in the ladle. Under conventional situations, an operator will manually charge the anti-foaming flux when this phenomenon occurs.

However, the foaming-suppression effect of this practice is largely dependent on operator skill. It is also difficult to continually charge the flux. In order to secure the correct foaming-suppression effect, the method of charging the anti-foaming flux into the ladle has been improved. This enables the independent operation of anti-foaming flux charging and desiliconization flux injection. The improved process flow is shown in **Fig.15.**

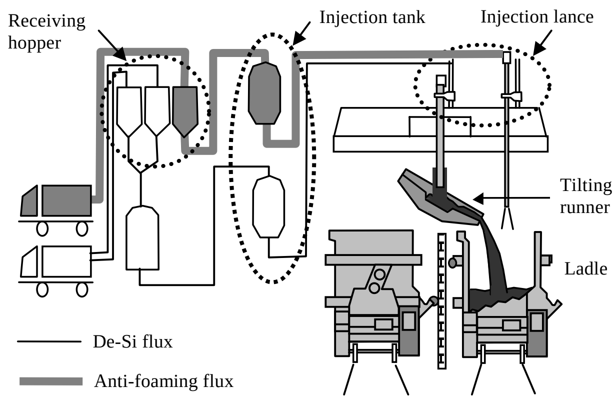

Fig.15 New desiliconization process flow

In this process, the anti-foaming flux is directly charged into the hot metal ladle and reacts efficiently in the ladle, suppressing the generation of CO gas that causes foaming. This process also allows for the steady injection of large amounts of desiliconization flux, making desiliconization more efficient. With this process, the hot metal already has a fairly low Si content when it is sent to the steelmaking process, and contributes to the achievement of a 100% zero slag steelmaking operation.

5. Recycling businesses applying ironmaking technologies

Since the second half of the 1990’s, efforts have been concentrated on applying ironmaking technologies to the development of new environmental businesses. Recycling businesses currently being carried out by the ironmaking division are introduced below.

5.1 Waste plastics injection into blast furnace feeding

Before starting up the waste plastics feeding system for the Keihin No.1 blast furnace, the effects on the blast furnace were investigated using the operating furnace[18]. **Fig.16** shows the results of photographing the interior of the tuyere using a high-speed camera (13500 frames/sec) during waste plastics injection. Two types of waste plastics, with different grain sizes, were injected. For comparison, the state during pulverized coal injection is shown as well. When pulverized coal was injected, the combustion flame was observed immediately after injection. In contrast, plastics with a large grain size did not start combusting immediately.

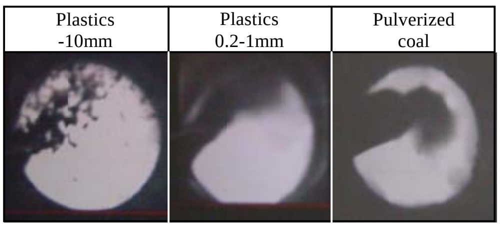

Fig.16 Interior photographs of the tuyere during waste plastics injection

As shown in **Fig.17**, the H_2 concentration in the furnace top gas was higher when plastics were injected as compared to that during conventional operations. Moreover, the difference in the two measurements with or without plastics injection became larger, nearer to the furnace center. These observations suggested that injected plastics remain swirling in the raceway for a certain period of time, and then are gasified near the far end of the raceway. Thus, it was found that the combustion gasifying rate could be increased by controlling the grain sizes of waste plastics within an appropriate range.

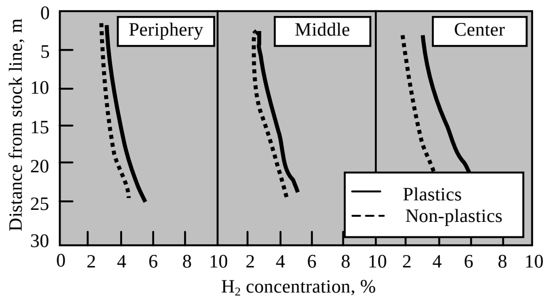

Fig.17 H_2 concentrations in blast furnace top gas during waste plastics injection

It was also verified that the amount of tar contained in the dust discharged along with the furnace top gas was at the same level as that in conventional operations thus posing no problems in furnace operations. Based on these results, Japan’s first waste plastics injection operation began in 1996 at the Keihin No.1 furnace. Since then, the same operation has also been used at the Fukuyama No.3 furnace. Currently, a combined total of 80000 tons of waste plastics is being treated in this way annually.

5.2 Effective use of wastes in the sintering process

Equipment that effectively uses waste toner from office machinery makers as a sintering material was started up at the Keihin sintering plant in 2000[19]. Toner powder is composed of iron and resin, and can be effectively substituted for iron ore and coke powder. However, toner powder is very fine with grain sizes in the order of micrometers, is difficult to handle, and has previously been disposed of in landfills. NKK installed a waste toner feeding line equipped with dust and explosion preventive systems, enabling large amounts of waste toner to be treated (**Fig.18**).

NKK will continue to investigate ideas, and use the sintering plant for effective resource recycling.

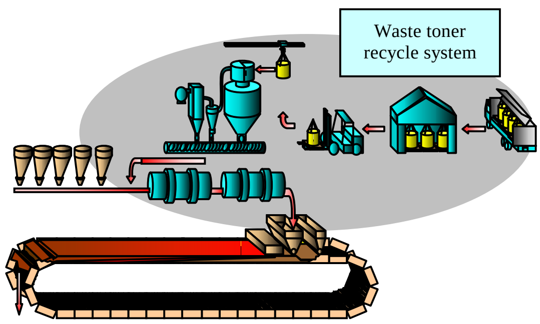

Fig.18 Waste toner recycling system at the Keihin No.1 sintering plant

6. Conclusion

The development of NKK's ironmaking technologies since the 1990's has been outlined. As stated in the beginning, recent technological developments in the ironmaking field are diversifying, centering on recycling businesses. NKK's ironmaking sector met the needs of society in the 20th century through developing highly efficient energy-saving technologies, and will continue to fulfill its social responsibility by leading the industry in responding to the needs of society in the 21st century.

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