ECONOMIC RESEARCH CENTER
DISCUSSION PAPER

E-Series

No.E12-1

Development of the Japanese Energy Saving Technology during 1920–1960 : The Iron and Steel Industry*

by

Satoru KOBORI**

January 2012

ECONOMIC RESEARCH CENTER
GRADUATE SCHOOL OF ECONOMICS
NAGOYA UNIVERSITY

* Research for this article was supported by the Japan Society for the Promotion of Science, Grant-in-Aid for Scientific Research (B), 21330084, 2009–2011.
** Nagoya University

Development of the Japanese Energy Saving Technology during 1920–1960:
The Iron and Steel Industry

Satoru KOBORI

Abstract

Purpose of this paper is to reveal how and why the Japanese iron and steel industry achieved the development of energy-saving technology after WWII. Not only did it realize rapid improvement of the basic unit for fuel, but its basic unit for fuel was already better than that of any other country by the early 1950s. Regarding the development of energy-saving technologies in steel-making processes, two technologies have been pointed out; heat control and oxygen steelmaking. Of these two technologies, heat control had developed since the interwar era; the latter was a new technology that was developing after WWII. The Japanese energy-saving technology after the war was not an exact copy of the U.S. technology. It was much different from the U.S. efforts in its objectives and contents. Its rapid improvement and diffusion was contributed by the exchange of technology between firms through ISIJ and the heat-control division and OJT of every iron and steel work. However the energy conservation development of the Japanese iron and steel industry was not only a success story. The development of the energy-saving technology by the Japanese iron and steel industry does not always decrease the environmental load. At least during the 1950s, it exacerbated environmental pollution.

Keywords : the Japanese energy-saving technology, heat control, oxygen steelmaking, environmental pollution

1. Introduction

Improving the basic unit for energy was an important measure for Japanese industrial rationalization during the reconstruction period because energy supplies were severely limited. Improvement of the basic unit for energy during reconstruction was truly as important a shift in development as that which occurred after the oil crisis (Takeda 2007, pp.62-70). Energy supply limitations stimulated the development of energy-saving technology at that time.

We must make a sharp distinction, however, between the "possibilities" of the development of energy-saving technology in the context of limited energy supplies and their "realization". Why did the Japanese energy-consuming industries not decline given the background of energy supply limitations during reconstruction? How and why did energy-consuming industries achieve the development of energy-saving technology to survive and grow?

This paper casts some light on the progress of the Japanese iron and steel industry to answer the questions raised above. Not only did the iron and steel industry realize rapid improvement of the basic unit for fuel, but its basic unit for fuel was already better than that of any other country by the early 1950s (Fig. 1). Regarding the development of energy-saving technologies in steel-making processes, two factors have been pointed out. First is heat control, for example changing fuel and improving industrial instruments, combustion, and combustion equipment. Second is the use of oxygen in open-hearth furnaces (OHF) (Table 1). Of these two technologies, heat control had developed since the interwar era; the latter was a new technology that was developing after WWII throughout world. This paper therefore specifically describes development processes of these two technologies to investigate why post-war Japan achieved rapid improvement of the basic unit for energy.

2. Improvement of heat control[1]

Regarding heat control, we must examine its development not only after WWII but also from the 1920s to WWII because its development before WWII contributed to that after WWII.

(1) During the interwar era

[1] This section is fundamentally referred from Kobori (2010).

Introduction of foreign energy-saving technology

During the 1920s, the Japanese took an increasing interest in energy-saving technology because the industrialization and the rising of domestic coal production cost made the price of coal increase (Fig. 2) and the quantity of coal imports exceed its exports (Fig. 3). The iron and steel industry was no exception, and energy-saving technologies in Europe and North America, especially in Germany, were of great interest. For example, Kuniichi Tawara, an outstanding engineer of the iron and steel industry, travelled to Europe and North America during June 1921 – July 1922 and reported, "[the US iron and steel industry] does not introduce many resource saving facilities because the US has sufficient resource. …[On the other hand Germany] does not have many resources, so the reason for the development of the German iron and steel industry was an attempt to develop its technology" (Tawara 1922, pp.815-16). He appreciated that Germany had aggressively developed energy-saving and resource-saving technologies under the constraints of a resource set that differed from those of the U.S. and U.K. He also said, "Japan is short of resources for iron and steel and its quality is bad, so we have to study hard like the German engineers." He thought that the Japanese iron and steel industry were compelled to follow the example not of the US rationalization, which used plenty of natural gas and heavy oil, but German rationalization, which tried with great difficulty to conserve coal. He further emphasized the aggressive technology exchange in Germany, which promoted technological development.

Heat control was a representative technology that was researched and exchanged aggressively. Verein Deutscher Eisenhüttenleute (German Iron and Steel Institute) established Hauptwärmestelle (the Central Heat-Control Office) in Dusseldorf to promote energy-saving. The tasks of Hauptwärmestelle were not only research of heat control but also training engineers, exchanging technology among iron and steel mills, advertising of heat control, and so on. Each iron and steel facility also established a Wärmestelle (heat-control center) and employed Wärme Ingenieur (heat engineers) to improve heat control not by a skilled worker's intuition but by an engineer's instrumentation.

Franz Kofler, who was actively involved in introducing heat control at the Showa Steel Works (SSW), remarked that heat control was accomplished in two steps (Kofler 1934). He said, "The first step …is to recycle the energy which is generated at a process to decrease the quantity of fuel." This effectively means the recycling of surplus energy, for example, that of blast furnace gas and coke oven gas. It is however only "the easiest step." He continued: "the second step is saving the quantity of energy which is necessary to produce iron and steel." The second step includes improvements of the basic unit for energy at each process and the needed R&D, accurate instrumentation to measure the use of energy, and technological guidance for building and improving furnaces from the viewpoint of thermal economy. It was heat control on its way from the first to the second step that the Japanese engineers had observed in Germany during the interwar era.

Energy conservation practices during the interwar era

These energy-saving technologies were actually introduced at some Japanese plants. The Yawata Iron & Steel Works started reusing by-product gases, as entailed in the first step of heat control. In November 1922, Yawata started to use coke-oven gas mixed with producer gas for heating OHF at its No. 2 steelmaking plant. More Yawata plants thereafter came to use by-product gas. At the neo-No.1 steelmaking plant established in April 1935, Yawata did not install gas producers and used only the mixed gas of coke-oven gas and blast-furnace gas. The more such surplus energy Yawata used, the greater the share of coal that came to be used for coke-ovens. The per-steel -product-ton consumption of coal was reduced by half from the 1920s to the early 1930s (Fig. 4)[2].

No department such as a heat control center, which investigates and guides the heat economy of all plants of a factory, was established. No branch can carry out a centralized control of coke-oven and blast-furnace gas or guided plants to a different mode of using gas. They noticed how much coal was conserved when using mixed gas at each furnace, but they did not pay attention to the basic unit for all fuels (coal plus gas) at each furnace.

Although energy-saving activities at Yawata had these limitations, the factory that had installed German heat control technology was SSW in Manchuria[3]. In fact, SSW started the integrated iron and steel works in April 1935, and SSW "was stimulated by German technology at that time and felt the importance of heat control strongly." It planned heat control "as the first trial in the East" (SSW 1940). SSW founded a heat control center in 1934 and the center undertook full activity in the second half of the 1930s, for example repair and control of instruments, R&D with some plants, and guidance to the job sites. More than 100 staff worked at heat control center, and the varieties and quantities of instruments increased and recording of combustion are exercised automatically. In the second half of the 1930s, SSW installed and expanded German heat control technology more rapidly than Yawata did.

The heat control at SSW was gradually recognized in the Japanese homeland. The formal stage of it was achieved by the Iron and Steel Institute of Japan (ISIJ). From November 1926, ISIJ held research meetings once or twice a year "in order to promote the growth of the Japanese iron and steel industry and of the technology at the job site"

---

[2] According to Fujii (1985), conservation of coal contributed about 29% of the decrease in net manufacturing cost during 1928–32 at Yawata.

[3] SSW was named Anshan Iron Works until March 31, 1933.

(ISIJ 1945) and exercised presentations and discussions about some themes such as iron, steel, and steel products. During the late 1930s, each division started to place energy conservation on the agenda and a fuel-economy division conference was held in October 1938 (Table 2). The first meeting of the fuel-economy division conference at Osaka in October 1938 programmed "real scenes filmed for heat control at blast furnaces, open hearth furnaces and a control room presented by Showa Steel Works" (ISIJ 1941). The head of the SSW heat-control center said, "By a request of the committee [division], we filmed heat control and instrumentation at SSW and displayed the film at each committee [division] in each place" (Fukui 1961). Materials presented by the SSW Heat-Control Center provided concrete details about installations and kinds of instrumentation. The head of the Heat-Control Center explained the organization of the Center. Masao Shidara, who was involved in heat control at Yawata during wartime and who served a Chief of the Heat Control Section after war, related that heat control of SSW had been superior to that of Yawata and that Yawata referred the articles by SSW published on *the Journal of ISIJ* when it started to calculate the heat balance of its factory during wartime.

(2) During war-time

Introduction of heat control

As controls on the coal market were exercised and expanded after the start of the Sino–Japanese War, several iron and steel factories in Japan earnestly began to imitate heat control by SSW. Yawata, from May 1937, immediately before the start of the Sino–Japanese war, established the Fuel Division under the Iron Department to centralize the control of blast-furnace and coke-oven gas, which had been controlled separately until then. The Fuel Division was placed directly under the head of engineering in March 1942 and was changed to the Heat-Control Division in 1944. Tasks of the Heat-Control Division were added as "matters on heat control", as well as control of gas and fuels. An Engineering Subsection, which dealt with "enlightening and advertising concepts of heat control engineering", e.g. guidance of combustion at furnaces, measurements, and consulting about heat economy, in addition to analysis of gas. The status of the Heat-Control Division was higher than that of Fuel Division in 1937, indicating a broader scope of the factory. Its tasks became to contain the guidance in improvement of basic unit for fuel at each piece of equipment. Eventually, Heat-Control Divisions were established not only by Yawata but also by each factory of Nippon Steel Corp.: Hirohata, Kamaishi, Wanishi, and Kenjiho, in addition to the Kawasaki steel works of Nippon Kokan K.K. (NKK).

During wartime, the following three matters advanced: (1) heat-control campaign to grow interest in heat control at a job site and to improve basic unit, (2) organization of a heat-control committee, (3) improvement of instrumentation engineering. We deal those contents in light of the case of Yawata.

Yawata held a heat-control campaign for progress every year during fiscal years 1942–1944 and its contents grew. The first campaign in 1942 involved only advertisement, but during the second campaign undertaken in 1943, it entailed strengthening the repair of instruments and competition in terms of basic unit among plants. The second campaign also sought to establish a basic unit for heat in terms of caloric value.

The Heat-Control Committee of Yawata Steel Works was organized in August 1943. Its chair was the head of engineering. The committee made each Subsection and Division form a heat-control team and required that the team report to the committee chairman both the target and the actual quantity of gas use and the current circumstances of equipment, instruments, and gas leaks.

To improve instrumentation, technical guidance by domestic manufacturers of instruments, such as Shimazu, was exercised in an attempt to repair instruments at Yawata independently.

These activities meant that Yawata came to regard the importance of setting a goal of basic unit at equipment and to reach that goal by attention to instrumentation. The Japanese Engineers' interest in energy conservation, which had been limited to reuse of surplus energy during interwar era, came to be improvement of the basic unit for fuels at a furnace, which was the "second step" of heat-control exercised by SSW.

Limits of heat control during the war

Did these efforts bear fruit at that time? To begin from the conclusion, basic unit for fuels became much worse during the wartime era (Fig. 4) for four reasons.

The first reason was the worsening of coal quality, which posed a general limitation to the Japanese wartime economy. It severely affected the iron and steel industry because of the decrease of producer-gas coal brought from mainland China.

Second was a lack of instrumentation. It was not a comprehensive solution for the steel industry to attempt to repair instruments through its own efforts. After 1937, it became much more difficult to import instruments from abroad and the supply of industrial instruments for heat control stagnated because domestic production of instruments was focused on aircraft instruments and instruments for oil refining. Repair of instruments independently was insufficient because of the lack of spare parts. They could only perform simple repairs.

Thirdly, it was difficult to make workers ignore their intuition and pay attention to the display of instruments under circumstances entailing a lack and insufficient repair of instruments. A heat-control engineer at Kawasaki Steel Works remembered the following after war (Kuwabata 1952 p.12).

> “Engineering of production and operating industrial instruments for heat control was too poor for skilled workers at a job site to trust the instruments. Therefore, we often had quarrels with workers over operation of instruments…because workers felt they were watched by instruments and regarded instruments as a hot potato, workers sometimes intentionally threw a gauge off and put instruments backwards to the intended installation as a gesture of disagreeing with the instruments. Therefore, we made small enclosures for instruments with a glass case, iron door, and key. ”

Fourthly, even if a steel plant was operated according workers’ intuition, the engineering level could not help being worse than in the interwar era because many skilled workers were drafted into the armed forces and many unskilled workers were employed to increase output. The proportion of drafted workers to all employees at Yawata grew from 10.0% in the end of 1937 to 14.5% at the end of 1941. The length of a worker’s continuous employment decreased from 11 years and 10 months in 1934 to 7 years 3 months in 1940. After the start of the Asia–Pacific War, “special workers” such as students, Koreans, prisoners, and corps of women volunteer workers increased. They had to perform tasks not only as assistants but also as regular workers. It is not difficult to imagine that these conditions lowered the engineering level at a job site that relied heavily on the experience and skill of long-term employees.

During the wartime era, the heat control organization was introduced. Engineers noted that it was necessary to improve basic unit for fuels using instruments, heat control campaigns were held, and repairing instruments independently was attempted. These trials show that energy conservation technology developed dramatically during wartime. These trials did not bear fruit sufficiently at job sites because of the limits imposed by the war. The war fostered interest in energy-conservation technology, but the war also prevented its realization.

(3) During reconstruction

Technical guidance by U.S. engineers

During the reconstruction period, severe restrictions of energy usage were imposed as they had been during wartime. In fact, in many instances and industries, conditions were worse than during wartime. Heat control was regarded as extremely important not only by the steel industry but also in general. When the lack of coal became extremely severe in 1946, the Japanese government adopted the “Fundamental Policy for Strengthening Heat Control to Break the Coal Crisis” at a cabinet meeting in December. The government aimed to strengthen heat control as an "increase of coal output on the consumption side" in concert with a policy for increasing coal output. The Japanese energy policy at that time was the priority production system in supply side and the heat control on demand side (Kobori 2010, Chap.2). In the context of these circumstances during reconstruction, the problems that had been acknowledged during wartime by iron and steel engineers started to be solved gradually.

It is impossible to ignore the technical guidance by American engineers in discussing the iron and steel industry during the reconstruction period. Technical guidance by American engineers started in 1947–1949 when the Strike Mission (1947) and the first and second Scrap Iron and Steel Mission (1948–1949) were executed. Full-scale guidance to escape from steel industry's dependence on subsidies from the US thereafter started by the direction of the Industry Division, Economic & Scientific Division (ESS), GHQ/SCAP. First, W. G. Walk and R. S. Coulter, who were members of second Scrap Iron and Steel Mission, remained in Japan for a month in 1949 after the Mission finished and guided the main steel factories' efforts at OHF and heat control. Moreover F. N. Hays, J. T. MacLeod, and E. W. Hill came to Japan to exercise technical guidance in OHF and heat control.

They presented comprehensive advisory opinions related to fuel conservation, increase of furnace productivity, and improvement of operations. In those opinions, they presented four important points of advice related to heat control: (1) converting pressures in OHF and heating furnace from negative to positive; (2) converting low calorie fuel to high calorie, and especially switching from gas-producing coal to heavy oil, and mixed gas to coke-oven gas; (3) expansion and conversion of furnaces; and (4) improved instrumentation. They also reported that if this advice was exercised simultaneously, basic unit would be further improved.

Points (1)–(3) of this advice had been popularized in the Japanese steel industry by April 1950, which was the next year of the guidance. The advice that popularization delayed was (4), which had already been regarded as problematic during the war. Indeed micromanometers, which were necessary for positive pressure operations, were popularized but installation of other instruments for heat control such as thermometers and flow meters was delayed. Moreover, regulation and standardization of combustion using instruments was not done. A mission of ISIJ issued the following warning (ISIJ 1950a, p.12).

> "Almost no factories have any facility to examine and repair instruments and instead depend on manufacturers for them. We found some incorrect broken instruments used at a job site. That would cause severe mistrust of instruments."

Exchange of technology through ISIJ

How did countermeasures against such problems progress? We focus on ISIJ and steel companies to consider the reasons for rapid improvement and diffusion of heat-control technology.

The ISIJ played an important role in technology exchange. The Liaison Conference for Research of Iron and Steel Technology was held in July 1948 by ISIJ, the Japan Iron and Steel Association (called The Japan Iron and Steel Federation from November 1948, JISF), and the Steel Bureau of Ministry of Commerce and Industry. They sought to make the divisions of ISIJ active. Then ISIJ established eight divisions such as pig iron, steel-making, and steel products, and some divisions placed heat control as a research subjects. In the OHF division, each attending company announced and criticized technology (e.g. a burner blueprint) for one another to encourage standardization of technology. The OHF division also researched oil-burning, furnace structure, and oxygen steelmaking (Table 3). This example illustrates that, by restoring research divisions in the 1920s–1930s, exchange of technology was already started before technical guidance from U.S. engineers.

These exchange relations enabled the contents of the U.S. engineers' guidance to be closely shared among the Japanese steel companies. For example, when Hays and others visited Yawata, some heat control engineers belonging to other Japanese steel company such as NKK and Sumitomo came along and watched their guidance at Yawata. Hays and Macleod gave lectures about the contents of their guidance at a meeting held by ISIJ. The guidance report by Walk and Coulter was published and sold.

A division responsible for instrumentation and heat-control technology was also established when Hays visited Japan. It was the Heat Economy Division. Subsequently, heat-control technology was exchanged and discussed at this division.

The predecessor committee of the Heat Economy Division was established in October 1948. This committee discussed means to enhance and maintain heat-control instruments. These activities were passed on to the new Division in June 1949. The Steel Bureau of the Ministry of International Trade and Industry (MITI) chose to place the Division under the Liaison Conference for Research of Iron and Steel Technology and to place a heat-control committee at each iron and steel production facility.

The Heat Economy Division established three special committees assigned to Instruments for Heat Control, Heat Balance, and Melting Furnaces. At these special committees, technology of instrumentation and relining work were exchanged; standards were realized and published by Maruzen (ISIJ 1953, 1954).

Investigations of factories and technology exchange were conducted. In April 1950, the Investigative Commission on the Heat Economy of Iron and Steel Industry was dispatched to 27 factories throughout Japan to clarify the scores during the year after the establishment of the Division. Investigation of a factory took 1–4 days depending on its scale, and the Commission made intensive investigations about fuel management, instruments, heat-control education, etc. and opened these investigations. The exchange of technology was continued thereafter. To the Heat Economy Division, each factory presented its monthly heat-control report for blast furnaces, coke ovens, OHF and rolling. According to Shidara, factories did not hide work efficiency and knew each other's figures and circumstances. During reconstruction, technology exchange through ISIJ, which started in the interwar period, was sufficiently displayed. Each iron and steel factory cooperated and competed for the development of heat-control technology mutually.

Heat control of Yawata Iron and Steel Works:

Heat Control Division and Steel Plants

As the exchange of technology progressed, each iron and steel factory expanded its activities to improve the basic unit in relation to fuel. Details of the activities of Heat Control Division and a job site in Yawata are given as shown below (Table 4).

The main subsections of Heat Control Division in post-war era were Instruments and Engineering. The Instruments Subsection firstly established an instrument repair shop. It invited an engineer belonging to Shimazu as a temporary employee to give training. The Instrument Subsection thereafter started to repair and inspect instruments in 1946–1947. It also started visiting job sites to show workers how to use instruments in 1948 and received the responsibility and authority to buy all instruments at Yawata in 1951. When a plant installed instruments, the chief of the Instrument Subsection also attended the meeting of the plant to give advice. During 1946–1951, the staff of the Instrument Subsection became 2.5 times larger and its amount of work increased by 11 times.

The Engineering Subsection after the war had triple the staff as that in war time and the amount of its work (heat audit and consultation) started to grow in the 1950s. Some good cases of its consultations were also reported on *the Journal of ISIJ*.

The Engineering Subsection also hosted the Liaison Committee for Heat Control and Heat Control Month. Not all Yawata plants were interested in heat control. Some plants often invited heat consultation, but others did not. Therefore, the Engineering Subsection had to enlighten its clients about heat control.

The Liaison Committee for Heat Control consisted of the Heat Control Division and the member of job sites. Its responsibilities included the present situation of fuel supply, the present situation and goals of basic unit for fuel at each plant at Yawata, the heat audit and consultation results, the present situation of instruments and their purchase plan, standardization of heat control, and the circumstances of basic unit for fuel and heat control technology of other companies. Regarding Yawata, information about other companies' heat control was obtained through ISIJ or the Investigative Commission on the Heat Economy of Iron and Steel Industry and delivered to job sites. The information was used to campaign for heat control. To compare each plant's score or goal seemed to contribute to cultivation of a competitive spirit related to heat control.

Heat Control Month, which occurred annually in February, also seemed to contribute to a growing competitive sense. Yawata divided important points of Heat Control Month every year and awarded the head of a department a prize for a superior factory of each department and the president a prize for superior factory achievement among the factories which obtained the department head prize. Kiyoshi Sugita, who entered Yawata in 1954, said, "We exercised many projects during the Month because an inspection came to factories…Not only the Heat Control Division but also big names came to check our score and give us advice. The score was one of our valued points" (Sugita 2008).

As the Heat Control Division expanded, heat control activities at job sites also progressed. At steel plants, guidance from U.S. engineers was installed through "on-the-job training", which was exercised to advance heat control technology.

Each factory of Yawata started not only to improve furnaces but also to equip them with instruments and to use heavy oil. The combination of these improvements and OJT enabled Yawata to improve basic unit for fuels. Steel Plant No. 3 was a shining example. Basic unit for fuels at Steel Plant No. 3, which was about 1,600 thousand kcal/t at the beginning of 1952, became 958 thousand kcal/t in February 1953 and 703 kcal/t in February 1955. Steel Plant No. 3 was the first steel-making plant whose basic unit for fuels became less than 1,000 kcal/t in Japan. During this development, Steel Plant No. 3 improved furnaces, used heavy oil, and installed several instruments. Moreover, it was attempted to prevent instruments from being installed incorrectly "in order to make workers trust them" and standardized combustion was sought at each furnace and stage.

However, instrumentation was not soon realized through these exercises. Because workers at Steel Plant No. 3 also "had obeyed their intuition", instrumentation was very stiff for workers. Therefore, "it took very long time and energy for engineers to make workers recognize the value of standardizing burning and obey the standard spontaneously". The engineers of Steel Plant No. 3 tried various means to interest workers in instrumentation and heat control and thereby improve basic unit for fuel, such as adjustment of the arrangement of staff members to arouse competitive spirit related to heat control, making workers calculate the basic unit for fuels for themselves at every tapping and compare the scores with those of other factories or those in foreign countries, trying special programs to get the president prize of Heat Control Month, and instilling confidence of workers in their heat control.

It is important that Steel Plant No. 3 was not isolated from the Japanese iron and steel industry. The information about basic unit for fuels of other factories which was used in OJT included data that had been exchanged at ISIJ and which had been reported through the Liaison Committee for Heat Control of Yawata. Heat Control Month was also used to arouse workers' competitive spirit. Other companies' technology, as reported on *the Journal of ISIJ* or through the Divisions of ISIJ, would be tried. The Japanese iron and steel industry created a multi-tiered (worker→subsection→division→department →company) structure of competitiveness on heat control. Using this structure, interest in heat control rose and heat control technology was improved. Eventually, consciousness of heat control, which engineers had become interested in during the interwar era and which had started during the war, permeated into the job site.

3. Improvement of oxygen steelmaking

(1) *Installation of oxygen steelmaking*

The use of oxygen for OHF was tried even before the end of war. In Japan, Kawasaki Heavy Industry Fukiai factory experimented using oxygen at a gas producer in 1928 (Yoshikawa 1949) and Kobe Steel Ltd. (KOBELCO) blew oxygen into OHF from 5–6 cylinders in about 1937. Because KOBELCO manufactured oxygen generators at the machinery department, it planned to use a surplus oxygen generator (50 m^3/h) for OHF in 1943 but did not exercise it in earnest (KOBELCO 1954, pp.158-59).

Full scale use of oxygen started after WWII throughout the world because the development of big-scale oxygen generators such as Linde–Frankl type devices started during the 1930s to decrease the cost of producing oxygen rapidly. After the Steel Company of Canada Co. began experimentation with oxygen steelmaking at OHF in March 1946, the large U.S. steel companies started similar experiments from August to the autumn 1946 and *The Iron Age* reported some activities on oxygen steelmaking at OHF by the U.S. and Canadian steelmakers. At Proceedings of the Open Hearth Conf. held by the American Institute of Mining, Metallurgical, and Petroleum Engineers (AIME) in spring, 1947, studies of oxygen steelmaking at OHF were reported increasingly in the literature (Iihama 1981 pp.43-48, Sanso Kyokai 1998, pp.49-54).

In Japan, the Basic Process Division of ISIJ was established in March 1947 which was the same time of the Conf. by AIME. The Basic Process Division of ISIJ held up the "way to use oxygen" as one of "the subjects to be researched most urgently" and the experiment by Kawasaki in 1928 and recent activity in the U.S. were reported (Yoshikawa 1949).

The first oxygen steelmaking experiment in Japan was undertaken by Amagasaki Steel Works (ASW) in cooperation with Teikoku (meaning *Imperial* in Japanese)

Oxygen Co. (TOC) in June 1948. Each company reported this experiment as described below. The ASW said, "at the beginning of 1947, we investigated foreign literature that had been delivered to Tonomura's laboratory at The University of Tokyo and recognized that the U.S. had succeeded in using oxygen at OHF" (Iihama 1981 p.44). In contrast, the TOC emphasized its own initiative. Although TOC had been established under joint French–Japanese management, its French managers were deported during the war and the right of management had been actually held by the Japanese Navy. When they returned to Japan after the war, it was a problem for TOC to find a new market because TOC had lost its largest customer: the Imperial Navy. At that time, the French Head Engineer, Pierre St. Leu, had become aware the use of oxygen steelmaking, which had been already introduced into France. St. Leu "busily introduced [it] to the managers of steel companies" and set his eye on ASW, which had restarted production. He persuaded ASW to introduce oxygen steelmaking (TOC 1981, pp.56-59).

We cannot clarify which company first performed the experiment. It was clear that ASW got the information of oxygen steelmaking by March 1947 because it became the topic at ISIJ. Not only TOC but also other oxygen producing companies were compelled to find new markets because they had lost military contracts and had surplus equipment. Therefore, the steel industry faced a daunting market (Sanso Kyokai 1998, p.97). Presumably, the offer by TOC enabled ASW to secure oxygen, which was necessary for oxygen steelmaking experiments that ASW had been interested in since one year prior. The negotiating process to start the experiment was not as difficult as we might infer, even though TOC told that TOC "had persuaded" ASW to conduct experiments.

TOC supplied the oxygen from its Kobe factory and manufactured a decompression valve to increase the amount of oxygen because "though there was the decompression valve of which the flow was a little, there was no decompression valve of which the flow rate was 2–10 m^3 per minute in Japan". At the first experiment, which started in June 1948, 50 containers of oxygen and six decompression valves were used. In the next experiment in August 1948, 160 containers and 12 valves were used. The method of using a burner was investigated simultaneously in experiments. "Several hundred containers of oxygen were carried from Kobe to Amagasaki during the high season of the experiment" (Iihama1981 p.44).

The experiments by ASW were investigated and reported at the division of ISIJ. On the Steelmaking Division, "they inspected real works of oxygen steelmaking and discussed" at ASW on 29 October 1948 and "results of the experiments were reported and analyzed in detail" in April 1949. The other steelmaking company also opened its oxygen steelmaking plan to mutual criticism in January 1949 (Table 3).

Furthermore, in February 1949, JISF, ISIJ, manufacturers of oxygen generator, the Ministry of Commerce and Industry and so on discussed oxygen steelmaking and decided to undertake joint experiments at ASW. Eventually, JISF and eight steel companies started joint experiments for oxygen steelmaking at ASW in June 1949 (Sanso Seiko Kyodo Kenkyu Iinkai 1950 pp.2-3). During 1949–1950, some companies (Sumitomo, Yawata, NKK, Kawasaki and KOBELCO) also experimented with oxygen steelmaking independently (Iihama1981 pp.44-45, Sanso Kyokai 1998 p.119).

As described above, the Japanese steel industry had keenly researched oxygen steelmaking in 1949 when the U.S. heat control engineers undertook technical guidance. It was noted that the U.S. engineer was negative about the introduction of oxygen steelmaking ([NKK] 1949 p.7).

> "You said the U.S. pamphlets report that oxygen was used for 80% of steel production, I imagine about 0.5% of all American steel factories use oxygen. You should not mind oxygen [steelmaking] for some time and should try to conserve heavy oil and firebrick, shouldn't you?"

The process of introducing oxygen steelmaking was extremely independent.

(2) Full-scale implementation of oxygen steelmaking

KOBELCO was the first company to put oxygen steelmaking to practical use (KOBELCO 1954 pp.158-60, 187). Its implementation had two characteristics. First, KOBELCO made and used an oxygen generator for private use. Second, KOBELCO not only made oxygen blow into OHF but also operated slagging gas producers, which used oxygen and domestic low-quality coal.

As described above, KOBELCO had a machinery department. It manufactured a freezer for fisheries before 1924, but KOBELCO tried to apply it in other fields about 1932 (Makita 1953-54). KOBELCO first test-manufactured a low-temperature air separation unit in 1934 because of an order from the Army Engineering Division and supplied an air separation unit to manufacture oxygen for the Agochi plant of Japan Nitrogen Fertilizer Co in 1937. This actual capacity was at first less than half of a nominal capacity, 2,000 m^3/h, and KOBELCO reformed it through inspection of a Linde–Frankl type oxygen generator that had been bought by the Mitsubishi Kasei Kurosaki Plant. During 1934–1945, KOBELCO manufactured 28 air separation units and 25 hydrogen separation units and others (some were unfinished).

After the war, in 1948, KOBELCO decided to practice oxygen steelmaking. The purpose was improvement of basic unit for heavy oil. Because of the scarcity of coal after the war, KOBELCO planned conversion from coal to heavy oil and did so at three furnaces during 1947–1948. However, two of these furnaces were operated at high basic unit for heavy oil because of overuse during the war. Therefore, KOBELCO introduced oxygen steelmaking to improve the scores. KOBELCO expected to use "its highest technology and manufacturing capacity in Japan" for an oxygen generator for steelmaking to relieve its energy-related constraints.

KOBELCO set up a new oxygen-generating plant in February 1950 and used a 250 m^3/h generator for an OHF. KOBELCO exercised two stages of experimentation during 1950–1951 and added a 2,000 m^3/h oxygen generator in July 1951 to start "a full scale oxygen steelmaking". KOBELCO planned and manufactured all generators.

KOBELCO also started to research a slagging gas producer. For a general gas producer, a gas-producing coal (more than 6,500 kcal/kg, with low coking properties and high melting point of ash) was requested but the highest quality domestic coal was far inferior to the gas-producing coal that had been imported from Manchuria before the war. KOBELCO, however, expected that, "if we can exhaust ash of a gas producer in a molten state, gas-producing coal becomes unnecessary and a general coal can be used as fuel for OHF". Based on that expectation, KOBELCO started an experiment for a slagging gas producer in February 1951. A subsidy from the Industrial Technology Agency was used for establishing the furnaces. "Though a slagging gas producer had been researched in several countries, it was used for a chemical industry. Its main fuel was coke and few slagging gas producer used coal as the main fuel. KOBELCO was the first company to use a slagging gas producer for steelmaking". KOBELCO was awarded a patent for it and succeeded in industrialization in August 1951. A slagging gas producer was a quite original technology based keenly on the expectation of its usage of domestic resources.

In light of those two experiences of KOBELCO, oxygen generators for private use were popularized among the other steel companies during the 1950s, but slagging gas producers were not.

During the 1950s, gas producers were actually almost abolished because of the conversion from producer gas to heavy oil. The Steelmaking Division reported that a slagging gas producer presented some merits but could not help being operated unsustainably and uneconomically (Steel Division 1955, p.295). It was unavoidable for a slagging gas producer, which was similar to a general gas producer, to be converted to heavy oil when the supply of heavy oil became sustainable. However, at the beginning of the 1950s, although the conversion from coal to oil had begun, the energy revolution, which had already finished in the early 1950s at OHF (Kobori 2010, chap.4) had not been anticipated at all. Indeed, in autumn 1951, when KOBELCO had succeeded in industrializing a slagging gas producer, engineers from Yawata and NKK also greatly looked forward to using them (Round-table 1951, pp.13-14). Although they knew a gas producer was more inefficient than heavy oil, they suspected in the early 1950s that the Japanese resource endowments and restriction of the amount of heavy oil imports would compel them to use gas producers even in the future.

However, each company progressed in installing oxygen generators for private use during the first rationalization period (Table 5) and shared 15–20% of the amount of investment in plant and equipment of steel processing (MITI 1957, p.333). The government promoted the installation through accelerated depreciation (MITI 1952, p.474). It was also interesting that KOBELCO supplied oxygen generators for use by other steel companies.

According to data of April 1958, the number of factories with installed oxygen generators for private use was 18. All 13 molten iron plants had installed them and 13 of 17 cold pig iron plants used oxygen steelmaking. Five of them had generators for private use (Steel Division 1959, pp.219-21). As generators for private use became popularized during the 1950s, basic unit for oxygen were increasing and those for fuels were decreasing (Table 6). The amount and degree of oxygen use in Japan was very high among all countries of the world (Fig. 5).

(3) Energy conservation and environmental load

When Hays returned to visit Japan in 1958, he had some opinions to share about oxygen steelmaking (NKK 1958, p.62).

> "One of the reasons why oxygen steelmaking was not popularized in the U.S. was the reddish brown smoke, which was peculiar to oxygen steelmaking. In the U.S., smoke was severely regulated by city rules for public hygiene."

Although it was necessary to examine whether smoke regulation in the U.S. were as stringent as his statements imply, it was certain that development of energy conservation by the Japanese iron and steel industry during the 1950s was encouraged by loose smoke regulations and tacit acknowledgment by neighbors of plants that smoke from the plant was a symbol of their prosperity. Oxygen steelmaking actually worsened air pollution. The first experiments for preventing smoke by the Japanese steel industry were undertaken in June 1957 at the Hirohata Plant of Fuji Iron Works, and popularization of dust collectors occurred after 1960. Its speed had been delayed more than the rapid popularization of oxygen steelmaking (K 1960, p.46, Shoji and Miyamoto 1964, pp.40-41, Sugita 1997, p.41)[4].

This example revealed that energy-saving technology did not always decrease

---

[4] It was in 1958 that a famous film director Keisuke Kinoshita described a hero and heroine who "wished their happiness each other while watching the smoke [from Yawata] like a rainbow" as the last scene of *Kono Ten no Niji* (A Rainbow in the Sky). (http://www.walkerplus.com/movie/kinejun/).

environmental loads. At least during the 1950s, the development of energy-saving technology not only increased environmental loads; it was also promoted by a Japanese society that permitted worsening pollution.

4. Conclusions

The Japanese iron and steel engineers became interested in energy conservation during the 1920s because the supply–demand circumstances of coal changed drastically (increasing its imports and price). After the Sino–Japanese War broke out, heat control also appeared. Although energy conservation technology entailed only the recycling of surplus energy initially, it developed to include improvement of basic unit for fuel at each furnace. The Research Divisions of ISIJ often placed heat control on the agenda since the 1930s. The iron and steel industry during wartime came to increase the use of instrumentation, establish the Heat Control Division and Heat Control Committee, and to hold heat control campaigns to improve basic unit. Although these attempts did not bear fruit in improving basic unit because of various restrictions, which were particular burdensome during the Japanese wartime, heat control after the war advanced from these first steps to solve the problems that had been identified during the war.

Introduction of U.S. technology also contributed to improvement in the basic unit after the war. Nevertheless, energy-saving technology developed after the war was not an exact copy of the U.S. technology. Japanese heat control technology after the war was much different from the U.S. efforts in its objectives and contents. Takami Ohta, who was the chief of No. 1 Steelmaking Division of Yawata Iron and Steel Works and inspected an overseas in 1954, reported that the basic unit for fuels of the U.S. steel industry was inferior to that of Japan and analyzed the reasons (Ohta 1954, p.770).

> "I intuited that Yawata and the other Japanese steel plants installed as high-level instruments and automatic controllers as the U.S. highest class plants… a job sites of the U.S. OHF operators were not necessarily interested in research or improvements for burning at OHF or in checking burning scores of daily work…The reason why basic unit for fuels is not necessarily superior was that they attach the greatest importance to the efficiency of steelmaking (t/hr)…"

Ohta saw that the most important objective of the formation of technology in the U.S. was the efficiency of steelmaking (t/h), and that the most important objective in Japan was the basic unit for fuels (cal/t). He also noticed that the difference in the formation of technology influenced the difference in daily work between the U.S and Japan. Kiyoshi Sugita also said about heat control during the 1950s, "Unexpectedly, many men got promoted because they were deeply engaged in heat control. [the man who succeeded in heat control was] remarkable. It was a little different from general improvements on output" (Sugita 2008). His comments indicate that heat control was an outstanding matter among the Japanese iron and steel industry during reconstruction. We shall fail in grasping the characteristics of the post-war Japanese iron and steel industry if notice only the introduction of U.S. technology and ignore the history of energy conservation activities, which bore fruit after the war.

The case of oxygen steelmaking was as similar as that of heat control. The introduction of oxygen steelmaking was extremely independent and the technology was actively exchanged, similarly to heat control. It was actually used much more than in any other country. The background of such aggressive introduction was a severe crisis of energy restrictions. In the beginning of the 1950s, the Japanese steel engineers apparently believed that heavy oil was much more effective than coal, but Japan could not secure sufficient heavy oil, unlike the U.S. It therefore seemed clear that they should use oxygen steelmaking to improve basic unit for fuel without heavy oil (Steel Division 1955, p.100). Because of these expectations, Japanese steel engineers regarded oxygen and the industrialization of a slagging gas producer as symbolic of their sense of crisis related to Japanese energy restrictions. Furthermore, after they became able to obtain heavy oil sustainably, they continued improving the basic unit for energy using both heavy oil and oxygen to rationalize firms and to strengthen international competitiveness.

Heat control and oxygen steelmaking, the two major factors of energy conservation by the iron and steel industry after war benefited from contributions of the introduction of technology, but the technology was introduced independently by Japanese engineers who understood the differences between the U.S. and Japan in terms of energy restrictions. The Japanese experience and the energetic exchange of technology which had accumulated since the interwar era enabled the technological developments, which attached the greatest importance to basic unit for energy, enabling them to develop and popularize the technologies much more than the West. Development of the Japanese iron and steel industry after the war started as energy conservation, which was the technological objective that had been pursued since the interwar era.

However the energy conservation development of the Japanese iron and steel industry was not only a success story. Energy-saving technology does not always decrease the environmental load. At least during the 1950s, the development of energy-saving technology, especially oxygen steelmaking, exacerbated environmental pollution. By and large, Japanese society ignored and permitted pollution, and instead promoted the development of energy conservation. To reveal the degree of this relationship and why it changed after the 1960s, we must examine not only factors inside of the firms and industry (business history, industrial history) but also those outside of them (political history, social movement history).

Articles

(All articles are in Japanese.)

Agency of Industrial Science and Technology (AIST) ed. (1966), *Netsukanri no Ayumi* (A History of Heat Control), The Central Council for Heat Control.

Fujii, Nobuyuki (1985), "The Profitability of the Yawata Iron Works and the Merger Movement in the Japanese Iron and Steel Industry at the Beginning of the 1930s", in *Socio Economic History*, vol.50, no.6.

Fukui, Makoto (1961), "Unno Saburo Shi wo Omou (Memories of Mr. Saburo Unno)" in *Heat Management*, vol.13, no.2.

Iihama, Uichiro (1981), "Heiro heno Sanso Seiko-ho no Donyu (Introduction of Oxygen Steelmaking to OHF)", in ISIJ, *Waga-Kuni ni okeru Sanso Seiko-Ho no Rekishi* (A History of Oxygen Steelmaking in Japan), ISIJ.

Iron and Steel Institute of Japan (ISIJ) (1941), "Report by a Society for the Research of Heat Balance at a Blast Furnace: Part 1", *The Journal of the Iron and Steel Institute of Japan*, vol.27, no.9.

ISIJ (1945), *Nihon Tekko Kyokai Yoran* (The Digest of ISIJ), ISIJ.

ISIJ (1950a), *Tekko Netsukezai Gijutsu Chosadan Hokoku-sho* (The report by the Investigative Commission on the Heat Economy of Iron and Steel Industry), ISIJ.

ISIJ (1950b), "Kenkyu Bukai Kiji (Proceedings of the Investigation Committee)", in *The Journal of ISIJ*, vol.36, no.10.

ISIJ ed. (1953), *Tekko Netsukezai Gijutsu Yoran: Keisoku-hen* (A Handbook of the Heat Economy: Instrumentation), Maruzen.

ISIJ ed. (1954), *Kanetsu-Ro no Sekkei to Jissai narabi-ni Netsuseisan no Hoshik* (Plan and Practice of a Melting Furnace and the Way of Calculating Heat Balance), Maruzen.

Japan Iron and Steel Federation (JISF) (1959), *Sengo Tekko Shi* (A History of the Iron and Steel Industry after War), JISF.

K (1960), "Dust Collectors for Exhaust Gas from OHF", in *Tekko Kai* (Bulletin of JISF), vol.10, no.3.

Kobe Steel Works Ltd. Co. (KOBELCO) (1954), *Shinko 50 Nenshi* (fifty-Year History of KOBELCO), KOBELCO.

Kobori, Satoru (2010), *Nihon no Enerugi Kakumei: Shigen Shokoku no Kingendai* (The Energy Revolution in Japan between Modern and Contemporary periods), the University of Nagoya Press.

Kofler, Franz (1934), "Heat-Economy in the Iron Works", in *The Journal of ISIJ*, vol.20, no.8.

Kuwabata, Kazuhiko (1952), "Seitetsu Gyo ni okeru Keiryo Kanri ni tsuite (Metrology Management of the Iron and Steel Industry)", *Journal of the Instrumentation Control Association, Japan*, vol.1, no.2.

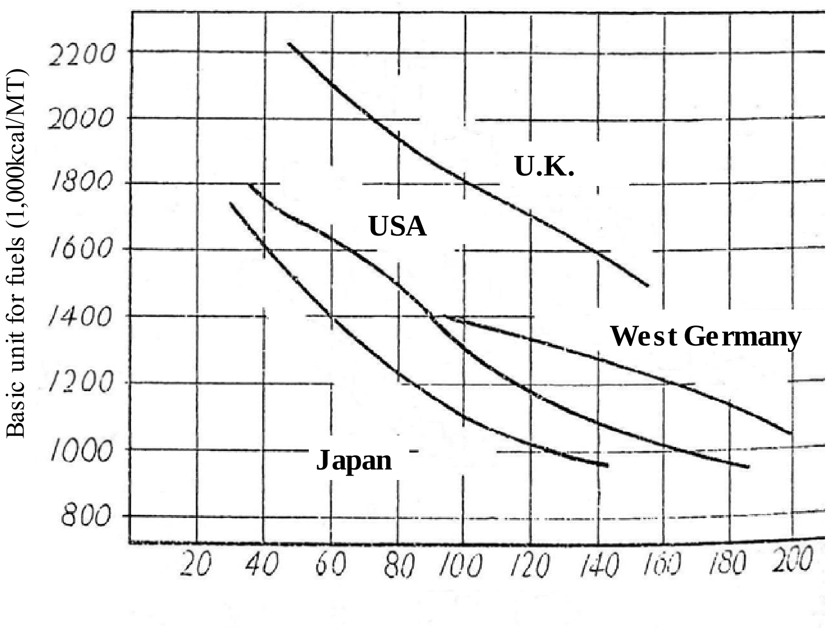
Makita, Kenjiro, (1953–54), "Ogata Sanso Sochi Seisaku Kushin no Omoide (Memories of Trying to Manufacture Big Oxygen Generators: Part 1, 2)", in *Kobe Seiko*, vol.3, no.4 - vol.4, no.1.

Ministry of International Trade and Industry (MITI) ed. (1957), *Sangyo Gorika Hakusho* (White Paper on

Industrial Rationalization), The Nikkan Kogyo Shimbun, Ltd.
MITI Kigyo-Kyoku (Firm Bureau) ed. (1952), *Kigyo Gorika no Shomondai* (The Issues of Rationalizing Firms), The Association of Industry and Science.
[Nippon Kokan K.K. (NKK)] Kikaku-Shitsu Gijutsu-Ka (Planning Office, Engineering Division) (1949), *Beikokujin Gijutsusha tono Shitsugi Oto:Sono 1* (Q & A with the U.S. Engineers: Part 1), in *Matsushita Chokyu Papaers* (owned by City of Yokohama Municipal Archives Reference Room), No. 395.
NKK Engineering Section, Kawasaki Works and Tsurumi Works (1958), *F.N. Hays Shi ni yoru Netsukanri Gijutsu Shido Keika ni tsuite* (On Heat Control Guidance by Mr. F. N. Hays) in *Soeda Arimichi Papaers* (owned by City of Yokohama Municipal Archives Reference Room), No. 585..
Ohta, Takami (1954), "Obe Tekkogyo no Insho (An Impression of the West Iron and Steel Industry: Part 1)" in *Yawata Technical Report*, no.209.
Round Table by Chiefs of Engineering Department (1951), "The Japanese Iron and Steel Industry from the viewpoint of Technology", in *Bulletin of JISF*, vol.1, no.10.
Sakai, Takeo (1961), "Oxygen utilized in the iron and steel industry: Part 2", in *Bulletin of JISF*, vol.11, no.2.
Sanso Kyokai (Oxygen Society) (1998), *Sanso Sangyo Shi* (A History of Oxygen Industry), Oxygen Society.
Sanso Seiko Kyodo Kenkyu Iinkai (Joint Research Committee into Oxygen Steelmaking) (1950), *Sanso Seiko Ho no kenkyu* (A Research for Oxygen Steelmaking), JISF.
Shoji, Hikaru and Ken'ichi Miyamoto (1964), *Osorubeki Kogai* (Fearful Pollution), Iwanami Shoten.
Showa Steel Works (SSW), Iron Division (1940), *Showa Seiko Sho 20 Nenshi* (Twenty-Year History of SSW), SSW.
Steel Division (1955), *Saikin ni okeru Heiro Seiko-Ho no Shimpo* (Recent Progress of Open Hearth Steelmaking), ISIJ.
Steel Division (1959), *Heiro Seiko-Ho no Shimpo* (Progress of Open Hearth Steelmaking: 1955-59), ISIJ.
Sugita, Kiyoshi (1997), "The Japanese Steel Industry Survived Postwar Energy Crisis: a condensed history based on the activities of the Heat Economy and Technology Committee in its infancy", in *Bulletin of the Iron and Steel Institute of Japan*, vol.2, no.12
Sugita, Kiyoshi (2008), *An Interview from Satoru Kobori*.
Tabata, Shintaro (1956), "Sengo Ju-nenkan ni okeru Seitetsu Gijutsu no Shimpo ni tsuite (Developments of the technology of the iron and steel industry during ten years after war)", in *Bulletin of JISF*, vol.6, no.3.
Takeda, Haruhito (2007), "Juyo Kozo: Sangyo Kigyo no Hatten to sono Seiyaku Joken (Demand Structure: The Developments of Industries and Firms and Those Restrictions)", in Takeda ed. *The Reconstruction of the Japanese Economy in the Postwar Decade: Structural Change Unaccomplished*, Yuhikaku.
Tawara, Kuniichi (1922), "A Talk on my Observation of the West Iron and Steel Industry", in *The Journal of ISIJ*, vol.8, no.11.

Teikoku Oxygen Co. (TOC), (1981), *Teikoku Sanso no Rekishi* (A History of TOC), TOC.
Tekko Kaigai Shijo Chosa Iinkai Ippan Bukai Kokusai Kyosoryoku Bunkakai Gijutsu Sho-Iinkai (Committee on Investigating Foreign Market of the Iron and Steel, General Division, International Competitiveness Subcommittee, Technology Small Committee) ed. (1963), *Nihon Tekko-Gyo no Kokusai Kyosoryoku no Hyoka: Dai 2 Hen Gijutsu* (Evaluation of the competitiveness of the Japanese Iron and Steel Industry: Part 2 Technology), Technology Small Committee.
Yoshikawa, Haruju (1949), "First Summarized Report of the Basic Open Hearth Research Committee of the Iron and Steel Institute of Japan", in *The Journal of ISIJ,* vol.35, no.1.
Yoshikawa, Haruju (1950), "Report of Steel Making Division, Investigation Committee of the Iron and Steel Institute of Japan (I)", in *The Journal of ISIJ*, vol.36, no.10.

Fig. 1. Basic unit for fuels of OHF in four countries in 1953.



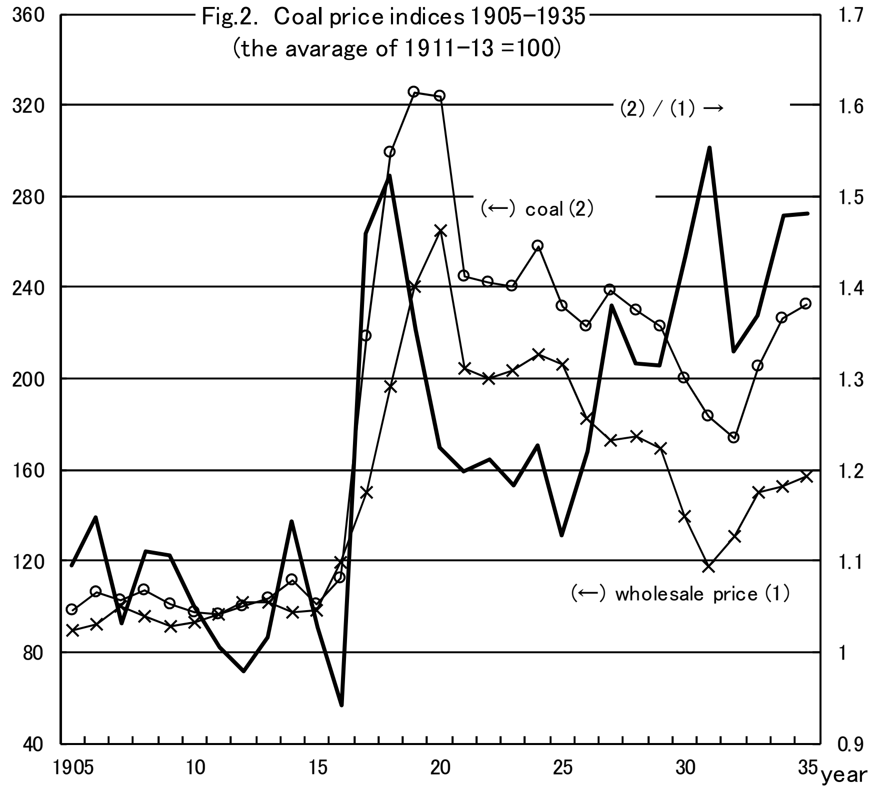
Capacity of an open hearth furnace (MT)

Source : Tabata (1956), p. 83.

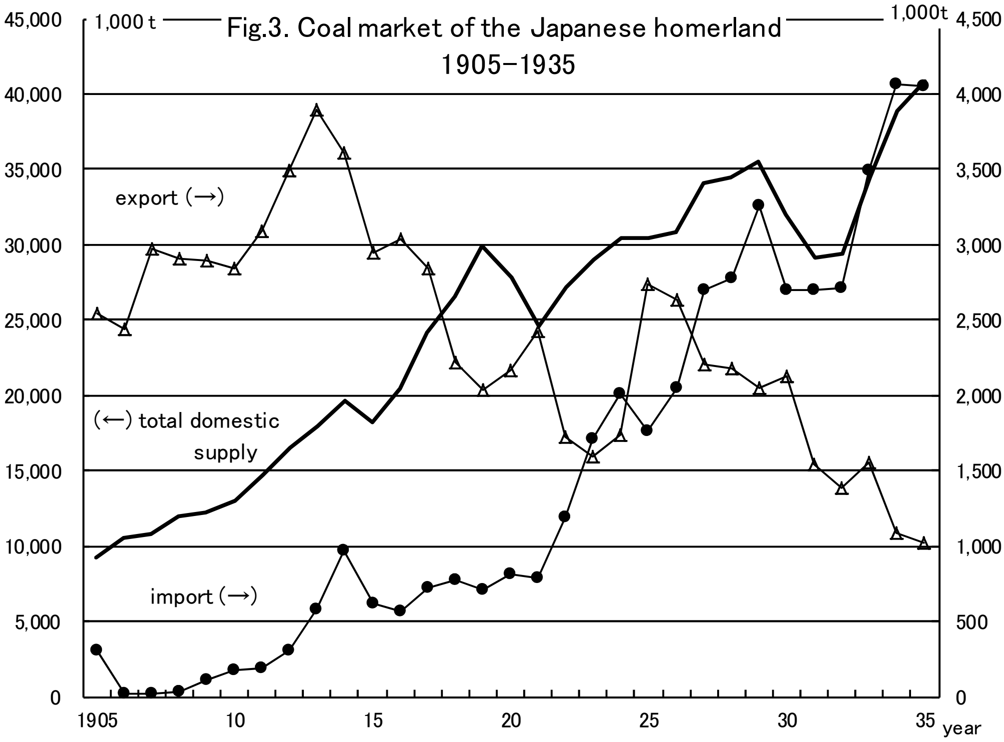
Notes : 1. U.K. and Japan: all of the basic OHF

2. USA: all of OHF

3. West Germany: all of the tilting OHF



source: Kobori (2010), p.36



source: Koboi (2010), p.35

Table 1 Factors of the improvement of basic units for fuels at major OHF plants

Factor	Japan Steel Works	Fuji		D	NKK	I	J	Osaka	Sumitomo Metal		
		Kamaishi	Hirohata		Kawasaki			Nishijima	Pipe & Tube	Wakayama	Kokura
Change of fuel (producer gas to heavy oil)		1							1	1	1
Improvement of instruments	3						1		2		
Thoroughness of combustion control		3		2	2		2		3	2	
Improvement of combustion equipment	2					2					2
Reconstruction and expansion of furnace	1	2		1		3	3			3	1
Exercise of heavy charge					1						
Utilization of oxygen								1			
Reduction in time			1		3			2			
Improvement of work						1					

Factor	Nichia Steel		Amagasaki Steel	Kawasaki	Yawata			
	Amagasaki	Kure			No.1	No.2	No.3	No.4
Change of fuel (producer gas to heavy oil)		1			2	3	3	
Improvement of instruments	2			3	1	2	1	2
Thoroughness of combustion control	1	3	3					4
Improvement of combustion equipment		2	2	2			2	
Reconstruction and expansion of furnace								
Exercise of heavy charge								
Utilization of oxygen			1	1	3	4	4	3
Reduction in time								
Improvement of work								

Source : Steel Division (1955), p. 180.

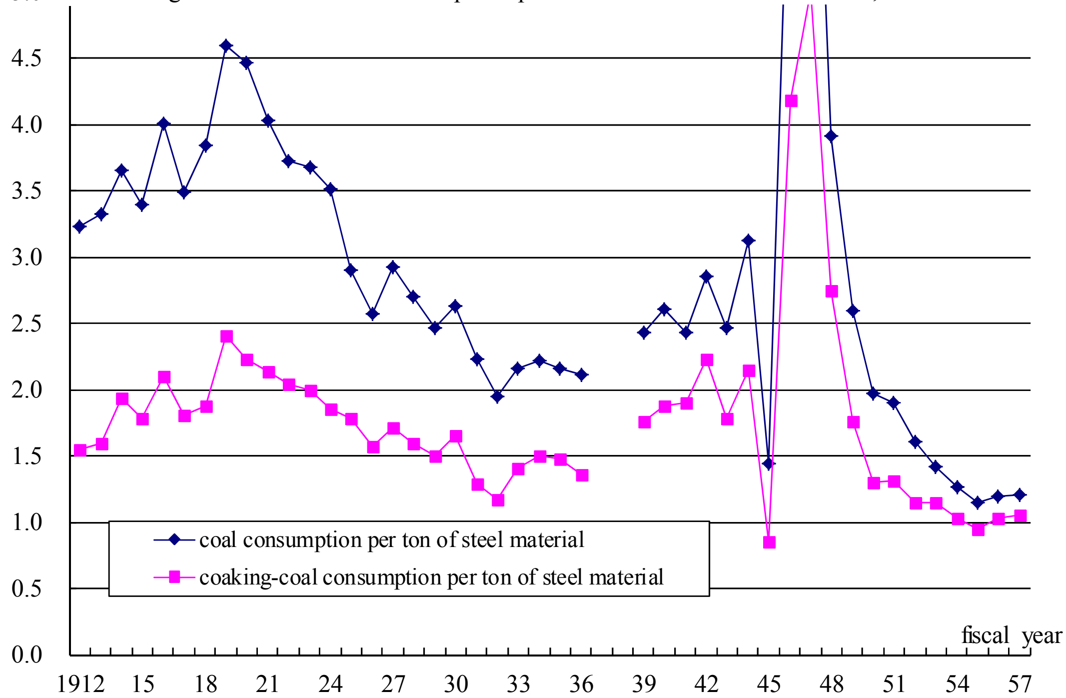
Notes : 1. Number means the rank of importance of each plant.

2. Data are based on the research exercise conducted during October--December 1953.

3. In the source, the name of plants are hidden and expressed by symbols. Reading the other pages of the source and several numbers of *the Journal of ISIJ* , we specified as many actual plants' names as possible.

4. Although there are some inconsistent scores, e.g. Yawata No. 2, we do not modify them.

Fig. 4. Amount of coal consumption per a ton of steel material at Yawata, 1912-57.



Source: Kobori (2010), p. 107.

Table 2 Investigations of ISIJ Divisions on energy saving technology

No.	Year/Mo.	Place	Research Division	Subjects
2	1927.11	Tokyo	1st Steel Division	Gas producer, selection of fuel and improvement of gas quality
6	1931.10	Yawata	2nd Iron Division	Dedusting of blast furnace gas
6	1931.10	Yawata	2nd Steel Division	Regenerator of OHF
12	1935.10	Kobe	2nd Steel Material Division	Heat economy of steel material plant
13	1936.04	Tokyo	3rd Steel Material Division	Heat economy of steel material plant
14	1936.10	Fukuoka	7th Steel Division	Heat balance of OHF
15	1937.04	Tokyo	8th Steel Division	Heat balance of OHF
16	1938.04	Tokyo	9th Steel Division	Heat balance of OHF
17	1938.10	Osaka	1st Fuel Economy Division	Heat balance of blast furnace
18	1939.04	Tokyo	2nd Fuel Economy Division	Heat balance of OHF
20	1939.11	Tokyo	3rd Fuel Economy Division	Heat balance of blast furnace
22	1940.11	Tokyo	4th Fuel Economy Division	Heat efficiency of iron and steel making
24	1941.06	Tokyo	5th Fuel Economy Division	Heat efficiency of iron and steel making
28	1943.05	Anshan	6th Fuel Economy Division	Heat balance of OHF and regenerator
33	1944.10	Hirohata, Kobe	7th Fuel Economy Division	Heat balance of OHF

Source: ISIJ (1945), pp. 9-12.

Table 3 Activities of ISIJ Steel Division, 1948--50

Order	Date	Place	Main subjects	No. attending	No. submitted materials	Note
1	1948.8.5-7	Yawata Iron and Steel Works	How to use heavy oil	87	35	
2	8.20	Tokyo（ISIJ）	Combination ratio of iron, materials for a furnace bed	20	7	
3	10.29	Amagasaki Steel Works	Oxygen steelmaking	75	2	Inspection of real works of oxygen steelmaking and discussion
4	1949.1.25	Tokyo（ISIJ）	Oxygen steelmaking, materials for a furnace bed	30	14	Opening own oxygen steelmaking plan and mutual criticism.
5	4.1	Tokyo（IISI）	Oxygen steelmaking, gas producer	39	7	Experiments for oxygen steelmaking at ASW (6 November 1948) was reported and analyzed.
6	5.29-30	Amagasaki（Nichia Steel, Amagasaki Steel Works）	Oxygen steelmaking, heavy oil burner	35	8	
7	8.5	Tokyo (IISI)	Structure of OHF, heavy oil burner	38	14	Each company submitted a blueprint of a burner used at present and examined ways of operation and amounts of fuel use. (rows 7–8)
8	10.27	Tokyo（IISI）	Structure of OHF, heavy oil burner, casting mold	45	22	
9	1950.2.3-4	Tokyo（Tohto Steel, IISI）	Gas producer, heavy oil, materials for a furnace, structure of OHF, sound ingot	50	13	
10	50.4.1	Tokyo (IISI)	Structure of OHF, sound low carbon steel (pipe)	42	14	
11	50.6.7	Tokyo（IISI）	Producer gas, substitute materials for a furnace bed, structure of OHF	41	12	
12	50.8.8	Tokyo (IISI)	Lecture by Eitaro Tomiyama on steelmaking technology of the U.S. Structure of OHF, sound carbon steel（sheet bar）	41	8	

Source: Yoshikawa (1950), pp. 510-13, ISIJ (1950), p. 513.

Table 4 Activities of the Heat Control Division of Yawata, 1944--54

Fiscal Year	Engineering Subsection			Instrument Subsection				All employees
	Staff		No. operations	Staff		No. operations		
		Engineers			Engineers	Own	Outsourcing	
1944	13	3	—	—	—	—	—	66,740
45	14	4	—	—	—	18	—	35,526
46	17	3	20	20	7	383	—	28,407
47	37	8	12	33	6	1,050	—	27,930
48	37	8	27	37	8	1,743	—	32,706
49	37	8	12	44	8	2,769	—	35,362
50	37	8	30	44	8	3,557	—	35,038
51	43	9	41	49	8	4,255	2,731	37,087
52	43	9	49	49	9	4,470	4,897	36,729
53	—	—	62	—	—	4,244	6,586	35,431
54	81	10	82	47	—	4,309	7,403	34,578

Source: Kobori (2010), p. 143.

Table 5 Oxygen generators for steelmaking completed during the First Rationalization Plan

Company	Plant	Style	Year and month	Nominal capacity (m^3/h)	Manufacturer
ASW		Linde	1952.05	500	KOBELCO
Osaka	Nishijima	Linde	1952.05	500	KOBELCO
Kawasaki	Chiba	Linde--Frankl	1955.09	2,000	Japan Oxygen
	Fukiai	Linde--Frankl	1952.01	2,000	Japan Oxygen
Japan Steel Works		Claude	1953.12	500	Imperial Oxygen
NKK	Kawasaki	Linde--Frankl	1953.03	2,000	Japan Oxygen
Fuji	Muroran	Claude	1954.04	500	KOBELCO
	Kamaishi	Heiland	1954.05	500	Mitsubishi Kakoki
	Hirohata	Linde--Frankl	1954.01	500	Japan Oxygen
Yawata		Kaken	1953.05	500	Hitachi
		Linde--Frankl	1955.11	2,000	KOBELCO

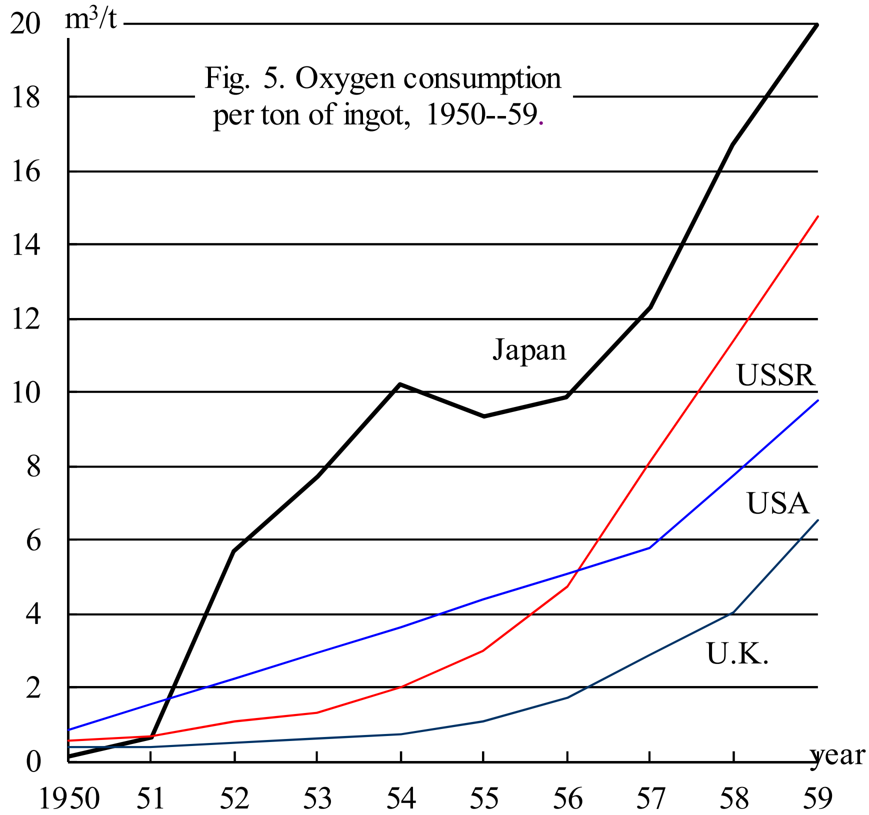
Source: Sanso Kyokai (1998), p. 122.

Table 6 Oxygen steelmaking and basic unit for fuels, 1950--59

Year	Amount of ingot production at OHF	Amount of ingot production at factories using oxygen	Share of oxygen steelmaking	Amount of oxygen consumption	Basic unit for Oxygen		Basic unit for fuels
	(1)	(2)	(2)/(1)	(3)	(3)/(1)	(3)/(2)	
	t	t	%	1,000m^3	m^3/t	m^3/t	1,000 kcal/t
1950	4,269,192	117,615	2.8	599.8	0.14	5.10	1,819
51	5,710,330	496,501	8.7	3,537.8	0.62	7.13	1,771
52	5,688,473	2,512,705	44.2	32,398.1	5.70	12.89	1,609
53	6,394,655	4,484,716	70.1	49,347.9	7.72	11.00	1,357
54	6,327,455	4,642,092	73.4	64,547.7	10.20	13.90	1,157
55	8,101,652	6,196,731	76.5	75,485.5	9.32	12.18	1,051
56	9,360,119	7,530,016	80.4	92,360.7	9.87	12.27	1,025
57	9,562,959	8,431,933	88.2	117,255.8	12.26	13.91	995
58	9,899,028	9,166,500	92.6	164,997.0	16.67	18.00	842
59	13,056,559	12,220,939	93.6	260,306.0	19.94	21.30	758

Sources : JISF (1959), p. 768, AIST (1966), p. 85, Sakai (1961), p. 63.

Note : Basic unit for fuels does not include the score at acid OHF.



Sources : Table 6, Tekko Kaigai Shijo Chosa Iinkai (1963), p. 74.