THE IRON AND STEEL INDUSTRY

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INTRODUCTION

WHEREVER man lives, technology and iron invariably exist due to human wisdom at work, may it be in the East, in the West, in an advanced country, or in a less developed country. One can consider that together with the use of iron mankind created civilization and he has since advanced his technology and intelligence.

Moreover, as long as mankind has access to iron, iron making technology and its related economic activities will not only enrich an individual nation but also will contribute to world culture. Individual nations, in return, will receive feed-back from world culture.

It is a matter of common knowledge that modern steel making technology in Japan developed on the basis of transferred technology from the West. However, it was on one hand the creative intelligence of the Japanese themselves and on the other, their organized productive force that nurtured capabilities and the accumulation of technology in Japan. As a result, Japan became the third steel manufacturing country and the first steel exporting country in the world, thus contributing internationally.

In order to clarify the developmental process of modern steel making technology in Japan, this paper shall first discuss a highly sophisticated endogenous technology based upon centuries of manual experience which existed up to the 1850s without any scientific framework. In other words, there was a solid foundation of endogenous technology upon which any forthcoming modern technology could be built.

I. CHARACTERISTICS OF ENDOGENOUS TECHNOLOGY

Dr. Cyril Stanley Smith, a contemporary American metallurgist, referring to the techniques epitomized in Japanese sword making aptly compared the characteristics of steel making technology existent in Japan prior to the introduction of Western technology with those existent in Europe in his *History of Metallography* (1960). He wrote as follows:

> The finishing of a Japanese sword and its furniture is a metallographer's art par excellence. Yet, though it depends so intimately on an appreciation of the structure of the metal beautifully revealed to the naked eye, and has served to control practical forging and heat treating procedures, it has contributed nothing to the scientific understanding of the nature of metals or the manner of their solidification or trans-

> formation. In Europe where both the microscope and the intellectual curiosity existed from the seventeenth century onward, the only metal surfaces available for study were either fractures or surfaces abraded or burnished so as to disguise the structure completely. Had either the Japanese been scientifically inclined or the Europeans better artists in metal, the history of metallography could hardly have failed to have been very different. [12, p. 62]

As Dr. Smith pointed out, when the instrument for scientific observation and measurement called a microscope was used for research on metals, the science of metals was developed in Europe ahead of Asia. In Japan, however, techniques for the heat treatment of metals had been established ahead of Europe without the knowledge of such scientific theories or the laws of physics and chemistry. Herein lies a unique characteristic of Japanese iron and steel making technology up to the late Edo period. In other words, it was technology based upon ingenuity.

The traditional technique of making good steel (generally known as *tama hagane*) for a Japanese sword is called *tatara-buki* ("bellows-blown") method. This is a method of smelting and refining iron sand with charcoal as reducing agents which was developed in the Chūgoku region, centering on Izumo Province (present-day Shimane Prefecture). Thus the first prerequisite for making good steel was fulfilled by the purity of iron sand obtained in Izumo Province. It is difficult to find any better iron ore than Izumo iron sand in this volcanic country. The second was the use of charcoal with few impurities for fuel which made the production of good steel (*tama hagane*) possible, whereas coke with a high sulphur content could have never produced good quality steel. The third was accomplished by a low smelting temperature which prevented impurities coming out of the furnace wall from affecting the steel as was the case with high temperature smelting.

The seemingly primitive bellows-blown method produced superior steel because the above-mentioned three factors were fulfilled. Thus the endogenous technology in Japan was able to yield steel far superior to that produced in Sweden which is world known for the production of excellent steel. Japan's bellows-blown method, in one sense, can be considered to have been a harbinger of today's direct reduction methods such as Wiberg's method. Although the Japanese were not so adept at grasping scientific laws as to readily develop instrumentation on the scene of production, they were able to master abundant knowledge or technical truths owing to centuries of technical experience. A Japanese classic book on ferrous metallurgy entitled *Tetsuzan hitsuyō-kiji* [Vade mecum to iron makers] (1784) [11] which is comparable to the European *De Re Metallica* by Georgius Agricola (1556) contains numerous passages revealing such technological truths.

II. INDIGENOUS THOUGHTS ON IRON MAKING

The *tatara-buki* ("bellows-blown") method which used iron sand as the principal material, nevertheless, was not suited for mass production, thus contributing little to accelerating the adoption of modern technology. Modern steel making technology that enabled mass production in Japan developed only after the introduction of the Western blast furnace, with a new endogenous method of iron making invented through the combination of the traditional smelting techniques existent in the Tōhoku region using iron ore called *mochi-tetsu* (a magnetite of high purity) and the theories of modern ferrous metallurgy nurtured in Europe.

A distinct discontinuity between the bellows-blown method and the modern iron and steel making process is obvious. However, when the onset of modern iron manufacturing is examined, one should not overlook the fact that European technology took root, prevailed, and developed on Japanese soil solely because of Japan's industrial technology regarding iron which had been empirically cultivated. These were the traditional techniques nurtured by the notion of "technology based upon ingenuity," namely the bellows-blown method of iron sand smelting and *mochi-tetsu* ("iron ore") smelting and the related techniques of utilizing iron.

Baien Miura (1723–89), a scientific thinker of the eighteenth century Japan, most accurately grasped the role of iron in human life in his *Kagen* [The principles of economic values] (1773) as follows:

> *Kin* ("metal") is the generic term for the five metals, which are gold, silver, copper, lead, and iron. They are collectively referred to as *kin*. Among the five metals, iron is considered the greatest treasure, followed by copper and then lead, because it is inexpensive yet useful for many purposes. People cannot live a day without iron. [5, p. 42]

B. Miura very appropriately pointed out that iron was the most valuable treasure because it was extensively used by many people and could not be dispensed with, not even for a day. There were also many other writers who duly appreciated the value of iron during the Edo period. Shigenaka Shimohara (1738–1821) who wrote the aforementioned *Tetsuzan hitsuyō kiji* stated that "iron contributes greatly to the welfare of the people of all estates," and that "while agriculture is the basic of political economy, iron is the foundation of agriculture, and thus iron must never be neglected" [11, p. 632]. Nobuhiro Satō (1769–1850), an economic thinker and metallurgist of the late Edo period, coined in *Keizai yōroku* [Principles of economy] (1827) a phrase which became well-known namely that "iron is the most beneficial to human life among the seven metals" [9].

Another noteworthy statement with regard to industrial ideas was made by Nariakira Shimazu (1809–58), lord of the Satsuma fief, who successfully had a reverberatory furnace built following a model installed in the Saga fief. In addition, he had Japan's first Western-style blast furnace built in Kagoshima. He expressed his belief concerning his industrial technological policy by stating that the primary factor in promoting agriculture lay in the production of farming tools and that "agriculture is the foundation of any nation, may it be in Japan, China, or one in the West and iron is the foundation of agriculture" [10, p. 40].

While such ideas regarding "iron" were deep-rooted in the indigenous Japanese culture, some Japanese who had come in contact with European books on science and technology imported via Nagasaki began to actively study and absorb Dutch technology. It was about this time when seemingly the first Japanese book on modern metallurgy entitled *Taisei shichikin yakusetsu* [A study on the seven metals of the West] (1854) [1] was published. By the early nineteenth century, the technological climate in Japan was mature enough to accept Western iron making methods. Because of this very reason Japan out of all other Asian nations was able to "take off" in her process toward modernization.

III. THE SYSTEMATIC ACCEPTANCE OF DUTCH LEARNING

Taisei shichikin yakusetsu, the first Japanese literary work showing a local understanding of modern European metallurgy, was compiled by Sadayoshi Baba (1787–1822), a scholar of Western learning in the late Edo period. He first served as a Dutch interpreter in Nagasaki and later contributed greatly as a translator (from Dutch, Russian, English, etc.) for the Office of Astronomy (*temmon-kata*) of the Shogunate. We must add that the work which was published in 1854 is regarded highly in the history of modern printing in view of the fact that it was printed with the use of types made of wood.

As its title indicates, the work consists of translated accounts of "seven metals," supplemented at the beginning with seven pictures under the heading of "pictures of Western processes of smelting seven metals." The first volume pertains to gold, the second to silver, copper, and iron, the third on tin and lead, and the fourth and fifth volumes to mercury. There are such descriptions on each metal as the areas and conditions of production, different types, smelting methods, characteristics, and their usages.

S. Baba is also known as the translator of a medical work entitled *Tonka hiketsu* (completed in 1820, published in 1850). It was the first book that introduced into Japan *An Inquiry into the Causes and Effects of the Valiolae Vaccinae Known by the Name of the Cow-pox* announced in 1798 by Edward Jenner of Britain who explained an effective vaccination method to prevent the contraction of smallpox. The book thus proved the superiority of Western medicine on the practical level.

Japan at the beginning of her modernization could take pride in the fact that such scholars of Western learning paved the way in the spread of Western knowledge concerning metals and above all that pertaining to iron as a basic necessity of human life.

S. Baba wrote in his general consideration of gold in volume 1 of *Taisei shichikin* that "among various metals, iron is the most useful to man who cannot dispense with it even for a moment. Iron should be most highly valued" [1, p. 34]. He further stated that "as far as household use is concerned, iron should be considered the foremost of all metals" [1, p. 35]. This idea can be regarded as following the same trend of thought held by the aforementioned Miura, Shimohara, and Satō whose ideas were nurtured by indigenous technological ideas.

Moreover, S. Baba reiterated in volume 2 that "iron cannot be dispensed with even for a moment in everyday human life," and he pointed out that "iron provides people with the most valuable benefits" because its "principal benefits" are yielded "when it is used for tools and as medicine" [1, p. 125].

In short, ideas shared by Baba and his predecessors reveal that both indigenous and European thoughts could germinate from an identical foundation when the very fundamentals of human life are taken into consideration.

The fact that Japanese pioneers in the Edo period showed no military orientation in their "thoughts on iron" deserves attention. The author would like to point out that theirs were enlightened ideas which had germinated from the above-mentioned indigenous technological thinking. Thus their thinking differed totally from the ideas concerning iron with priority (overriding emphasis) on military needs which developed after the establishment of the Meiji government.

Japanese pioneers in Western learning and technology came into direct contact with a Dutch technological book in the 1850s and positively understood and absorbed the theory and practice of iron making technology itself. The title of the book is *Het Gietwezen in 'sRijks Ijzer-Geschutgieterij, te Luik* [The casting processes at the National Iron Cannon Foundry in Luik] (1826). It is a book on military technology and arms engineering which describes in detail the iron shell and cannon making processes used at the Dutch National Cannon Foundry then situated in present-day Liège. It was written by Ulrich Huguenin (1755–1834), a major general of the Dutch army who was the director of the foundry at the time. This book being the first work on modern iron making technology practiced in the Netherlands at that time, it also served as a metallurgical textbook which described the properties of iron and its various manufacturing methods in detail. The book was able to fully satisfy the intellectual needs of the intelligentsia in the late Edo period who acutely felt the military pressures from foreign nations. It was thus translated by various fiefs under different titles, and the construction of reverberatory furnaces to cast cannon in various parts of Japan was consequently made possible in the 1850s.

Karl J. B. Karsten (1782–1853), a German ferrous metallurgist, is frequently quoted in the section on blast furnaces, which reveals the Huguenin's historical understanding of iron making. Karsten was an engineer who compiled the basic theory of iron making technology and its practical applications into a textbook entitled *Archiv für Bergbau und Hüttenwesen* [A compendium on mining and metallurgy] and thereby was able to propel ferrous metallurgy into the position of a modern engineering science. Thus a technological book which had been compiled with the intention of helping the Kingdom of the Netherlands which lagged behind Britain and France in iron making happened to find its place in the soil of Western learning which had been nurtured in Japan. This book served as one of the sources of information for the construction of blast furnaces and for the manufacture of pig iron in this country, e.g., in Kagoshima (the southwestern part of Japan), in Kamaishi (the northeastern part), and in Hakodate (Hokkaidō).

IV. SUCCESS IN WESTERN-STYLE BLAST FURNACES

A vital task for Japan around 1850 was to fundamentally reform its iron making process to facilitate mass production in order to tackle the increasing military pressures imposed by Western nations which demanded the opening of Japan. Thus the resultant need for a massive supply of pig iron to be charged into reverberatory furnaces for the casting of cannon induced Western blast furnace technology to be transplanted into this country under the leadership of Takatō Ōshima (1826–1901) and other pioneering engineers. Ōshima who studied Dutch learning in Nagasaki began to pave the way for modern technology and during the process he and Ritsuzō Tezuka jointly translated Ulrich Huguenin's book which taught them the principles of European iron making.

Ōshima who was born in Morioka in the Tōhoku region, after being engaged in the construction of a reverberatory furnace in Mito fief, strongly expressed the urgent need for the industrial application of Western-style blast furnaces which would supply a massive volume of pig iron. Thus he attempted the exploitation of the Kamaishi iron mines in his home region of Tōhoku to obtain pig iron to be charged into the Mito furnace.

Before we delve into the blast furnace construction in Japan, a brief description on the development of reverberatory furnaces will be given. The first reverberatory furnaces were built in 1850 in Saga fief using Huguenin's book as a manual. The development of the cannon casting project undertaken by the Saga fief amazed the rest of the nation, and many from the Bakufu and elsewhere requested the fief to either impart its casting process or to cast cannon for them. Likewise, the Satsuma fief achieved brilliant success in its own reverberatory project. The influence of the scientific and technological views of Nariakira Shimazu, lord of the Satsuma fief, should be remembered in this regard, as he was the one who constantly gave appropriate instructions to his engineers in the belief that "Westerners are human beings, Saga-ites are human beings, and so are Satsuma-ites" [10, p. 40]. Moreover, along with the process of establishing a Western-style military industry, the smelting factory (*seiren-kata*) founded in Saga and Satsuma nurtured research in physics and chemistry and stimulated the development of the chemical and shipbuilding industries. It may be relevant to add that these activities had a close geographical bearing on the establishment of the Bakufu's naval academy and iron works in Nagasaki (present-day Mitsubishi Heavy Industries, Ltd., Nagasaki Shipyard).

Preparations for the construction of the reverberatory furnace in Izu began in 1853 under the leadership of Tan'an Egawa (1801–55), a scholar of Western learning, with technical assistance provided by the Saga fief, and the work on the furnace and further development of the cannon casting project were successfully accomplished. What is noteworthy in this connection was the fact that a joint research group called Nirayama Dutch Book Translation Office (*Nirayama ransho honyaku-kata*) was formed by first-rate scholars of Western learning so that experts coming from various fiefs could engage in a joint project.

While reverberatory furnaces were thus built in quick succession, the Satsuma fief pioneered the construction of a Western-style blast furnace in 1854 as a logical consequence of its cannon project. However, the fief was unable to continue full-scale industrial production due to the limited supply of raw materials and to the demand for products, and thus it had to be content with the honor of simply being a pioneer.

Another blast furnace was built in 1855 at Kobui (Hokkaidō) under the administration of the governor of Hakodate. Although it was undertaken by Ayasaburō Takeda, a scholar of Western learning who is also well known for his design of a Dutch-style fortress (Goryōkaku), it turned out to be a failure because it was designed to use iron sand as the principal material.

In the same year, the aforementioned reverberatory furnace was constructed in Mito under the leadership of Takatō Ōshima. In 1856, this reverberatory furnace was advanced enough to cast mortar cannon using *Unshū-sen* (pig iron produced in Shimane Prefecture). This reverberatory project subsequently led to the establishment of a Western-style blast furnace at the Kamaishi iron mines in Ōshima's home province because he urged its construction so that iron ore instead of iron sand could be used to obtain a massive quantity of pig iron suitable for the casting of cannon. Thus Kamaishi eventually became the origin of modern iron making technology in Japan.

The question arises as to why industrial-scale production of pig iron with a blast furnace was successful only in Kamaishi but not in Kagoshima or Hakodate. One may consider that it was due to Ōshima who had acquired sufficient knowledge on the European iron making process through the translation of Huguenin's book, and strongly advocated the development of blast furnaces as a matter of course. It should be remembered here, however, that many parts of the Tōhoku region including Kamaishi had been more advanced than elsewhere in the mining and processing of such metals as iron, gold, and copper since ancient times. It may be presumed that Ōshima himself epitomized the folk spirit of Tōhoku.

Ōshima already had plans to obtain "iron from Kamaishi" and to construct a Western-style blast furnace as early as July 1854 before the construction of the Mito reverberatory furnace had even started. As an engineer he confided his ambition to an official of the Mito fief as follows:

> The Western process is the best of all. One has to be selective about the quality of iron. Even if a reverberatory furnace is built, it will serve no purpose without mild iron [pig iron made from iron ore]. Cast iron can be produced only where there are both mild iron and a furnace, but neither is dispensable. Therefore, I will never agree to make a cannon out of the other kind of iron. [8, p. 33]

Moreover, he aptly explained the qualitative difference between "mild iron" and the other pig iron (from iron sand) in the following metaphor:

> The other kind of iron is like ordinary rice, which cannot be kneaded smoothly however thoroughly it may be polished. Mild iron is like glutinous rice, which of whatever grade can be well kneaded into rice cake. [8, p. 34]

Ōshima did not negate the *tatara* furnace in principle. Should the intention of the Mito reverberatory furnace be to melt pig iron to be used in the casting of cannon, he knew that a massive quantity of necessary pig iron which was highly fluid and homogeneous could never be obtained from the *tatara* furnace.

It can be seen that his scientific recognition was very sound from the beginning of his participation in the Mito reverberatory project due to the fact that he had a firm grasp not only of the endogenous iron ore smelting technology in Tōhoku but also of the European method of iron making.

Consequently, having Takatō Ōshima's engineering leadership, it was possible nowhere else but in Kamaishi to accomplish the tremendous task of successfully building a Western-style blast furnace during the Edo period when no machinery could yet be imported. The task thus was entirely dependent on local know-how, materials, and labor, the guidelines being provided by Dutch technical books and engineering dictionaries together with the financial assistance of local capitalists. The first Western-style blast furnace in Kamaishi (also known as the charcoal-burning blast furnace because it used charcoal as fuel) was characterized by the use of a water mill to motive power, which tactfully exploited a natural advantage.

The founding of a Western-style blast furnace to achieve the industrial smelting of iron ore, rather than that of iron sand, was an epoch-making event which marked the first step away from the traditional small-scale, inefficient *tatara* method, and thus began the dawn of modern iron making technology in Japan.

Ōshima called his creation a "Japanese-style blast furnace"; he never referred to it as a "Western-style blast furnace." His attitude would be understood if we pay due consideration to why a Western-style blast furnace in Kamaishi could become the starting point of the development of modern iron and steel making technology in Japan. It was not because the furnace was foreign but because the principles of European ferrous metallurgy were scientifically materialized against the background of indigenous Japanese culture by the personal contribution of Ōshima.

In contemporary China, the spirit of indigenous culture, the so-called *tu-fa* ("indigenous method"), is expressed in the phrase *chiu-ti chü-tsai* ("choose materials according to local circumstances"). This denotes a new approach in technological creativity starting from familiar ways of making things to actively accepting Western ways as long as they fit the natural environment and the availability of local resources. In this manner, the Western ways are ultimately improved. Ōshima's approach was identical to the basic way in which today's China is trying to develop its industry.

V. THE COKE-BURNING BLAST FURNACES IN KAMAISHI

Following the first Western-style charcoal-burning blast furnace installed in 1858 at Ōhashi in the Kamaishi iron mining area, this process subsequently became on a broader scale popular at Hashino. (The well-preserved remains of Hashino blast furnaces in Kamaishi are designated as a historical site by the government.) Immediately prior to the Meiji Restoration (1868), there were about ten blast furnaces in the district with a total annual output of 700,000 to 800,000 kan (about 3,000 metric tons). The military industry initiated by the Mito fief which brought about the Kamaishi blast furnaces resulted in failure because of political reasons. Nevertheless, the outcome was the germination of the local iron industry in the Tōhoku region.

It was in this historical context that the Meiji government in 1874 decided to nationalize the Ōhashi iron mine in Kamaishi, and in the following year it embarked on a program to build modern-scale iron works under the nationwide slogan "increase production and promote industry."

In June 1874, T. Ōshima set about planning the construction of new iron works in cooperation with L. Bianchie, a government-employed German engineer. However, he disagreed with Bianchie over the location of the planned iron making plant which was to use the iron ore extracted from mines in Kamaishi. Ōshima's conviction was based upon his knowledge of the local peculiarities of the area where he was born and raised as well as on the details of his experience in technological development. Bianchie, on the other hand, was a proud specialist from an advanced European country.

There was no major difference between them as to the criteria of the site such as the availability of water indispensable for iron making, access to a seaport, and space for future expansion. The fact that Ōshima attached greater importance to the environmental conditions of the workers is noteworthy. The site chosen by him was as follows:

> [it was] enclosed by hills on three sides, west, north, and east, and only open on the south side, so that it would be affected by no rain storms in any season and be less cold in winter, thus permitting continuous operations day and night. [7, p. 783]

In the overall context of how to make the iron works project take root in that locality, there was an irreconcilable difference between the two proposed sites both of which were to be found along the Morioka highway facing the beach of Kamaishi. From the onset, Bianchie who came from Germany which had already gone through the industrial revolution intended to build big iron works comprising two relatively large, efficient blast furnaces, a modern railway to transport iron ore by steam locomotive–drawn trains, and a rolling mill to roll wrought iron prepared from pig iron. In contrast, Ōshima, due to his experience, selected the safest available site for night-and-day operations and proposed the construction of five relatively small blast furnaces whose iron ore would be carried by economical horse-drawn rail carts, all of which matched the Japanese technological standards of those days. He thus intended to gradually develop the technology on a safer path, following the Japanese proverb "to bear a small baby and raise it big."

The best timing from the viewpoint of economic growth for a developing nation today should it wish to establish an integrated steel works of its own, is believed to be found in the phase where the per capita steel consumption has reached twenty to thirty kilograms a year. However, Japan's per capita annual consumption of wrought iron and steel when the state-owned Kamaishi Iron Works (under the Ministry of Industry) was planned is estimated to have been even less than one kilogram. Growth of new technology in any country is dependent upon whether or not its promoters are aware of the characteristics of the indigenous culture, including the factors of demand, whether they have the technology to establish productive forces therein, and above all whether they have a general technological framework with a broad perspective.

Unfortunately, senior officers in the Ministry of Industry rejected Ōshima's proposal and adopted Bianchie's, for they paid more respect to the opinion of a foreign engineer from an advanced nation. Subsequently, Ōshima was transferred from Kamaishi to the Kosaka silver mines in Akita Prefecture. It was decided that two large British-style blast furnaces (naturally complete with refractories and all other necessary materials), railway components, and other incidental equipment should be imported from England to facilitate the state-owned Kamaishi Iron Works. The construction of the works was completed in September 1880 under the guidance of a newly invited British engineer, and pig iron making was thus started.

Operation of the iron works resulted in one failure after another, and the Ministry of Industry had to decide upon its closure in December 1882. Even though tremendous investments were made to install the latest large blast furnaces as well as machinery and a railway, it was impossible for the entire industry to achieve steady development, if the peripheral areas were underdeveloped and if the operations had to rely on primitive techniques solely dependent on manual labor. This only led to an increased accident rate. It was precisely this point that Ōshima was most concerned and worried about in the controversy over the location of the iron works.

Yukichi Fukuzawa (1835–1901), a distinguished advocate of enlightenment in the period of Westernization fever during the early Meiji years, pointed out as follows in his *Oboegaki* [Memoirs] of 1875,

> Japanese government officials today, though they once contributed to the reformation of the state, are poor in knowledge from the outset. . . . [Consequently,] they treasure government-employed foreign experts as their almighty cards whose help they count on in defending themselves. [2, p. 657]

Fukuzawa thus sharply criticized the Meiji bureaucrats for their lack of independent spirit and for their attitude of colonial servility. Therefore, the technical activities of Ōshima in the Meiji period were synonymous with a battle against such bureaucrats who lacked ideas of their own. This was especially so because he came from the Morioka fief which had opposed the civil war fought by men from Satsuma and Chōshū who subsequently formed the Meiji government. The history of modern iron and steel making technology in Japan could have been quite different, if some of the high ranking officials of the Ministry of Industry had had their thinking rooted in the realities of Japan's economy and technology. Instead of being blind admirers of things Western, they should have been courageous enough to accept the views of personalities like Ōshima who had both a scientific spirit and technological arguments.

The progress of not only the Kamaishi iron works but also of Japan's iron and steel making technology from the 1890s onward had to be sought through a complete investigation into and the overcoming of the technical failure of the state-owned Kamaishi Iron Works.

It was Chōbei Tanaka (1834–1901), a civilian merchant, and his family who attempted to restart iron making in Kamaishi after the closure of the state-owned iron works. He began to buy the machine parts used at the Kamaishi Iron Works at the recommendation of Masayoshi Matsukata, then minister of finance, which gave him the opportunity to try an iron making business. After experiencing many difficulties, he eventually established the Kamaishi Mines Tanaka Iron Works in July 1887.

It was beyond the technical knowledge and capability of the people of the Tanaka Iron Works who were complete amateurs in iron making. It necessitated their operation of twenty-five ton British-style blast furnaces (the "twenty-five ton" refers to the quantity of pig iron produced per day). Working these huge furnaces was a tremendously difficult task. To cite but one example, procurement of charcoal was restricted by the natural conditions of Kamaishi. Consequently, they adopted a new approach of first selecting a site "convenient for procurement of firewood and charcoal," and then building a small blast furnace with a daily output of five to six tons (like the one Ōshima had built) and gradually expanding the scale of operations as they became more skilled.

In the meantime, an attempt was started to refine the pig iron produced by the Kamaishi Mines Tanaka Iron Works into steel and process it into weapons and military machinery at the army's Osaka Arsenal which was playing a pioneering role in steel making technology. According to tests conducted in August 1890 to compare bullets made from Kamaishi pig iron with those made from Italian Gregorini pig iron, the results demonstrated that Japan's pig iron was no inferior, if not quite superior, to the world famous Gregorini pig iron. This success enabled the Tanaka Iron Works to find a major consumer for its product in the Osaka Arsenal. A sufficient amount of capital was eventually accumulated for the Tanaka Iron Works to realistically contemplate the revival of the large blast furnaces inherited from the Ministry of Industry as well as the establishment of pig iron making technology using coke as fuel. In 1893, it was decided to move headlong towards the revival of the "big blast furnaces." Kageyoshi Noro, doctor of engineering (1854–1923), then a professor of the Engineering College of the Imperial University (the present-day Faculty of Engineering of the University of Tokyo) and an authority on ferrous metallurgy, was invited as advisor together with one of his pupils, Koroku Kōmura (then an assistant engineer in the Ministry of Agriculture and Commerce, later a doctor of engineering), as chief engineer.

The operation of the coke-burning blast furnace resulted in great success as they first used coke supplied from Yūbari Coal Mine, Hokkaidō from August 1895. (They had initially used charcoal.) In reviving these blast furnaces, Dr. Noro took every conceivable step to improve them based on his ideas and technological knowledge, including the reshaping of their interiors and the redesigning of the common chimneys exclusively for the boilers. New roasters were also installed because the insufficient roasting of iron was anticipated. Japan already had technical leaders by the 1880s who were capable of critically taking in Western know-how and adapting it to the conditions of Japanese materials from a scientific point of view. Noro is noteworthy in this respect. He studied mechanical and electrical engineering at London University after graduating from the Department of Mining and Metallurgy, Faculty of Science, Tokyo University in 1882. In Germany, he furthered his knowledge concerning the theory and practice of iron and steel making technology by learning from Adolf Ledebur (1837–1906), then the foremost authority on ferrous metallurgy at Bergakademie Freiberg.

The pig iron output of the Tanaka Iron Works which stood at about 8,000 tons in 1893 reached some 13,000 tons in the following year. It surpassed the combined output of the various kinds of iron produced by *tatara* method in the Chūgoku region, and this accounted for 65 per cent of the total iron output of the nation. In this sense 1894 can be considered to be the year in which the basis of modern iron making was established for the first time in this country.

VI. THE STATE-RUN YAWATA STEEL WORKS

As a result of a combination of the following reasons, iron and steel making at the state-run Yawata Steel Works (sponsored by the Ministry of Agriculture and Commerce) commenced in 1901: (1) the pig iron making technology established at the Kamaishi Mines Tanaka Iron Works, (2) Western steel making technology developed mainly at the army's arsenals and the navy's dockyards by the 1890s, (3) the scientific knowledge and views of pioneering engineers including Kageyoshi Noro, (4) activities of enlightened political leaders such as Takeaki Enomoto who emphasized the importance of industrial development, and (5) the active demand of the Japanese in the Meiji period for iron and steel.

Nevertheless, a similar technical and managerial failure as that which had transpired at the state-owned Kamaishi Iron Works was repeated. Blast furnace No. 1 of the state-run Yawata Steel Works which was blown in February 1901 was designed by Fritz W. Lührmann who was a well-known German blast furnace engineer. It had a capacity of 495 cubic meters, giving a nominal daily output of 160 tons. The furnace, however, proved quite unsatisfactory in operation, and the pig iron it produced was unsuitable in quality for steel making as well as being very small in quantity, only 80 tons a day on the average. Moreover, the coke ratio (the amount of coke consumed for making one ton of pig iron) was as great as 1.7 tons. A succession of troubles finally necessitated the operational suspension of the furnace in July 1902.

The man who was asked to rehabilitate this blast furnace and who played the central role in its technological consolidation in 1904 was the aforementioned Kageyoshi Noro. He had retired from a professorship at the Imperial University owing to certain circumstances after which he gave technical advice to private iron and steel enterprises. Assuming the post of advisor at the request of Yūjirō Nakamura, director-general of the state-run Yawata Steel Works (a lieutenant-general of the army and subsequently president of the South Manchurian Railway Co.), Noro, after conducting a thorough scientific investigation concerning the failure of the blast furnace, identified the problems to be as follows: (1) structural defects of the furnace itself, (2) faulty blending of the charge, (3) coagulation of the charge in the furnace, and (4) repeated blast stoppages. He concluded that the faulty operation was essentially due to the following:

> the commissioning of the project to aliens who had no experience with Japanese-produced raw materials, the overly large diameter of the tuyere and its excessive projection into the furnace, the use of poor quality coke and inappropriate blending of the charge inviting an excessive basicity of slag. [6, p. 1130]

He immediately modified the original design as much as possible and at the same time made necessary preparations including the improvement of coke for the resumption of furnace operations. In this manner the blast furnace resumed operations.

One of Prof. Noro's pupils, Susumu Hattori (later a doctor of engineering) who was then the pig iron making manager of the works endeavored to rehabilitate the blast furnace. Hattori wrote as follows in an article entitled "On the Blast Furnace Operation in the State-run Steel Works":

> Today's prosperity of what initially was a failure is not the result of a natural process like fine weather after a rain storm but that of investigation into the cause of every aspect of failure, followed by efforts to correct all the faults so identified. [3, p.444]

It is unreasonable to deny the contributions of guidance given by foreign experts in iron and steel making technology during the initial phase of the state-run Yawata Steel Works. It is, however, incorrect to draw the conclusion that the development of modern steel making technology in Japan was solely attributable to their guidance, or that it was solely due to the technical knowledge and skills of the Japanese. It should be mentioned here that all of the German engineers and foremen totalling about twenty who had been employed at the time of the inauguration of the state-run Steel Works were dismissed between 1902 and the end of March 1904 except for one converter foreman.

The following statement made by K. Noro deserves to be kept in mind in an assessment of the significance of transferred European technology in the history of modern steel making and mining technology in Japan:

> Whether or not the planning and operation of an entire works should be commissioned to foreigners deserves careful consideration. Foreign mining technology introduced to such mines as those in Sado, Ikuno, Innai, Ani, and Kosaka all proved unsuccessful. When the instances of iron and steel making in Kamaishi and Yawata where the initial failures were reversed by subsequent endeavors by Japanese engineers are taken into consideration, one cannot help but become half-hearted regarding the introduction of foreign technology. [6, p. 10]

The technological success of the state-run Yawata Steel Works was only made possible through the attempts of Japanese engineers such as K. Noro and S. Hattori. They critically reassessed the formalistic design of the imported blast furnace which disregarded the peculiarities of Japanese raw materials as well as the careless way in which coke was used or treated. Thus they were able to reorganize these factors concerning pig iron making on the basis of their technological convictions.

From 1904 onward the blast furnace of the state-run Yawata Steel Works significantly improved its productive efficiency due to its reshaping, the expansion of its capacity, and progress of operational skills. The capacity at Yawata in the 1910s was two to three cubic meters in contrast to the 25-ton blast furnaces at the Kamaishi Mines Tanaka Iron Works where the capacity per ton of pig iron produced was four to five cubic meters. A 500-ton furnace (blast furnace No. 1 at Yawata's Kukioka Plant) which was the first modern large blast furnace in Japan was completed and put into operation in 1930. This finally reached 1.2 cubic meters which was comparable to the German standard before World War I.

Similar troubles to those in the blast furnace also existed in the open hearth sector of the steel making process in the initial phase of the state-run Yawata Steel Works. Kaichirō Imaizumi, another trusted pupil of Prof. Noro and a classmate of Hattori, who was the first steel making manager of the works stated as follows:

> The open hearth belonging to the steel making department which was designed by Mr. R. M. Daelen also had not a few defects. In 1903, I personally confirmed with Mr. Daelen who was my good friend in Germany that the design was a mere desk plan which had never been tested anywhere else before. Among the most serious defects, the arrangement of the nozzle could be improved after experiments but the elongation of the overly short nozzle and the installation of a slag chamber could never be corrected due to the lack of space. [4, p. 12]

In short,

> The plant could not be adequately operated for years due to these defective designs of the vital parts of both the pig iron and steel making sectors as well as because of the inexperienced personnel. [4, p. 12]

The trouble was further aggravated by the poor quality of coke according to Imaizumi who further stated as follows:

> Few other iron works used coke of so poor quality as that which was initially used at this steel works. As reported by Dr. Noro, it not only caused frequent troubles in the operation of the blast furnace but also invited production of inferior pig iron with too much silicon and sulphur content and an insufficient yield. Coupled with the defects in the design of the blast furnace, this shortcoming seriously obstructed the production of pig iron and steel. This indeed was one of the major causes of the tremendous costs entailed in pig iron and steel making in the initial phase of the steel works. [4, p. 14]

The state-run Yawata Steel Works earned its first profit in 1910, which owed as much to the establishment of coking technology resulting from the introduction of the Solvay-type coke oven as to the overcoming of the defects in the pig iron and steel making equipment. Thus, viewed from the standpoint of fuel for iron making, the development of the integrated iron and steel works was achieved due to the following factors: (1) increasingly effective utilization of gas from the coke oven and blast furnace in the steel making and rolling stage, (2) maximum practicable reduction of coal consumption in the gas generator, and (3) supply of the whole thermal energy needed for the entire process solely with coal charged into the coke oven.

The integration of iron and steel making and the rationalization of fuel economy led to the concentrated use of coal in the form of coke. Together with the shift in power source from steam to electricity which rapidly progressed in the 1910s, this trend resulted in a sharp decrease in coal consumption per ton of steel produced at the state-run Yawata Steel Works, namely from 4 tons around 1920 to 1.58 tons in 1933.

VII. THE RISE OF PRIVATE STEEL ENTERPRISES

Until World War I, 80 to 90 per cent of the steel output in Japan was produced by the state-run Yawata Steel Works. However, the war stimulated the nation's heavy and chemical industries which achieved rapid growth. At the same time, private steel companies successively merged in Japan, and thus it became possible to meet the increasing demand for steel needed by the growing industries. The Promotion of the Iron and Steel Industry Act which was enforced in 1917 facilitated the development of private steel making ventures.

The production system adopted by these private steel enterprises, however, was not the integrated pig iron–steel making process with the use of blast furnaces, but the open hearth steel making process or the scrap iron method which utilized cheap pig iron imported from India and scrap iron from the United States. It was a logical choice on the part of private enterprises to opt for a developmental process in which technology is suited to yield maximum profit. Indian pig iron (especially that from Tata) was not only less expensive than Japanese pig iron, but the least expensive in the world. Consequently, it was possible for private Japanese steel makers to avoid reliance upon either the state-run Yawata Steel Works or the blast furnace operator in Kamaishi. Nippon Kōkan Co. which was established in 1912 in the Tokyo-Yokohama industrial zone was a typical private enterprise which acted as a pioneer in solving the problem of an insufficient supply of pig iron.

The massive steady import of cheap American scrap iron and Indian pig iron well corresponded to the pursuit of economic rationality undertaken by the private steel makers. The financial position of the major Japanese steel companies reveals that open hearth steel makers including Nippon Kōkan were far better off than the blast furnace iron makers belonging to the *zaibatsu* groups of Mitsubishi and Mitsui. Thus it is noteworthy to realize that by the early 1930s private steel enterprises had come to account for a greater share in the total crude steel output than the share held by the state-run Yawata Steel Works.

The dark clouds of the era of autarky, however, already overshadowed the world horizon. First of all, the predominant dependence on open hearth steel making always contained a risk, namely that its very basis would be lost once the economic advantage of cheap Indian pig iron and American scrap iron ceased to exist. Secondly, mass production of ordinary steel with open hearths which were originally intended for production of superior steel in the European setting was by no means an orthodox practice. On top of this, no converter had been introduced which could dispense with scrap iron. The situation was quite different from the United States where civilization centering around the automotive industry was so highly developed that there was a large output of scrap iron. The dissolution of these contradictions had to be carried over until after World War II.

CONCLUSION

In the stage of technological development when both the state-run Yawata Steel Works and private steel enterprises coexisted (namely, integrated and non-integrated steel making), the iron and steel manufacturing industry in Japan had completely shifted from a mining type to an industrial type of industry. In addition, fundamental research on iron and metals in general began to positively take root during this stage due to a close interrelationship which evolved between the theoretical and practical sectors engaged in iron and steel making.

Representative research organizations were the Iron and Steel Institute of Japan (Kageyoshi Noro was the first president) established in 1915 and the Research Institute for Iron and Steel at Tōhoku Imperial University (renamed the Research Institute for Iron, Steel and Other Metals in 1922; Kōtarō Honda, doctor of science, was the first director) established in 1919. The history of iron and steel in Japan, thus, progressed into the era of scientific technology from the 1910s.

As is well known, iron and steel manufacturing in Japan which was devastated by World War II corresponded to the international economic environment in the postwar period. Technological innovation was accomplished on the basis of technology transfer from the United States and Europe and thus the industry became capable of competing in the international market. As a concluding remark for this article, the author would like to point out that the postwar iron and steel makers were not only independent and creative but also were able to rely on organizational force. On the basis of the experiences and accumulation of modern iron and steel making technology which developed from the 1850s, they were able to rechannel their route to the production of basic materials needed for the improvement of the standard of living for the citizens as a peace industry rather than as a war industry.

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