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The Introduction and Impact of Tunnel Kilns in the Japanese Ceramic Industry During the Early 20th Century

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Ⅰ. Introduction

Advancements in the ceramics industry between the 1860s and 1920s revolutionized production in Japan, leading to significant improvements in fuel efficiency, product quality, and manufacturing speed. This period coincided with the Meiji Empire's (明治, 1868-1912) broader industrialization efforts that would see Japan become a global leader in ceramic trade. Although kiln technology in Europe advanced nearly a century earlier during the Industrial Revolution (1760s-late 19th century), Japan narrowed the gap with Western powers through the early 20th-century adoption of continuously firing tunnel

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kilns.

The Meiji era marked a shift from artisanal craftsmanship to industrialized production driven by scientific and technical expertise. This transformation required potters to adopt roles as chemists, scientists, and engineers to parallel developments taking place throughout Europe and America. At the forefront of this evolution was the Morimura Group (森村グループ), a prominent export wholesaler instrumental in introducing and advancing tunnel kiln technology for diverse ceramic applications. The group's three largest companies—Nippon Toki Gomei Kaisha (日本陶器株式会社, now Noritake ノリタケ株式会社), Toyo Toki (東洋陶器株式会社, now TOTO 株式会社), and NGK Insulators (日本碍子株式会社, now 日本ガイシ株式会社)—not only utilized tunnel kilns but also implemented key alterations that influenced broader industrial standards around the world.

This paper explores the transfer of tunnel kiln technology from the West to Japan, with a particular focus on the innovations developed by Morimura Group engineers. These refinements highlight Japan's industrial achievements during the Meiji, Taishō (大正, 1912-1926), and early Shōwa (昭和, 1926-1989) eras, underscoring its pivotal role in accelerating ceramic production at the turn of the 20th century.

Ⅱ. The Development of Tunnel Kilns in the West

Pottery kilns have been in use since as early as 3000 BCE, with up-draft kilns appearing across a range of cultures.[1] By the 6th century CE, East Asian potters began adopting cross-draft kilns, reflecting early efforts to enhance heat distribution and firing consistency.[2] These innovations laid the groundwork for more advanced technologies,

1 An up-draft kiln places the fire at the base, allowing heat to rise through the ware and exit through flues at the top. Felix Singer and Sonja S. Singer, *Industrial Ceramics* (New York: Springer, 1963), p. 969.

2 A cross-draught kiln directs heat horizontally from a firebox on one side to a flue or chimney on the other. Frank Hamer and Janet Hamer, *The Potter's Dictionary of Materials and Techniques* 3rd ed. (Philadelphia: The University

but it was the rapid urbanization, expanding consumer markets, and the growing need for public infrastructure such as sanitation and transportation systems during the Industrial Revolution that truly transformed ceramic production. In this new context, periodic kilns became a significant obstacle to large-scale manufacturing. As a result, interest in continuous firing methods intensified, setting the stage for the eventual development of tunnel kilns.

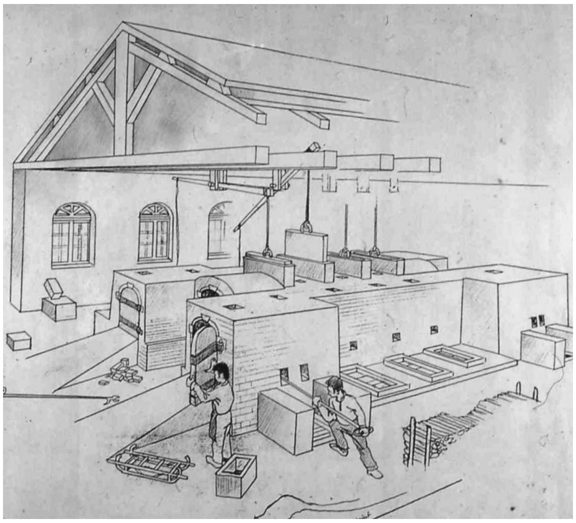

Fig. 1. Vicennes Tunnel Kiln Sketch (Antoine d'Albis, "Un plat d'entrée de première grandeur du service à fond vert du banquier Jean-Joseph de Laborde (1724-1794)," *Sèvres. Revue de la Société des Amis du musée national de Céramique* 30, p. 51)

The earliest clear step in tunnel kiln technology came in 1751 when Claude-Humbert Gérin (1705-1750), supervisor of France's Vincennes porcelain manufactory (est. 1740, later Sèvres), constructed the first continuously firing kiln. Designed for glost firing[3], this kiln suspended wares on metal hooks to optimize thermal exchange based on size and weight (Fig. 1).[4] Though the kiln remained in use at the factory until 1804, continuous

of Pennsylvania Press, 1991), p. 49.

3 Bisque (biscuit) firing is the first firing of ceramic ware. It hardens the dried clay and removes moisture, making the piece strong yet still porous enough to absorb glaze. This prepares the ware for a second firing, called the glost (glaze) firing.

4 Early experiments began with the brickwork factory Pippow in Stolp (now Słupsk, Poland), who operated a semi-continuous five-chamber kiln around 1770 that reached 30-40% fuel savings. However, as these designs more

kilns did not achieve widespread adoption during this time.[5] Instead, the late 18th and early 19th centuries focused on refining down-draft kilns. By the mid-19th century, down-draft kilns had become the industry standard, with English ceramic manufacturer Thomas Minton's 1873 patent shaping later designs.[6] In contrast, tunnel kilns remained rare due to high construction costs, extensive testing requirements, and the large space needed for installation.

As industrialization advanced in the mid-19th century, interest in continuous firing methods was revived. Early innovations such as the Hoffmann kiln (1854) and Mendheim kiln (1867), both developed in Germany, laid the foundation for further progress.[7] Building on these models, German engineer Otto Bock (1850-1913) began researching tunnel kilns in 1877, concentrating on improving airflow and gas control. His efforts led to the creation of more than 60 designs, contributing significantly to the standardization of tunnel kiln technology by the early 20th century.[8]

Unlike periodic kilns, which required separate heating and cooling cycles for each batch, tunnel kilns operated continuously, moving wares through an enclosed chamber divided into preheating, firing, and cooling zones. Their widespread adoption marked a turning point in ceramic manufacturing, laying the foundation for modern mass

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closely resemble cross-draft kilns, they are not included in this study. Willi Bender, *Vom Ziegelgott zum Industrieelektroniker: Geschichte Der Ziegelherstellung Von Den Anfängen Bis Heute* (Bonn: Bundesverband der Deutschen Ziegelindustrie e. V., 2004), p. 301.

5 Antoine d'Albis and Marino Maggetti, "Phase and Compositional Analysis of a Sèvres Soft Paste Porcelain Plate from 1781, with a Review of Early Porcelain Techniques," *European Journal of Mineralogy* 29, no. 3 (2017): p. 3.

6 Brett Cameron Phelps Sturm, *A Program for the Conservation, Interpretation, and Reuse of Downdraft Kilns at the Western Clay Manufacturing Company of Helena, Montana* (Master's Thesis, University of Pennsylvania, 2013), p. 24; Thomas Webb Minton, Minton Downdraught Oven, British Patent 1709, issued 10 May 1873. In a down-draft kiln, hot gases rise to the roof before being drawn downward through the stacked ware and exiting through flues at the base. Singer and Singer, *Industrial Ceramics*, p. 969.

7 The Hoffmann kiln's circular design enabled continuous operation by moving flames around stationary wares. However, circular structures eventually lost favor to straight tunnel kilns such as the Mendheim model, in which the wares themselves moved through a stationary flame path. George Granger Brown, "Clays and Shales of Michigan and Their Uses: Part 1," *Geological Series* 30, no. 36 (1924): pp. 78, 81.

8 Bock kilns used sand seals to maintain a consistent firing atmosphere while also ensuring that the kiln cars could move efficiently along the tracks. Carl Harrop, "Modern Method of Firing Clay Wares," *The Ohio State Engineer* 5, no. 1 (1921): p. 3.

production. Understanding the mechanics of early 20th century tunnel kiln models is essential for comprehending their impact on the ceramic industry at the turn of the century (Table 1).

〈Table 1〉 Development of the Modern Ceramic Industry

	Production Methods	Kiln	Fuel	Skills
Pre-Industrial Revolution	Craft Art	Climbing Kiln, Square Kiln	Firewood	Master Artisans
Industrial Revolution (1750s~20th c.)	Factory-based Craft Art, Mass Production	Round Kiln, Bottle Kiln	Firewood → Coal	Master Artisans → Labor Specialization
Mass Production (1920s-1970)	Large-scale Mass Production	Continuous Firing Kiln, Tunnel Kiln	Coal, Gas, Oil, Electricity	Labor Specialization, Automated Intelligence, Streamlined Manufacturing

1. Features of Early Tunnel Kilns and Key Models

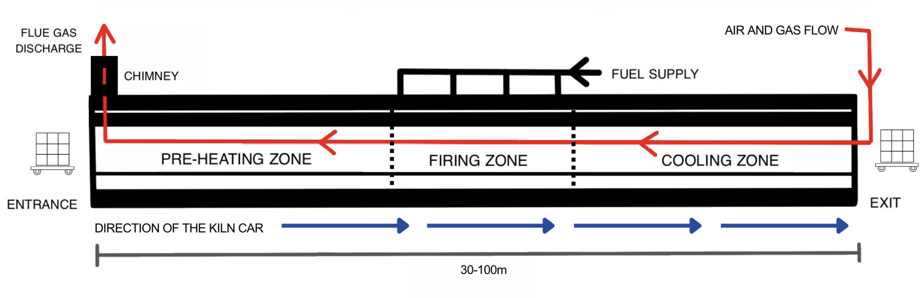

Fig. 2. Structural Features and Gas Flow of Early Tunnel Kilns (Figure by the author)

To comprehend the general function of tunnel kilns from the late 19th and early 20th centuries, it is essential to understand the gas and airflow within the preheating, firing, and cooling zones (Fig. 2). This controlled temperature gradient improved fuel efficiency, ensured uniform firing, reduced thermal shock, and, as advancements in airflow regulation and heat distribution progressed, facilitated sustained production at a lower cost.

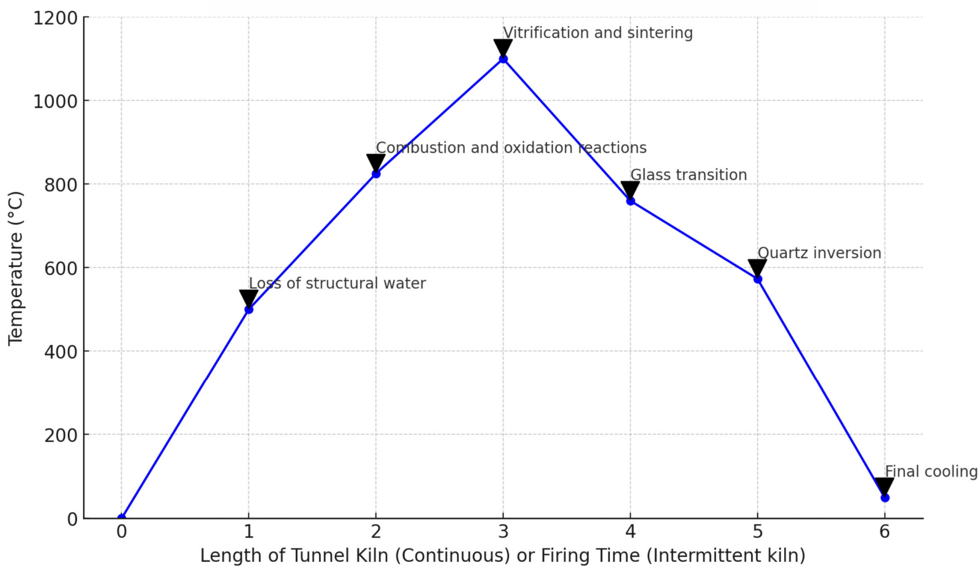

Fig. 3. Temperature Stages in a Tunnel Kiln (Figure by the author)

The preheating zone (50-1000°C) was where unfired ceramics were gradually heated by hot air and gases originating from the firing (1000-1300°C) and cooling zones (1300-50°C) which flowed counter to the direction of the moving wares. In the central firing zone, fuel compartments were strategically placed on the sides or top of the kiln to deliver direct heat to the kiln load. To vent exhaust, a chimney was positioned at either end of the kiln (Figs. 2, 3).[9]

Tunnel kilns typically ranged from 30 to 100 meters in length, with models predating the 1930s often measuring between 70 and 100 meters. Most were around three meters

9 In the cooling zone, the heat was reused via a draft of fresh air from the cooling end, often being redirected to a separate drying room via pipes. Alessandro Pedro Dadam and Vicente de Paulo Nicolau, "Numerical and Experimental Thermal Analysis of a Tunnel Kiln Used in Ceramic Production," *Journal of the Brazilian Society of Mechanical Science & Engineering* 31, no. 4 (2009): p. 297.

in height, and firing durations generally lasted between 40 to 60 hours, significantly shorter than the five to seven days required by large-scale down-draft kilns.[10] Inside the kiln, wares were transported on wheeled metal cars that moved along rails, with an average of 20 to 60 cars required for a single firing session.[11]

Despite these advancements over down-draft kilns, early tunnel kilns were not without flaws. The most significant issue was the uneven distribution of heat and gas, which failed to reach the wares in the center of the cars. To address this, dampers were refined from the 1910s onward, initially taking the form of narrower walls and lowered ceilings before evolving into mechanized systems integrated into the kiln's exterior. The most notable tunnel kiln models employing the aforementioned features were the Dressler (England), Harrop (America), and Kerabedarf (Germany) designs. These kilns would later be modified by Japanese engineers of the Morimura Group, making their distinctive features particularly significant for further study.

1) The British Dressler Kiln

Until the early 20th century, the United Kingdom's widespread usage of up-draft bottle kilns slowed the adoption of tunnel kilns, underscoring the influence of local and cultural industrial practices on technological advancements.[12] A significant turning point occurred in 1912 when potter Conrad Dressler (1856-1940) patented a muffle tunnel kiln for use in the northern pottery hub of Staffordshire (Fig. 4).[13]

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10 Singer and Singer, *Industrial Ceramics*, pp. 1028-30; Harry G. Seltzer, "Continuous Kilns in German Potteries," *Commerce Reports* 1, no. 60 (Minneapolis: Bureau of Foreign and Domestic Commerce, Department of Commerce, 1915), p. 1028.

11 Certain kiln models required fireproof boxes known as saggars to protect products from direct heat. Brown, "Clays and Shales," p. 79.

12 Pyŏngsŏn Pang 방병선, "Yŏngguk Bottŭl Obŭn(Bottle Oven) ŭi chejak kisul kwa pyŏnhyŏng koch'al" 영국 보틀 오븐(Bottle Oven)의 제작기술과 변형 고찰 [A Study on the English Bottle Oven's Production Technique and Change], *Misulsahak* 48 (August 2024): p. 51.

13 Conrad Dressler, Oven for Use in the Manufacture of Tiles, Pottery, and the Like, Patent No. US1023628 (A), filed 15 February 1911, and issued 16 April 1912; Yōichi Yamada 山田 陽一, "Ōkura Kazuchika ga sendō shita gijutsu kakushin: kindai tōjiki sangyō ni okeru tonneru kama dōnyū no kaishi" 大倉和親が先導した技術革新: 近代陶磁器

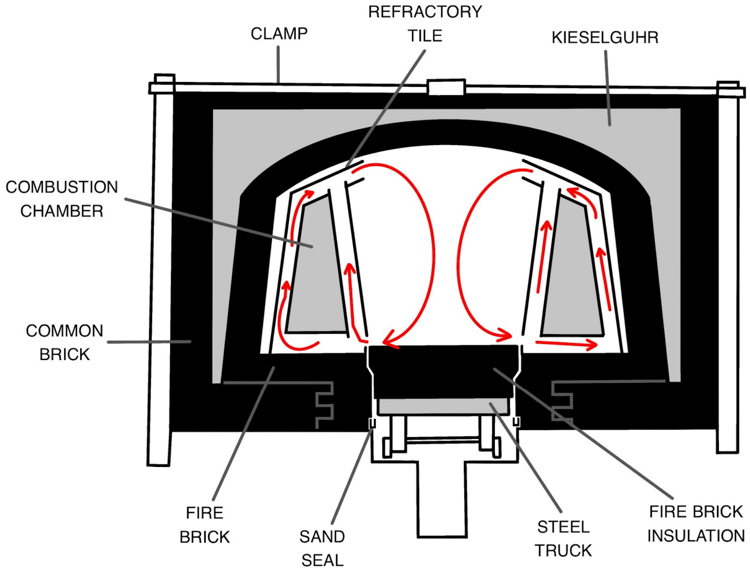

Fig. 4. Cross Section of a Muffle Tunnel Kiln (Figure by the author)

Early Dressler models measured approximately 70 meters long. Bisque firing, with 50 small to medium-sized pieces per cart, took nearly 42 hours for 24 carts, totaling approximately 1,200 pieces per session. In comparison, glost firing, with 350 small to medium-sized pieces per cart, required about 28 hours for 36 carts, totaling an estimate of 12,600 pieces per session.[14]

産業におけるトンネル窯導入の開始 [The Technological Innovation Led by Ōkura Kazuchika: The Introduction of Tunnel Kilns in the Modern Ceramic Industry], *Taishō Shōwa-ki ni okeru jūtaku kanren sangyō no tenkai to 'kurashi' no hen'yō ni kansuru sōgōteki kenkyū* Heisei 29-nen-dō Reiwa 2-nen-dō kagaku kenkyūhi hojokin (Kiban Kenkyū (B)) tōjiki-gyō han kenkyū seika hōkokusho (March 2021), p. 45.

14 Singer and Singer, *Industrial Ceramics*, p. 1053.

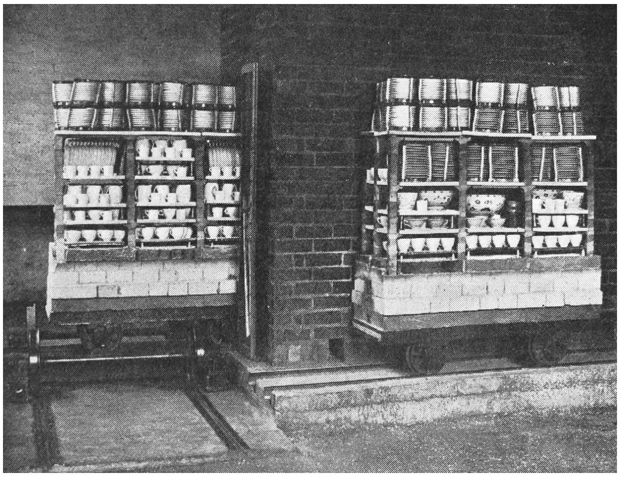

Fig. 5. Car Entering a Dressler Kiln at the Mintons Factory in Stoke-upon-Trent, England with Another in Waiting, 1936 (David Barker, "Developments in the Firing of Ceramics 1900-1939," *Northern Ceramic Society Journal* 37, p. 184)

Fig. 6. Villeroy & Boch, *Soup Tureens from the Winden Alt Mettlach 102-piece Dinner Set*, Early 20th Century, Porcelain (Courtesy of Bukowskis Auktioner AB)

The Dressler kiln's appeal lay in its muffle structure, which enabled it to maintain consistent internal temperatures and eliminate the need for saggars (Fig. 5). As a result, labor and material costs were significantly reduced. This made it particularly effective for firing large industrial products such as sanitary ware and tiles, and it was quickly adopted by leading European manufacturers such as Villeroy & Boch (est. 1836) in Mettlach, Germany (Fig. 6).[15] In contrast, Japanese engineers at Toyo Toki later adapted the Dressler design to run on heavy oil and utilize multi-burner systems, innovations that improved glost finishes and reduced discoloration. These modifications are discussed further in Section 4.1 ("The Dressler Kilns of Toyo Toki").

15 Philip Dressler (1893-1973), son of Conrad, introduced an expanded version of the kiln patented in 1920. Known as the American Dressler model, this design accommodated a wider variety of goods, including sanitary ware, industrial tiles, and tableware. George Brain, "The Dressler Kiln for Firing Sanitary Ware," *The Journal of the American Ceramic Society* 3, no. 9 (1920): p. 707; Philip Dressler, Tunnel-Kiln, Patent No. US1354541A, filed 22 January 1919, and issued 5 October 1920; Yamada, "The Technical," p. 56.

2) The American Harrop Kiln

In 1920, American engineer Carl Harrop (1880-1934) introduced a tunnel kiln with widened sidewalls that improved airflow and directed combustion gases downward to enhance heat consistency.[16] Early Harrop kilns, measuring approximately 100 meters long, processed one kiln car per hour, with glost firings lasting about 52 hours.[17] Until the end of World War II, they remained a favored model for large-scale ceramic production due to their durability, heat resistance, and reduced thermal shock.[18]

Fig. 7. Carl Tielsch and Co., *Bread or Dessert Plates with Pheasant Design*, 1920s, Porcelain (Courtesy of Edgebrook House)

One of the earliest adopters in Europe was the Carl Tielsch & Co. (est. 1845) porcelain factory in Altwasser, Silesia (today Wałbrzych, Poland) (Fig. 7). In the United States, Harrop kilns were mainly used in the industrial and refractory ceramic sectors. When introduced to Japan by NGK Insulators, the kilns were further modified to manufacture high-voltage insulators suited to Japan's rapidly expanding electrical infrastructure. These changes are examined in further detail

16 Magoemon Ezoe 江副 孫右衛門, "Gaishi shōsei-hō no kairyō ni tsuite" 碍子焼成法の改良に就て [Regarding Improvements in Insulator Firing] (Nagoya: NGK Insulators, 1929), p. 1. The Harrop kiln was directly influenced by the Faugeron kiln, developed in 1889 by French engineer Ernest Gabriel Faugeron (1869-1944). This kiln featured drop arches in the crown that acted as dampers, hollow perforated walls for gas distribution, and combustion chambers that generated an up-draft for even heating. Ernest Gabriel Faugeron, Process and Means for Firing Porcelain and Similar Products in Continuous Moving Hearth Kilns, UK Patent No. 13,386, issued 13 May 1899; Scott, Greenwood and Son, *The Pottery Gazette and Glass Trade Review* (London: Scott, Greenwood and Son, 1913), p. 114.

17 Harrop, "Modern Method," p. 4.

18 Nobutaka Odake and Yoichi Yamada, "Introduction of Tunnel Kiln in Modern Ceramic Industry: Technology Transfer and Improvement," *Proceedings of PICMET '13: Technology Management for Emerging Technologies* (2013), p. 2410.

in Section 4.2 ("The Harrop Kilns of NGK Insulators").

3) The German Kerabedarf Kiln

Invented in 1923 by German engineer Paul Gatzke (1895-?), the Kerabedarf kiln featured a multi-section muffle structure.[19] A fan system improved cooling by directing cold air over the wares, while recycled hot air powered around 20 gas burners to boost energy efficiency.[20] The kiln achieved fuel savings of up to 73% for fine ceramics and 70% for heavy ceramics compared to down-draft kilns. Its compact, 30-meter design with one-meter car spacing greatly minimized firing losses. Most models required 36 to 48 hours per glost firing, processing about 30 cars and 600-900 wares per session.[21]

Fig. 8. Rosenthal Porzellan AG, *Sanssouci 76-piece Dinnerware Set*, 1920-1930s, Porcelain (Courtesy of Bukowskis Auktioner AB)

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19 This division allowed for better control of the draft and more precise regulation of temperature throughout the kiln. Arthur Dodd, *Dictionary of Ceramics* 3rd ed. (London: The Institute of Materials, 1994), p. 221.; Ute Pothmann, *Arbeitsspuren - Lebensspuren* (Berlin: Berlin-Brandenburgisches Wirtschaftsarchive, n.d.), p. 27.

20 To prevent water deposits on cooling wares and mitigate sulfuric acid formation on the kiln's metal components, combustion gases were systematically removed at approximately 150°C before condensation or sulfur dioxide reaction could occur. This process was facilitated by the use of a tunnel dryer in line with the kiln, which supplied clean hot air and maintained the ware temperature between 120-150°C. Singer and Singer, *Industrial Ceramics*, p. 1042; British Intelligence Objectives Sub-committee, *B.I.O.S. Surveys Report-Issues 26-32* (London: H.M. Stationery Office, 1949), p. 111.

21 Singer and Singer, *Industrial Ceramics*, p. 1041.

During the interwar period, Kerabedarf kilns were adopted by major Western tableware manufacturers, including Rosenthal Porzellan AG (est. 1879) in Bavaria (Fig. 8). Noritake later refined the Kerabedarf model to mass-produce bone china and decorative wares tailored for export. As a result, Noritake's products soon ultimately surpassed the aesthetic and technical standards of Western porcelain in both scale and global appeal. More information on the changes made by Noritake engineers will be discussed in Section 4.3 ("The Kerabedarf Kilns of Noritake").

Ⅲ. The Evolution of Japan's Ceramics Industry During the Meiji Era

The late 19th century marked a pivotal period for the Japanese ceramics industry as the country transitioned from the Edo period (江戸, 1603-1868) to the Meiji period. Notably, the Treaty of Kanagawa (日米和親条約) of 1854 initiated a series of unequal trade agreements with Western powers such as the United States, France, the United Kingdom, Russia, and the Netherlands.[22] These agreements exposed Japan to economic disadvantages including trade imbalances, loss of tariff control, and increased foreign influence that undermined local industries. Foreign goods flooded the Japanese market, placing pressure on domestic production, and limiting Japan's ability to protect its industries. This economic strain fueled the Meiji Restoration of 1868 (明治維新), a state-led effort to modernize the nation and strengthen its economy in order to compete with dominant global powers. A central aspect of this transformation was industrialization, which was fueled by the adoption of foreign technologies and the shift from a primarily public-sector economy to one focused on private enterprise.[23]

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22 The Treaty of Kanagawa was signed between Japan and the United States. "Treaty of Kanagawa, 1854," *The Avalon Project: Documents in Law, History and Diplomacy*, Yale Law School, accessed April 8, 2025, https://avalon.law.yale.edu/19th_century/japan001.asp.

23 Hiroshi Ichihara, "The Human Resource Development, Occupational/Status-linked Personnel Management

Fig. 9. Gottfried Wagener, Late 19th Century (Toyokitsu Ueda, *Biography of Dr. Gottfried Wagener*)

Japan sought to assert its cultural influence by improving its ceramics industry, particularly as foreign fascination with Japanese decor under the "Japonisme" trend began to wane in favor of European Art Nouveau and Chinese craft art.[24] World exhibitions, such as the 1873 Vienna World Fair, played a crucial role in the country's shift toward modernization, as the events provided a platform for Japanese industrialists to study market dynamics and undertake training led by foreign experts.[25] Of the various beneficial influences stemming from these exhibitions, one of the most significant was German chemist Gottfried Wagener (1831-1892) (Fig. 9).

Wagener, who first arrived in Japan in 1868, introduced techniques to domestic manufacturers for improving underglaze and overglaze applications, as well as managing raw materials, while also teaching Ceramics at the Tokyo Industrial School (東京工業学校).[26] Wagener also recognized the abundant coal resources across Kyushu Island (九州) and subsequently encouraged the development of down-draft, coal-fired kilns as a sustainable and cost-effective alternative to Japan's traditional, wood-fired climbing kilns

Practices and Engineers in Japanese Corporations before the Second World War," *The East Asian Journal of British History* 5 (2016): p. 114; Tamaki Onishi, "Institutionalizing Japanese Philanthropy Beyond National and Sectoral Borders: Coevolution of Philanthropy and Corporate Philanthropy from the 1970s to 1990s," *International Journal of Voluntary and Nonprofit Organizations* (2016): p. 11.

24 'Japonisme' refers to the influence of Japanese art, design, and culture on Western art during the late 19th and early 20th centuries. Nobukata Kutsuzawa, "The 1873 Vienna World Exposition and Japan's Participation: Focusing on Japan's Industrial Promotion Policy in the Early Meiji Period," *Civilization* 23 (2018): p. 16.

25 Tai Wei Lim, "Interpretations of Japanese Modernity: A Case Study of Japan's Energy Transition in the Ceramics Industry," *Journal of Asian History* 47, no. 1 (2013): p. 116.

26 *Arita History and Folklore Museum East Arita Excavated Ceramic Museum: Museum Guidebook*, edited by Arita History and Folklore Museum (Arita: Arita Town Board of Education, 2022), p. 4.

(登り窯, *noborigama*).[27] His experimentation with a prototype kiln in the pottery hub of Arita (有田) marked one of the earliest efforts of the fuel source transition in Japan's ceramics industry (Fig. 10).[28]

Fig. 10. Wagener Coal Kiln Model (Courtesy of Arita History and Folklore Museum)

In the decades that followed, Japanese engineers and manufacturers built on Wagener's foundation by experimenting with new kiln configurations. Among these, the tunnel kiln stood out as a revolutionary advancement. One company that emerged as a leader during this period was the Morimura Group. Not only did the company establish a retail presence in the United States, but they also designed products tailored to the American market. Additionally, Morimura Group staff studied Western kiln technologies in order to improve domestic production methods and stabilize their role in the global market.

1. The Establishment of the Morimura Group

The Morimura Group was established in 1876 in Tokyo (東京) as an export wholesale company by brothers Ichizaemon Morimura VI (森村市左衛門, 1839-1919) and Toyo Morimura (森村豊, 1854-1899) (Fig. 11).[29] While facilitating exchanges of currency

27 Wagener's coal-fired kilns introduced a fire grate system where flames passed beneath the chamber floor, circulated through the ware chamber, and were vented through a chimney. Compared to climbing kilns, fuel costs were reduced by over 30%. Setsuo Sato, "Life of Dr Wagener and Japan in the Early Meiji Period (1)-(5)," *Tosetsu*, 1988, cited in Masumi Kimoto, "History: 400 Years of Arita Porcelain," *Arita Episode 2*, accessed April 10, 2025, http://arita-episode2.jp/history/history_13.html.

28 Tai Wei Lim, *Fired Clay in Four Porcelain Clusters: A Comparative Study of Energy Use, Production, Environmental Ecology, and Kiln Development in Arita, Hong Kong, Jingdezhen, and Yingge* (Lanham: University Press of America, 2014), pp. 44-45.

29 Kana Imakiire 今給黎 佳菜, "Morimura Gurūpu no hatten: Genzon suru Nichibei ōfuku shokan o chūshin ni" 森村グループの発展: 現存する日米往復書簡を中心に [The Development of the Morimura Group: Focusing on Existing Japan-US Correspondence], *Taishō Shōwa-ki ni okeru jūtaku kanren sangyō no tenkai to 'kurashi' no hen'yō ni*

Fig. 11. Toyo Morimura (Left) and Ichizaemon Morimura (Right), September 1889 (Courtesy of Morimura Bros., Inc.)

during the Edo period, Ichizaemon noted the disparity of finely crafted Japanese silver and gold being exchanged for copper-like Mexican dollars at a 150% profit margin.[30] Guided by the advice of entrepreneur Yukichi Fukuzawa (福澤 諭吉, 1835-1901), who urged that "the only way to retrieve the gold is by exporting goods from Japan," the brothers turned their attention to international trade.[31]

In November 1876, the Morimura Group established the Morimura Brothers retail shop in New York City for the sale of Japanese antiques.[32] By the 1880s, the company shifted

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kansuru sōgōteki kenkyū Heisei 29-nen-dō Reiwa 2-nen-dō kagaku kenkyūhi hojokin (Kiban Kenkyū (B)) tōjiki-gyō han kenkyū seika hōkokusho (March 2021), p. 113.

30 Yukio Sunagawa 砂川 幸雄, *Seito okoku o kizuita chichi to ko: Ōkura Magobei to Ōkura Kazuchika* 製陶王国をきずいた父と子: 大倉孫兵衛と大倉和親 [Father and Son Who Built the Ceramic Kingdom: Ōkura Magoebei and Ōkura Kazuchika] (Tokyo: Shōbunsha, 1989), p. 24.

31 Noritake Museum, *Noritake Museum: Nagoya, Japan* (Nagoya: Noritake, n.d.), p. 1.

its focus to ceramics after identifying a growing interest among American consumers for pure white porcelain typical of the Victorian era (1837-1901). At that time, however, no Japanese manufacturer had yet mastered the techniques or aesthetic preferences required for durable Western-style dinnerware. This gap created an urgent need not only for design innovation but also for industrial infrastructure capable of sustaining high-volume, high-quality output.

Although the first tunnel kiln in Japan would not be constructed by the Morimura Group until 1919, the company staff was already laying the groundwork for future mass production. In the 1880s and 1890s, they actively studied Western machinery, explored continuous firing systems, invested in scalable production facilities, and analyzed the material composition of Western tableware. Much of this initiative was led by Magobei Okura (大倉孫兵衛, 1843-1921), an early member of the company and brother-in-law to

Fig. 12. Magobei and Kazuchika Okura, Early 20th Century (Courtesy of Morimura Bros., Inc.)

32 Sunagawa, *Father and Son*, p. 31.

Ichizaemon, whose dedication to developing fine ceramics was mirrored by his son, Kazuchika Okura (大倉和親, 1875-1955) (Fig. 12).[33]

Recognizing the importance of proximity to ceramic production hubs and export docks, the Morimura Group opened an office in Nagoya (名古屋) in 1892, as well as a tableware production facility in 1894. Located near approximately 30 ceramic painting factories and the ancient pottery region of Tono (東濃), Nagoya quickly became a critical center for Morimura Group operations.[34] The surrounding Aichi (愛知県) and Gifu (岐阜県) prefectures were highly receptive to foreign technological advancements and would account for nearly 70% of Japan's dinnerware production from 1895 until the end of World War II.[35] This early groundwork laid the foundation for the Morimura Group to adopt tunnel kiln technology, which would become a defining moment in the industrialization of Japan's ceramic sector.

Ⅳ. Adoption and Advancement of Tunnel Kilns by the Morimura Group

By the early 20th century, widespread reliance on traditional down-draft round kilns presented a significant setback in mass production, as each firing cycle could take up to two weeks to complete. For an industrial-sized kiln, this meant producing anywhere from 30,000 to 80,000 pieces of tableware per batch.[36] The inefficiency of batch firing meant that factories had long periods of inactivity between firings, limiting output and

33 Bayside Antique and Collectibles Centre, "Noritake at Bayside," *Antiques and Art in Queensland* (2012): p. 49.

34 By July 1898, six prominent Tokyo painting factories (Kawahara [河原], Sugimura [杉村], Iguchi [井口], Fujimura [藤村], Ota [太田], Andachi [安立]) joined forces with the Saigo Factory (西鄕工場) from Nagoya and the Ishida Factory (石田工場) from Kyoto (京都) at the Nagoya site. Sunagawa, *Father and Son*, p. 47.

35 Many potters streamlined operations by selling semi-finished goods to Nagoya and Seto (瀬戸) wholesalers, leveraging their proximity to major export ports. Yoshie Itani, "Export Porcelain from Seto in the Meiji Era: The Development of Noritake Porcelain in the Context of the Japanese Ceramics of the Meiji Period" (PhD diss., University of Oxford, 2005), p. 17.

36 Singer and Singer, *Industrial Ceramics*, p. 998, table 228.

making it difficult to meet growing export demands. As a comparison, a tunnel kiln measuring anywhere between 50 and 70 meters long could fire approximately 200,000 wares for glost firing in just over 24 hours.[37]

Recognizing the need for more advanced firing methods, the Morimura Group sought expertise from Western experts. In 1902, English chemists and brothers Louis and Alfred Rosenfeld (dates unknown) traveled to Nagoya with the intention of studying Japan's gold dot relief technique (金盛絵, *kin mori-e*) which was commonly used on decorative porcelain.[38] In exchange for guidance on the technique and in establishing a Japanese retail shop in London, the Rosenfeld brothers allowed Morimura Group staff to inspect their modern factories in Stoke-on-Trent, England, and Karlsbad, Austria.[39]

The following year, Magobei Okura, Kazuchika Okura, Morimura Brothers store manager Yasukata Murai (村井保固, 1854-1936), and engineer Kotaro Asukai (飛鳥井孝太郎, 1867-1927) visited the Rosenfeld factories to learn about tunnel kilns. However, as most tunnel kilns were still in the experimental phase at this time, the Morimura team was unable to see one in operation.[40] Instead, Okura secured the rights to Thuringian down-draft round kilns, which were later adopted when the company

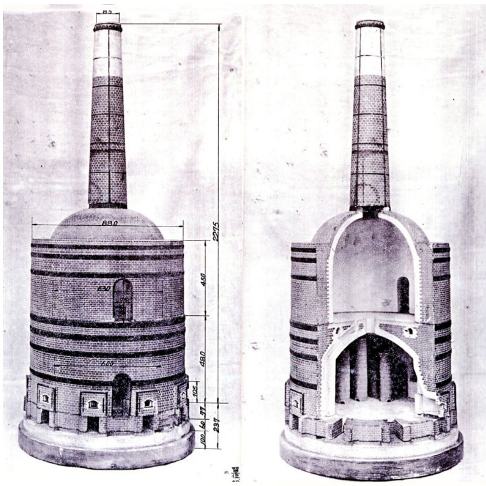

Fig. 13. Noritake Thuringian Down-draft Round Kiln, 1904 (Courtesy of Noritake)

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37 Ibid., p. 1062, table 236.

38 Yukio Sunagawa 砂川 幸雄, *Morimura Ichizaemon no muyoku no shōgai* 森村市左衛門の無欲の生涯 [The Selfless Life of Morimura Ichizaemon] (Tokyo: Shōbunsha, 1998), p. 115.

39 The Stoke-on-Trent factory was called Empire Porcelain (est. 1896), while the Karlsbad factory was Victoria Porzellan (est. 1883). Yamada, "The Technological," p. 46; Benedict Rosenfeld, "Lazarus & Rosenfeld," *The London Gazette* (1895).

40 Aichi Prefectural Ceramic Museum Curatorial Department, *Pottery and Japanese Modernization: The 100 Years History of Noritake China* (Seto: Aichi Prefectural Ceramic Museum, 2003), p. 100; TOTO, *Guide to TOTO* (Kitakyushu: TOTO, 2013), p. 82.

established its tableware production facility in Nagoya on January 1, 1904 (Fig. 13).[41] This facility was reorganized as Nippon Toki Gomei Kaisha (henceforth referred to as Noritake) with Kazuchika Okura serving as its first president.

Nearly a decade later, further advancements in tunnel kiln technology began to shape the Morimura Group's production capabilities. In 1912, Kazuchika Okura (henceforth referred to as Okura) and Research and Development manager Magoemon Ezoe (江副孫右衛門, 1885-1964) witnessed a functioning tunnel kiln at Carl Tielsch & Co. that produced white porcelain with up to 50% greater fuel efficiency than Noritake's down-draft round kilns.[42] The following year, Okura visited the German engineering company Schultze to observe another tunnel kiln that functioned in a reduced atmosphere, albeit with slight yellow discoloration appearing on the glaze. Morimura Group executives were unwilling to invest in imperfect technology and chose not to adopt the Schultze kiln at that time. Nevertheless, Noritake found success with its existing down-draft round kilns, successfully producing Japan's first dinnerware set, known as 'SEDAN', in 1914 (Fig. 14).[43]

Fig. 14. Noritake, *SEDAN Dinnerware Set*, 1914, Porcelain, Noritake Museum (Photograph by the author)

41 Yamada, "The Technical," p. 46.
42 Odake and Yamada, "Introduction," p. 2409.
43 Yoshie Itani, "Westernization of Japanese Food Culture and Export Porcelain in the Meiji Era," *The Bulletin of the International Society for Harmonization of Cultures & Civilizations* 6 (2005): p. 75.

During a research trip to Europe and the United States in 1915, Okura and Noritake Chief Engineer Momoki Saburo (百木三郎, 1880-1940) observed variations of the Dressler tunnel kiln that were employed by several sanitary ware manufacturers.[44] Convinced of the kiln's broader applications beyond tableware, Okura sought to acquire the Dressler kiln patent. However, the Morimura Group executives repeatedly declined due to the kiln's exorbitant cost of £10,000 GBP (approx. $6 million USD today). Determined to modernize production and expand Noritake's product line, Okura personally funded the purchase in 1918, marking the beginning of the Morimura Group's lasting relationship with tunnel kiln technology.[45]

The following sections chronologically examine the pivotal roles of the Dressler, Harrop, and Kerabedarf tunnel kilns in enhancing production rates, fuel economy, and product quality within the Morimura Group's three main ceramic companies: Toyo Toki, NGK Insulators, and Noritake (Table 2). Specifications of and advancements made to each kiln by Japanese engineers provide the foundation for an in-depth analysis of growth within the country's ceramic industry in the early 20th century.

〈Table 2〉 Comparison of Morimura Group Tunnel Kilns (Source: Odake and Yamada, "Introduction," p. 2412)

	TOYO TOKI	NGK INSULATORS	NORITAKE
Kiln Type	Dressler (England)	Harrop (USA)	Kerabedarf (Germany)
Installation Year	1920	1928	1934
Supervision	Rushton (England)	Perry (USA)	Japanese
Length	107.5m	120m	78.7m
No. of Burners	4	14	20
Fuel	Producer Gas	Heavy Oil	Producer Gas
Products	Sanitary Ware	Insulators	Tableware, Decorative

44 Odake and Yamada, "Introduction," p. 2409.
45 Sunagawa, *The Selfless*, p. 225.

Heating	Indirect	Direct	Direct
Atmosphere	Oxidizing	Reducing	Reducing
Saggar	Without	Without	With

1. The Dressler Kilns of Toyo Toki

At the start of the 20th century, sanitary facilities in Japan were primarily outdoor squatting toilets without a sewage system.[46] Motivated to improve hygiene facilities, Okura established a sanitary ware laboratory at Noritake in 1912. By 1914, the company had created the country's first seated flush toilet which led to the establishment of the Toyo Toki sanitary ware factory in Kitakyushu (北九州) in 1917.[47]

Fig. 15. Toyo Toki Staff and H. J. Rushton (Second from Right), 1920 (Courtesy of TOTO)
Fig. 16. Construction of the Dressler Kiln, 1918 (Courtesy of TOTO)

46 Olga Khomenko, "TOTO Group - The Sword, the Cup and the Toilet: A Story of Never Giving Up," *Japan Marketing History Review* 1, no. 1 (2022): p. 123.

47 Aichi Prefectural, *Pottery and Japanese Modernization*, p. 9.

Initially, Toyo Toki relied on British down-draft round kilns for production. In January 1919, English engineer H. J. Rushton (full name and dates unknown) visited the factory to provide guidance on the construction of a 107.5-meter-long Dressler kiln which had started a year prior (Figs. 15, 16).[48] This new installation reduced fuel consumption by 64% compared to previous down-draft kilns. After extensive testing, the kiln was officially installed in 1922. The system demonstrated improved firing consistency and eliminated heat damage to metal components, though slight discoloration remained due to firing in a reduced atmosphere.[49]

To meet the rising demand for durable sanitary ware after the 1923 Great Kanto Earthquake (関東大震災), Toyo Toki installed a second Dressler kiln in the same year and a third in 1926.[50] Before the installation of the third kiln, Toyo Toki engineer Reizo Tsuboi (坪井礼三, dates unknown) traveled to Europe to study the latest Dressler kiln advancements. His goal was not to adopt Western methods directly, but to identify areas for improvement.[51] Confident in Japan's engineering potential, he aimed to surpass foreign designs rather than wait for their refinement.

By 1931, Tsuboi had refined the Dressler kiln's burner chamber with a multi-burner configuration that allowed for more even firing. Additionally, the kiln's fuel source was switched from coal to heavy oil to improve ware cleanliness and reduce air pollution. Heavy oil also provided more consistent pricing and availability while maintaining efficiency levels similar to those of coal.[52] As Tsuboi refined the Dressler kiln, Okura was simultaneously laying the groundwork for the installation of tunnel kilns dedicated to industrial ceramics production.

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48 TOTO, *TOTO Hyakunenshi* TOTO 百年史 [TOTO 100-Year History] (Kitakyushu: TOTO, 2023), p. 65.

49 In reduced firing, oxygen is limited, causing chemical changes that can darken glazes or alter colors. In contrast, oxidized firing allows plenty of oxygen into the kiln, which produces bright, clean colors. Odake and Yamada, "Introduction," p. 2410.

50 Sunagawa, *The Selfless*, p. 220.

51 Odake and Yamada, "Introduction," p. 2410.

52 Kusuyata Tanaka 田中 楠彌太, "Tōen gama ni okeru dennetsu kikō to jūyu nenshō" 倒焔窯における伝熱機構と重油燃焼 [Heat Transfer Mechanisms and Heavy Oil Combustion in Downdraft Kilns], *Shigen gijutsu shikenjo* (1953): p. 336.

2. The Harrop Kilns of NGK Insulators

During the Meiji period, the widespread adoption of electricity in Japan created the demand for domestically produced high-voltage insulators. Although insulators had been manufactured in traditional ceramic centers such as Arita, Seto (瀬戸), and Aizu (会津) from the early Meiji period, no company specialized in domestic production.[53] In response to this need, engineer Keijiro Kishi (岸 敬二郎, 1867-1927) collected ceramic fragments from American insulator manufacturer R. Thomas & Sons (est. 1892) during a visit to the United States in the early 20th century.[54] These fragments formed the basis of his research on producing high-quality domestic insulators, which he pursued in collaboration with Okura. Their efforts eventually led to the establishment of NGK Insulators (日本碍子株式会社) in Nagoya in 1919.[55]

Like other Morimura Group companies, NGK Insulators initially relied on down-draft round kilns for production. By 1927, Magoemon Ezoe and engineer Kichijiro Yamada (山田吉次郎, dates unknown), recognized the potential of the Harrop tunnel kiln during a research trip to the United States. The following year, an American technician by the surname of Perry (full name and dates unknown) assisted NGK Insulators in constructing a Harrop kiln for approximately ¥322,000 JPY (approx. $152,000 USD today).[56] The 120-meter-long kiln was first fired in December 1928 and achieved a yield rate of 92%, a notable improvement over the 88% yield rate from previous down-draft kilns.[57]

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53 Yōichi Yamada 山田 陽一, "Noritake ni okeru seramikkusu to ro no gijutsushi" ノリタケにおけるセラミックスと炉の技術史 [The History of Ceramics and Kiln Technology at Noritake], Presentation at the Japan Ceramic Industry Promotion Association, *New Ceramics Forum*, Saga Ceramics Technology Center (August 28, 2016).

54 Kishi, formerly the managing director of Shibaura Engineering Works (芝浦製作所, est. 1875), began collaborating with Noritake to produce insulators. Sunagawa, *Father and Son*, p. 150.

55 NGK Insulators, *NGK Report* (NGK Insulators: Nagoya, 2017), p. 7.

56 Morimura Bros., Inc., "Nippon Gaishi kessan gaishi keiei uchiwake-hyō, uriage-daka jun'i hyō, tonneru kama kensetsu uchiwake-hyō" 日本碍子決算 碍子経営内訳表､売上高順位表 トンネル窯建設内訳表 [Nippon Gaishi Financial Statement, Nippon Gaishi Management Breakdown Table, Sales Ranking Table, Tunnel Kiln Construction Breakdown Table], D4-2 (Tokyo: Morimura Bros., Inc. Archives, 1922-1934).

57 "Yield rate" refers to the percentage of ceramic products that were successfully fired without defects during a kiln cycle. Sunagawa, *Father and Son*, p. 169.

Despite the success of the new tunnel kiln, Ezoe and Yamada introduced several modifications to further enhance production quality. The kiln's oxidizing atmosphere was adapted to function in either an oxidizing or reducing atmosphere. Airflow was regulated by injecting air from the first burner position in the firing zone to prevent excessive carbon monoxide buildup in the preheating zone. Additionally, the burners were repositioned to face one another, resulting in more even heat distribution, improved combustion efficiency, and better atmospheric control.[58] By 1938, NGK Insulators had installed three more Harrop kilns to solidify the technology's role in Japan's industrial ceramics sector.

3. The Kerabedarf Kilns of Noritake

With an influx of production ranging from 2,000 dinnerware sets in 1914 to 11,000 sets by 1916, Noritake was forced to expand its existing down-draft kilns from 15 to 28 in 1917.[59] By 1920, production exceeded 60,000 sets, and Noritake captured the largest share of the United States' imported ceramics market, surpassing British and German factories for the first time in history.[60] The rapid surge in demand, coupled with the proven success of tunnel kilns at Toyo Toki and NGK Insulators, prompted Okura to initiate plans for the installation of Kerabedarf kilns at Noritake.

The idea of constructing a Kerabedarf model for the tableware factory first emerged in 1929 during a European and American research tour by Noritake engineers Yaroku Harada (原田弥六, dates unknown) and Jiro Ishikawa (石川次郎, dates unknown).[61] This was part of a larger modernization plan spanning from 1933 to 1940, spearheaded by Noritake's second president Ippei Iino (飯野逸平, 1884-1963).[62] The objective was to

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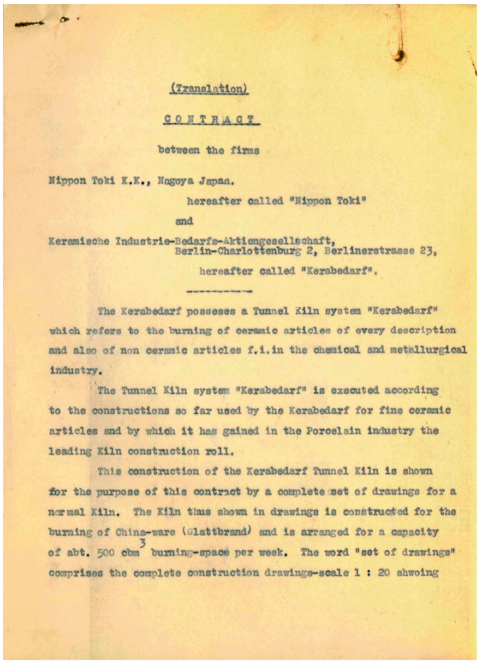
58 Odake and Yamada, "Introduction," p. 2410.
59 Yamada, "The Technological," p. 46.
60 Imakiire, "The Development," p. 114.
61 Sunagawa, *The Selfless*, p. 215.
62 Iino served as president of Noritake from 1939 to 1942. Imakiire, "The Development," p. 125.


(Translation)

CONTRACT

between the firms

Nippon Toki K.K., Nagoya Japan.

hereafter called "Nippon Toki"

and

Keramische Industrie-Bedarfs-Aktiengesellschaft,
Berlin-Charlottenburg 2, Berlinerstrasse 23,

hereafter called "Kerabedarf".

The Kerabedarf posseses a Tunnel Kiln system "Kerabedarf" which refers to the burning of ceramic articles of every description and also of non ceramic articles f.i.in the chemical and metallurgical industry.

The Tunnel Kiln system "Kerabedarf" is executed according to the constructions so far used by the Kerabedarf for fine ceramic articles and by which it has gained in the Porcelain industry the leading Kiln construction roll.

This construction of the Kerabedarf Tunnel Kiln is shown for the purpose of this contract by a complete set of drawings for a normal Kiln. The Kiln thus shown in drawings is constructed for the burning of China-ware (Glattbrand) and is arranged for a capacity of abt. 500 cbm³ burning-space per week. The word "set of drawings" comprises the complete construction drawings-scale 1 : 20 shwoing

Fig. 17. English Contract Between Noritake and Kerabedarf Regarding a Tunnel Kiln Patent, 1930 (Courtesy of Morimura Bros., Inc.)

mechanize production to become the first ceramic factory in Japan to produce bone china. The initial layout was comprised of two glost firing tunnel kilns and one bisque firing tunnel kiln for an approximate cost of ¥48,000 JPY (approx. $404,000 USD today).

By early 1930, Noritake sought to secure a license from the German firm Keramische Industrie-Bedarfs-Aktiengesellschaft (henceforth referred to as Kerabedarf) to construct their specific models (Fig. 17). Under the initial contract, Kerabedarf agreed to provide detailed technical drawings, construction guidance, and long-term consultation in exchange for an upfront payment of RM 100,000 (approx. $450,000 USD today).[63] At this time, Noritake had already secured a patent transfer agreement for a Kerabedarf kiln with the proposed arbitrator Leybold (レイボルド株式会社, est. 1850), a joint Japanese-German machinery trading company. Although Kerabedarf kilns were built with high-quality refractory materials and efficient insulation that improved heat retention and distribution, they were prone to interior damage and ware defects due to uneven carbon monoxide flow. Aware of these challenges, Noritake attempted to renegotiate several contract terms, seeking broader licensing rights, the removal of additional fees for modified kiln designs, and greater autonomy in technical adjustments.[64]

63 Noritake, Kerakerun to no keiyakusho ケラケルンとの契約書 [Contract with Keramische Industrie-Bedarfs-Aktiengesellschaft], D3-23 (Tokyo: Morimura Bros. Inc. Archives, 1930), no. 2.

64 Ibid., no. 1-9.

Negotiations became further complicated when Noritake learned that the General Kiln & Furnace Corporation of the United States had allegedly secured exclusive rights to Kerabedarf kilns outside of Europe in late 1929, casting doubt on the legitimacy of their agreement (Fig. 18).[65] In 1933, Noritake purchased only a sketch of the kiln rather than the full set of technical drawings.[66] By 1934, Noritake had successfully constructed a Kerabedarf-style tunnel kiln measuring 78.7 meters in length, marking the first time the Morimura Group completed a tunnel kiln without Western engineering assistance.[67]

Fig. 18. Entrance View of a Noritake Kerabedarf Kiln, After 1940 (Courtesy of Noritake)

The first major innovation led by Harada and Ishikawa was the injection of fresh air at the boundary between the preheating and firing zones to ensure the complete combustion of carbon monoxide generated in the firing zone's reduced atmosphere (Fig. 19). A fan-controlled carbon monoxide zone in the firing chamber helped direct fresh air between the preheating and firing zones. Without this fan, carbon monoxide would flow into the preheating zone, raising its temperature excessively and disrupting kiln efficiency.[68] This measure prevented the reducing flame from entering the preheating zone, maintaining a distinct oxidizing environment.

65 Ibid., no. 2.
66 Odake and Yamada, "Introduction," p. 2410.
67 Imakiire, "The Development," p. 124.
68 Yamada, "The Technological," p. 50.

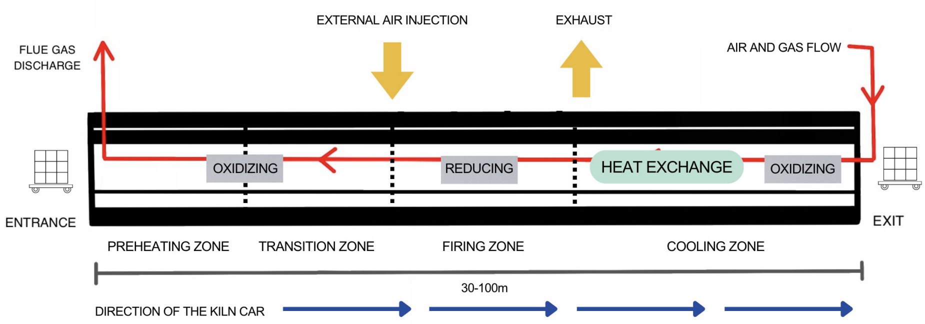


Fig. 19. Features of a Reduced Flame Tunnel Kiln (Figure by the author)

The fresh air injection system required precise adjustments, as even a 0.5-1mm change could significantly alter the airflow. Introduced at around 20°C, small amounts of fresh air had a noticeable impact on the kiln atmosphere, ensuring the firing zone maintained its reducing environment while the preheating and cooling zones operated as oxidizing environments. This approach was also applied at the exit of the cooling zone, where fresh air was introduced and combustion gases were partially extracted, contributing to overall atmospheric control throughout the kiln.[69]

In addition to the air injection system, structural improvements optimized airflow and gas pressure regulation. For instance, opening a damper too much prevented the glaze from melting properly. These adjustments eliminated the backflow of flames into the cooling zone and improved the kiln's thermal efficiency. Furthermore, the carbon monoxide concentration in the firing zone was reduced to 3%, significantly lower than the industry standard of 7% for ceramic firing.[70] As a result, a single Kerabedarf kiln could achieve the same output as six traditional down-draft round kilns.[71]

By 1938, Noritake had constructed a mass production plant that included four tunnel

69 Noritake adopted the Askania control system from Czechoslovakia to stabilize furnace pressure by regulating gas supply and flue drafts to resolve issues with reducing flame control in the preheating and cooling sections in order for the glaze to properly melt. Ibid., p. 50.
70 Yamada, "The Technological," p. 50.
71 Odake and Yamada, "Introduction," pp. 2410-2411.

kilns for glost firing and three for bisque firing, leading to the deconstruction of all 28 multi-layer round kilns.[72] The engineering advancements implemented at the facility soon attracted the attention of Kerabedarf, which sent personnel to inspect the modifications. Their request was denied, as Noritake sought to maintain exclusive control over its high-quality reducing atmospheric tunnel kiln.[73] This case illustrates a moment of reverse technological transfer, in which Japanese innovations in kiln design began to influence their European counterparts.

4. The Expansion of Tunnel Kilns in Japan

The remarkable innovations of Morimura Group engineers, combined with Kazuchika Okura's unwavering commitment to high-quality production, propelled the company to become Japan's largest export wholesaler from the early 20th century until the outbreak of World War II. During this period, ceramics dominated Western markets and emerged as Japan's leading export from 1868 to 1939.[74] The integration of tunnel kilns within the Morimura Group's operations provided a strong foundation for sustained industrial growth.

Notably, Noritake achieved remarkable growth in the late 1930s, employing over 4,000 workers in its decorative painting departments, a significant increase from the total workforce of 2,000 in 1917.[75] Toyo Toki also opened a second manufacturing facility in

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72 Odake and Yamada, "Introduction," p. 2411. Noritake implemented a new coal gas generator that integrated technological features from Wellman-Seaver (USA) and Power Gas (UK). Various automatic machines were introduced to enhance production efficiency, streamlining operations from raw material grinding to final product packaging. In 1935, these advancements culminated in the official development of Noritake's bone china. Yamada, "The History."

73 Tanehiko Koide 小出 種彦, "Yushutsu Tōjiki Monogatari" 輸出陶磁器物語 [The Story of Exported Ceramics], *Bōeki no Nihon* (1958-1959), n.p.

74 The outbreak of the Second Sino-Japanese War (日中戦争, 1937-1945) halted the majority of exports in Japan until the end of World War II. Richard J. Schonberger, "Japanese Manufacturing Techniques: Nine Hidden Lessons in Simplicity," *Operations Management Review* 1, no. 3 (1983): p. 13; Aichi Prefectural, *Pottery and Japanese Modernization*, p. 88.

75 Sung Jae Koh, "The Place of the Pottery and Porcelain in East Asian History," *Journal of Korean Studies* 1, no. 1

Fig. 20. Noritake, *Dinner Set* (Formerly Owned by the Okura Family), 1934, Porcelain. Noritake Museum (Photograph by the author)

Chigasaki (茅ヶ崎) in 1937, while NGK Insulators made major advancements in acid-resistant porcelain and automotive and aircraft spark plugs, culminating in the establishment of NGK Spark Plug (日本特殊陶業株式会社, now Niterra) in 1936.[76] Through responsiveness to market demands and resilience amid geopolitical challenges, the Morimura Group played a pivotal role in strengthening Japan's industrial capabilities (Fig. 20).

The introduction of tunnel kiln technology to Japan was not merely a technical upgrade. Instead, it reshaped the ceramic industry's production structure, labor demands, and regional distribution. While early adoption remained confined to major firms with sufficient capital and technical expertise, the decades that followed saw the gradual diffusion, adaptation, and eventual standardization of this technology. The prewar concentration of tunnel kilns among heavy industry leaders, the postwar reconfiguration of production in response to fuel shortages, and the eventual shift toward domestically developed, medium-scale kilns collectively made mechanized ceramic manufacturing more widely accessible.

By the 1930s, tunnel kilns had expanded beyond the Morimura Group to other sectors of Japan's ceramics industry, but adoption was primarily limited to capital-intensive enterprises. The refractory industry, closely aligned with the growth of steel and construction sectors, was an early beneficiary. In 1934, Japan Iron & Steel (日本製鐵株式会社) in Kitakyushu pioneered the use of a 140.5-meter-long German Dressler tunnel kiln

(1969): p. 161; Bayside Antique and Collectibles Centre, "Noritake," p. 49.

76 By 1935, approximately 12% of NGK Insualtors' products were being exported overseas. Sunagawa, *The Selfless*, p. 229.

for refractory brick production. Soon after, Shinagawa Refractories (品川リフラクトリーズ株式会社, est. 1875) in Tokyo, Osaka Yogyo (大阪窯業株式会社, est. 1882) in Osaka (大阪), and Shofuku Industries (松風工業, est. 1917) in Kyoto (京都) integrated tunnel kilns into their operations.

The tile industry also saw major advancements in 1934, when MS Tile Works (月星建陶社, founded prior to 1926) constructed an oil-fired Harrop kiln entirely under the guidance of Japanese engineers. Similarly, Saji Tile Works (佐治タイル, founded prior to 1930) collaborated with the German Dressler company to build a direct-flame tunnel kiln for rigid tiles and a semi-muffle model for glazed tiles in 1937. That same year, Morimura Group-owned Ina Seito (伊奈製陶株式会社, est. 1924, now INAX) constructed a Kerabedarf kiln with a coal gas producer.[77] However, these developments remained clustered within larger firms that could afford foreign engineers or import advanced components. Smaller firms, lacking access to such capital, continued to rely on climbing or down-draft kilns.

While prewar expansion in the wider tableware market promise, the outbreak of World War II stalled technological dissemination in the industry. Notably, Nagoya Seito Sho (名古屋製陶所株式会社, est. 1908) began constructing a Dressler kiln in the late 1930s with assistance from a German engineer, but the project remained unfinished when World War II broke out in 1939. By that time, approximately 50 tunnel kilns were in operation across Japan's refractory and ceramics industries. Post-war fuel shortages caused this number to drop to 32 by 1952, forcing smaller manufacturers to rely on rationed firewood and coal for fuel. Consequently, traditional kilns and coal-fired periodic kilns remained in regular use until after the war. By the 1950s, the industry standard had shifted mostly to 30-meter Harrop tunnel kilns powered by heavy oil.[78]

Another key standardization occurred in 1953, when an engineer by the surname of Suzuki (鈴木, full name and dates unknown) began constructing medium-sized tunnel

77 Odake and Yamada, "Introduction," p. 2413.
78 Ibid., p. 2414.

kilns (approx. 50 to 70 meters) at Takasago Industry (高砂工業株式会社, est. 1953), specifically designed for tableware production in the Tono region. As demand for smaller kilns increased after the war, Takasago met this domestic need while also assisting Japanese manufacturers in optimizing their production processes. As a result, Takasago became the country's largest producer of tunnel kilns and were responsible for the first exports of Japanese-made tunnel kilns abroad.[79] While the Morimura Group's contributions are undeniable—as the first to introduce and improve tunnel kiln technology in Japan—it was Takasago that transformed these advancements into a commercially viable product. By producing the technology domestically and making it accessible to a wider range of manufacturers, Takasago played a pivotal role in expanding its use and ultimately paved the way for innovations such as roller hearth kilns.[80]

By the latter half of the 20th century, tunnel kilns were gradually supplanted by roller hearth kilns, which offered faster firing cycles and greater adaptability to changing product types. Yet this transition did not diminish the importance of tunnel kilns. From concentrated prewar investments to postwar standardization and regional empowerment, tunnel kilns served as a bridge between traditional craftsmanship and modern industrial ceramics.

V. Conclusion

The adoption and advancement of tunnel kiln technology played a pivotal role in the industrialization of Japan's ceramics industry from the Meiji era through the mid-20th century. Initially developed in Europe and America, tunnel kilns underwent significant

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79 Ibid., p. 2414.

80 A roller hearth kiln is a continuously firing kiln that features a series of rotating rollers that transport ceramic products through the kiln in a linear motion similarly to a tunnel kiln. George Bickley Remmey Jr., *Firing Ceramics* (Hackensack: World Scientific, 1994), p. 132.

refinements in Japan through the efforts of Morimura Group companies Toyo Toki, NGK Insulators, and Noritake. Tunnel kilns not only enhanced production efficiency but also set new benchmarks in product quality and manufacturing scalability. By integrating the Dressler, Harrop, and Kerabedarf kiln models into domestic production, Morimura Group engineers optimized firing conditions, reduced thermal inconsistencies, and improved overall manufacturing output.

Throughout the early 20th century, Japan's implementation of tunnel kiln technology positioned it as a dominant force in the global ceramics trade. The Morimura Group demonstrated an unparalleled ability to blend foreign technological advancements with local expertise, fostering an era of rapid industrial growth before World War II. This transformation, however, was not without challenges. The financial and technical demands of tunnel kilns largely confined their adoption to major enterprises across Japan, leaving small and medium-sized manufacturers reliant on older periodic kiln models until post-war economic stabilization enabled broader diffusion. Nevertheless, the successful adaptation of tunnel kilns helped Japan surpass Western competitors in the ceramics export market.

This paper emphasizes the crucial role of tunnel kilns in shaping Japan's ceramics industry and their broader influence on global kiln technology advancements. Future research should explore the socio-economic impacts of this industrial shift, particularly its effect on traditional artisans and the role of technological transfer in regions colonized by Japan, such as the Korean Peninsula and China. Additionally, this work highlights the value of interdisciplinary research, especially the collaboration between art history and the sciences, in enriching our understanding of how innovation influences both creative expression and large-scale production. By examining the relationship between past advancements and modern manufacturing needs, we gain a deeper appreciation for the enduring impact of tunnel kilns and their role in shaping global ceramics.

* 주제어(keywords)_ 터널가마(tunnel kilns), 森村グループ(Morimura Group), ノリタケ陶器(Noritake ceramics), 산업혁명 도자기(industrial revolution ceramics), 明治(Meiji Era), 大倉和親(Kazuchika Okura), 도자기 기술 이전(ceramic technology transfer), 가마 설계(kiln design), 일본 도자기 산업(Japanese ceramic industry), 大正(Taishō Era), 初期昭和時代(Early Shōwa Era)

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국문초록

본 논문 「20세기 초 일본 도자 산업에서 터널 가마의 도입과 영향」은 터널 가마가 일본 도자기 생산의 산업화에 있어 중추적인 역할을 수행했음을 고찰한다. 특히 메이지(明治, 1868~1912), 다이쇼(大正, 1912~1926), 쇼와(昭和) 초기(1926~1945) 시기를 중심으로 기술적 발전과 산업 구조 변화의 흐름을 추적한다. 서구에서 발전한 가마 기술에 대한 분석을 출발점으로 하여, 일본 내 터널 가마의 도입 및 개량 과정을 살펴보며, 노리타케(ノリタケ, Noritake), 토요토키(東洋陶器, TOTO), NGK 인슐레이터스(NGKインシュレーターズ, NGK Insulators)를 포함한 모리무라 그룹(森村組)의 주력 계열사가 이룬 중요한 공헌을 중점적으로 조명한다.

간헐적이고 노동 집약적인 전통 가마에서 연속 소성 방식의 터널 가마로의 전환은 도자기 생산의 효율성과 대량 생산 규모 모두에 근본적인 변화를 가져왔다. 수출 전문 상사였던 모리무라 그룹(森村組, Morimura group)은 영국의 드레슬러(Dressler), 미국의 해롭(Harrop), 독일의 케라베다르프(Kerabedarf) 등 유럽식 터널 가마 모델을 일본 실정에 맞게 정교하게 개선하는 데 핵심적인 역할을 했다. 이들은 공기 흐름 및 연소 제어 기술을 조정하여 연료 효율을 높이고 온도 분포의 균일성을 확보하는 등 여러 기술적 진보를 이루어냈고, 그 결과 생산 비용과 소성 시간이 대폭 절감되었다. 이러한 기술 혁신을 통해 일본 내 도자 기업들은 처음으로 고급 도자기, 위생 도기, 절연체 등 고품질 제품을 대량 생산할 수 있게 되었다.

본 논문은 주요 터널 가마 모델과 그 개량 사례에 대한 구체적인 분석을 통해, 터널 가마 기술이 20세기 초 일본이 세계 도자기 산업의 선두 주자로 도약하는 데 어떤 역할을 했는지를 규명한다. 아울러 제2차 세계대전(1939~1945) 전후를 전후한 시기, 높은 초기 투자 비용과 넓은 부지 확보의 어려움으로 인해 중소 규모 제조업체들이 겪은 도입상의 어려움도 함께 조명한다. 그럼에도 불구하고 터널 가마의 확산은 일본 산업용 도자기 분야의 성장을 견인하는 토대를 마련하였으며, 전통 도자기뿐만 아니라 타일 등 새로운 분야로의 확장을 가능하게 했다.

결론적으로 본 연구는 터널 가마 기술이 일본 도자 산업에 미친 장기적인 영향을 성찰하며, 이 기술이 단순한 생산 방식의 변화에 그치지 않고, 보다 넓은 제조업 혁신의 흐름에 기여했음을 밝힌다. 일본에서의 터널 가마 도입은 세계 산업 도자 기술사에서 중대한 전환점이 되었으며, 오늘날까지도 그 유산은 산업 전반에 지속적인 영향을 미치고 있다.

Abstract

The Introduction and Impact of Tunnel Kilns in the Japanese Ceramic Industry During the Early 20th Century

Allison Needels*

The paper "The Introduction and Impact of Tunnel Kilns in the Japanese Ceramic Industry During the Early 20th Century" explores the pivotal role tunnel kilns played in the industrialization of Japan's ceramic production. It focuses particularly on developments during the Meiji (1868 to 1912), Taishō (1912 to 1926), and early Shōwa (1926 to 1945) eras. Beginning with an analysis of kiln technology advancements in the West, the study traces the adoption and improvement of tunnel kilns in Japan. In particular, it emphasizes the significant contributions of the Morimura Group through its flagship companies: Noritake, Toyo Toki, and NGK Insulators.

The shift from periodic, labor intensive kilns to continuous firing technology marked a fundamental change in both the efficiency and scale of Japanese ceramic manufacturing. The Morimura Group, an export wholesale company at the forefront of this transition, played a key role in refining European tunnel kiln models such as the Dressler (England), Harrop (America), and Kerabedarf (Germany) kilns. Morimura Group engineers modified these designs by adjusting airflow and combustion controls to improve fuel efficiency and achieve more consistent temperature distribution. These and other key advancements led to a reduction in production costs and firing times. For the first time in the country's history, domestic ceramic companies were able to mass produce high quality products, including fine china, sanitary ware, and insulators.

Through detailed case studies of major kiln models and their adaptations, the paper shows how tunnel kiln technology helped Japan become a global leader in ceramic production in the early 20th century. It also explores the difficulties smaller manufacturers faced in adopting these kilns, especially before and during

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World War II (1939 to 1945), due to high upfront costs and the large amount of land required. Despite these obstacles, the spread of tunnel kilns laid the foundation for the growth of Japan's industrial ceramics sector to support traditional potters and also expand to new areas such as tile production.

The paper concludes by reflecting on the long term impact of these innovations. Tunnel kilns not only transformed the Japanese ceramic industry but also contributed to broader trends in manufacturing practices. The transition to tunnel kilns in Japan was a pivotal point in the global history of industrial ceramic innovation and continues to shape the industry today.