Introduction of Tunnel Kiln in Modern Ceramic Industry: Technology Transfer and Improvement

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Abstract--**In the ceramics industry, the system of work always depends on the kiln in use. The industrial revolution in Europe brought the widespread use of the coal-fired round kiln which changed the working style from in-home craft work to factory manufacturing. The introduction of the tunnel kiln to the modern ceramics industry is considered to be an important innovation which was initiated by Kazuchika Okura, one of the founders of ceramic industry in Japan. The ability to make practical use of the tunnel kiln marked the start of mass production system in the ceramic industry. The most up-to-date kiln after the tunnel kiln has been the roller hearth kiln which has changed the production system from the mass production to the 'flexible specialization.' In the history of the innovation of the kiln in ceramic industry, as a first step the process of enterprise introduction of the tunnel kiln are clarified which contributed to the rapid development of a modern ceramic industry in Japan, seen from the viewpoint of technology innovation.**

I. INTRODUCTION

In the ceramics industry, production systems greatly depend on the types of kilns at the time. Production methods of ceramics have been developed; since the late 18th Century along with the Industrial Revolution from in-house craft work to the industrial factory manufacturing, then to the mass production in the early 20th Century. In this process, kilns have also been developed; from the traditional rectangular kilns and round kilns at the early stage to the larger scale round kilns, then to the tunnel kilns which are capable of continuous firing and optimal for mass production. The practical application of tunnel kilns, first realized in Europe in the early 20th century, was a big innovation for the ceramics industry striving for mass production, as it enabled continuous production for the first time in the history, even though the tunnel kiln is now succeeded by further developed smaller kiln, as more flexible production system is required currently. Tunnel kiln invention and realization of practical application was achieved in Europe and it was rapidly diffused in the USA, newly industrialized at the time.

Invention of tunnel kilns and its translation into the practical application was carried out in Europe, then the tunnel kilns were rapidly diffused in the USA. As for Japan, Noritake, which was established in 1904 striving for modern production of dinner set for export, started ahead the modern factory manufacturing of ceramics, by introducing the latest technology and facility, such as round kilns from Germany. Kazuchika Okura, the president at the time, saw the great potential of the tunnel kiln at the early stage of its development in Europe when he heard the news of its development, and realized its practical application for the first time in Japan. The introduction of tunnel kilns at his affiliate ceramic plants of sanitary ware, insulator and table ware turned out to be the important technological transfer which enabled great improvements in the products quality, work methods, cost, etc. Tunnel kilns were introduced at his affiliate companies of Toyo Toki for sanitary ware, NGK Insulators, and Noritake for porcelain tableware. This introductions one after the other, brought a great improvement in their production; such as quality, work method, and cost. It was also an important technology transfer to realize mass production systems. Introduction of more than a dozen of the state-of-art tunnel kilns, the latest in the world at the time, was achieved ahead of any other industries in Japan: this formed the basis of mass production of ceramics in Japan.

About the tunnel kiln itself, such as its development and structure has been studied by M.Suzuki [18], T. Kakita [8], and F. Singer[15], and these studies were introduced in the journal of the Ceramic Association, Japan[16][14]. A Study on the introduction of coal-fired kilns to Japan at an earlier time and from an economic history perspective is carried out by Miyachi[9]. However, only fragmentary reports on how and why the tunnel kiln was introduced to Japan and its implication are left; a study on tunnel kiln introduction to Japan from the perspectives of technological history and the change of production systems is missing.

This paper reveals how and why the tunnel kiln was introduced to Japan from overseas and its technological implication in the case of the three major ceramic manufacturing companies of Japan. The research methods of the study are; literature review, including research of the corporate history books, interview of kiln technology experts of various companies, and field research in Japan and in Europe.

II. DEVELOPMENT OF MODERN KILNS IN EUROPE

The first technological innovation in European ceramics industry is invention of the round kiln. The form of the conventional kiln was very simple; the fuel was burned at the front and the combustion gas was channeled to the stack at the back. The temperature distribution in the kiln was not even and the fuel efficiency was bad, so it was also uneconomic. The round kiln enabled an equal heat distribution by heating from four or six directions and channeling the combustion gas to the stack at the top. The round kiln was developed in the 1760's at the KPM Berlin [16]. It was two stories structure and biscuit firing was carried out in the upper floor. The next innovation was the

change of fuel from firewood to coal. This new technology was also developed first at the KPM Berlin and the first success was reported in 1797 [16].

The Industrial Revolution begun in the 18th Century brought changes in industrialization in Europe, along with energy revolution such as hydro, coal and steam power and accelerated factory manufacturing in many industries.

In the areas of pottery industry such as Limoges, Stoke on Trent and Bohemia, coal fired round kilns were disseminated at that time. The progress of industrialization led to a development of transportation systems and an expansion of people's mobility. As a result, the demand for porcelain ware at the hotels increased. The private demand also expanded, as people's quality of life was improved. In such a circumstance, many porcelain plants were established in Bohemia, the area rich in brown coal and kaolin. Also in Bohemia, most round kilns were operated by coal by the 1840's [12]. The technological innovation following to this was the invention of the round kiln with down draught structure by Minton in England. Even though the round kiln itself also aimed for the equal heat distribution, the down draught system further realized improved heat distribution. Minton invented a groundbreaking structure, that enabled to bring the once raised combustion gas down to the bottom of the kiln once by force: the gas was then to brought up, used for heating, and then released through the exhaust channel finally. The down draft structure was excellent in its capacity of equal heat distribution, Havilland in Limoges adopted it immediately [2]. It was disseminated widely in many pottery industry areas in Europe. The concept of the down draft structure is still utilized as the basic concept for the current periodical kilns and the continuous kilns.

III. PRACTICAL REALIZATION OF THE TUNNEL KILN

The concept of the tunnel kiln existed before the round kiln stated above. It is recorded that in the middle of 18th century a tunnel kiln for over glazed decoration process existed at the Vincennes, the predecessor of Sevres in France [2]. There had been many test and trial production of tunnel kilns, because many advantages are expected by realizing continuous firing, a shift from the periodical batch firing. However, it was not realized till the late 19th Century, because there had been many difficulties to overcome, such as heat control in the tunnel and prevention of the negative heat impact on the metal parts of the kiln car. In 1891, Faugeron realized the practical application of tunnel kiln in France and acquired patent. Dressler in the United Kingdom also realized the practical application and acquired patent in 1910. These two cases were the beginning of practical application of the tunnel kilns.

A. Tunnel kilns in the early stage

Development of tunnel kiln started in the mid 18th Century in France [2], [18]. Various ingenious attempts and ideas have been tried out since then in Europe. In comparison with non- continuous kilns that need to heat up and cool down the whole kiln every time when firing, tunnel kiln was estimated to be more efficient as they keep certain temperature and the products run through the kiln. However the realization of its practical application was difficult. The estimated benefits and the reasons for the difficulty, as well as technological transfer to Japan are summarized in the table 1.

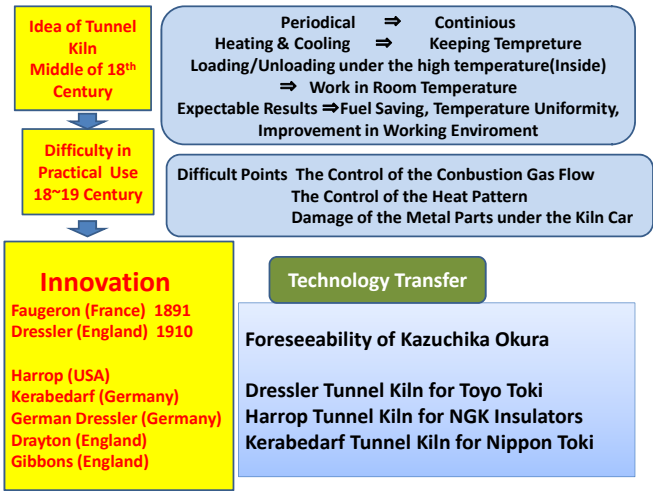

Fig. 1 Invention, Implementation, & Technology Transfer of Tunnel Kiln

The benefit of non-continuous kiln is that the kiln is heated up and cooled down, in a way that the whole burning chamber is kept in the same temperature; therefore, it is easier to change the temperature and atmosphere of the burning chamber of the kiln, in accordance with each firing phase. The down draft type kiln enabled further unification of temperature distribution, as the high temperature combustion gas at the top of the chamber is guided to the exhaust channel by circulating it down while forcibly exchanging its heat.

In the case of tunnel kilns in the early stage, it was relatively easily realized to make the target temperature zone around the center of the long tunnel space; however, it was difficult to guide the combustion gas to the inside and lower part of the products stack on the kiln car. It turned out that there was a great difference in the heat history, depending on the parts and places where the products are stack on the kiln car.

Many ingenious improvements were required in order to realize the practical application of the tunnel kilns, as it was difficult to change the temperature and atmosphere of each part uniformly depending on the firing phase, and many important controlling factors could not be managed as intended; for example, temperature control of the products, heat history control management, and atmosphere control management. New kilns that utilizes exhaust heat by circulating it was invented, such as the Hoffman Ring Kiln in 1856, and the Mendheim Kiln in 1872. While they were used for firing the refractory ceramics, the kiln for porcelain tableware was still mostly multi-layer round kilns.

B. The predawn of tunnel kilns

In 1899 Faugeron succeeded to realize the practical application of tunnel kiln [18]. The distinctive features of the Faugeron type tunnel kiln are that it is direct flame firing system and has drop arch at the ceiling and an obstacle to prevent the easy flow of combustion gas placed on the upper part of the kiln car. The gas circulation and the temperature uniformity was improved by making resistance to the combustion gas that usually flows at the top of the kiln, and guiding the combustion gas to the inside and lower part of the products stack on the kiln car. In 1910, Didier March in the USA adopted the Faugeron type tunnel kiln for firing refractory ceramics. It was the first practical application of the tunnel kiln in the USA [18]. Conrad Dressler acquired the patent in the same year in the UK and the Dressler type tunnel kiln was realized for floor tile in Stoke-on-Trent in 1912. The Dressler type tunnel kiln was with the muffle structure and coal fired. It was an epoch making, as the products could be fired without putting them into the sagger. In 1913, General Electric Company in the USA constructed the Faugeron type tunnel kiln for electric porcelain in New York [18]. At the time, in 1915, there were only about three tunnel kilns were operated all over the USA. The typical tunnel kilns at the time were the Faugeron type which was direct firing type, and the Dressler type which was indirect firing type. These two became the source of the modern tunnel kilns [11]. It was an innovation that ceramics kilns realized continuous firing for the first time. The tunnel kilns diffused rapidly in the ceramics industry as well as refractory industry, reflecting the situation of the US industry at the time, introducing the mass production: the tunnel kilns increased by200 by 1927 [18].

TABLE 1. COMPARISON OF ROUND KILN AND TUNNEL KILN

	Dawndraft Round Kiln (coal fired)	Early stage tunnel kiln
Heat Effect Variability	3 to 4 cone By Seger Cone	1.5 to 2 Cone
Style Of Work	Loadong & Unloading at inside of kiln, hard enviroment	Work for the kiln car in the room
Fuel Saving	1 100 100	1/7 (Universal) 36 (Toyo Toki) 15-30(C.B.Harrop)

Prepared by the author, by reference to [5][7]

The tunnel kiln was diffused as the suitable kiln for mass production, enabling the continuous firing. It also excelled in quality improvement, as it has the uniformity of heat effect, depending on the products places on the kiln car. For that reason, small-lot producing high class ceramics manufacturers for example in Meissen and Okura Art China also adopted tunnel kilns.

IV. THE INTRODUCTION PROCESS TO JAPAN

A. Dressler type tunnel kiln

It was 1903 when Kazuchika Okura learned about tunnel kiln, the latest technology at the time. He gained the information and became interested in the tunnel kiln, when he visited Europe, a trip to prepare to establish Noritake. He gained information about tunnel kiln, which was at the testing phase in the UK, on his way back from Victoria Porcelain in Karlsbad, Austria. Okura visited Victoria Porcelain again in 1912, when the western tableware production by the round coal fired kiln at Noritake was starting to settle. After the visit, he observed a tunnel kiln at Tielsch in Altwasser. He wrote a letter to his staff such as Murai, stating that he wishes to adopt the tunnel kiln soon, as it should achieve fuel savings by 40 to 50 percent [17]. In addition, during his visit to Europe in the next year, Okura received a news that a German company Schulze succeeded in the firing method using reducing atmosphere. He visited the company and made a provisional contract right away to introduce the tunnel kiln to be used at Noritake. However, he refrained its introduction, as he realized by checking the sample products that "yellow discoloration[1]" cannot be avoided [6]. Even though Okra's will for introduction was quite strong, introduction of the tunnel kiln was not ready yet, as the firing of porcelain in tunnel kiln using the reducing atmosphere method was still difficult.

The first full-scale tunnel kiln in Japan was the Dressler type introduced for sanitary ware to Toyo Toki in 1920. In 1915, the American Dressler Tunnel Kiln Inc succeeded to make tunnel kilns for sanitary ware into practical application at the Universal Rundle Corp. The kilns were operated successfully and the American Dressler Tunnel Kiln Inc[2]. acquired the patent for the USA. In the same year, Okura, with his staff Momoki and Tsuboi visited sanitary ware plants of Europe and the USA. He saw the success of the tunnel kilns of at the American Dressler Tunnel Kiln Inc. at the Universal Rundle Corp.,and became convinced that the tunnel kilns for sanitary ware entered the phase of practical application [17]. Since the planning phase of the Toyo Toki, Okura had the sanitary ware plant concept with tunnel kilns as the major production facility. Since 1912, Okura consulted with the board members of the Morimura Group[3] to obtain

[1] "Yellow discoloration" means the common defect of the white porcelain. It occurs when the reducing atmosphere is not enough; the glaze melts and the porcelain body changes its color.

[2] American Dressler Tunnel Kiln Inc. was established by Philip Dressler, the son of Conrad Dressler. In 1915 they succeeded in firing the sanitary ware at Universal Rundle Corp. USA. It was consolidated by Swindle Furnace and became Swindle Dressler in 1930.

[3] Morimura-Gumi was founded in 1876 in Ginza, Tokyo by Ichizaemon Morimura and his brother Isamu Morimura. In the same year Magobee Okura joined and they established Hinode-Shokai (later changed the name to Morimura Brothers Inc.) in NY. They established Noritake (1904), Toyo Toki (1917), and NGK Insulators (1919). Kazuchika Okura is the son of Magobee Okura

the exclusive right for the kilns; however, it was difficult to gain the approval in the company of introduction of the tunnel kiln with an excessive capacity that also involves a huge investment [20].

TABLE 2. TUNNEL KILN DEVELOPMENT PROCESS AND INTRODUCTION TO JAPAN
Prepared by the author by reference to [8][15][18]

Year	Matters
1751	The First Tunnel Kiln Record in Vincennes (France)
1858	Feter : Twin type Tunnel Kiln
1860	Yordt : Tunnel Kiln for Bricks
1877	O.Bock : Tried 60 Tunnel Kilns
1889	J.C.Anderson : Tunnel Kiln in Chicago
1899	G.Faugeron : The First Successful Tunnel Kiln
1910	C.Dressler : Successful Tunnel Kiln ,Stoke on Trent
1910	Didier-March : The First successful Tunnel Kiln Operation in USA by Faugeron Type
1913	General Electric : Introduction of Faugeron Type
1915	Universal Rundle : Successful Operation by Dressler
Japan	
1920	Toyo Toki : 3 Dressler Kilns (1920-1926)
1928	NGK Insulators : 3 Harrop Kilns (1928-1938)
1933	Noritake : 3 Kerabedarf Kilns (1933-1940)
1934	Japan Iron & Steel: 3 German Dressler Kiln (1934-1938)

Okura; however, was still eager for the introduction. He finally gained the approval with conditionality that he purchases it with his private expenses and also takes responsibility when it fails. Even though the negotiation for the exclusive right did not proceed at the time of the First World War, Luis Rosenfeld of the UK, who introduced Okra's visit to the Karlsbad plant earlier, when establishing the Noritake, mediated the negotiation again. In 1918 they reached an agreement and a large Dressler type tunnel kiln was placed at Toyo Toki. In January 1919, British engineer Rushton came to Japan for technical guidance and the kiln started its operation in January 1920. At the beginning, many defectives appeared such as the breaking and cracking. Only firing method with sagger was possible and firing without sagger, the biggest advantage of indirect heating, was not possible. Momoki reported the advantage of the tunnel kiln can be seen that "fuel was saved by about 64 percent in the seven months test operation period, the work such as loading, firing, and unloading became easier, firing result have been precise and constant with less changes, no kiln damage was seen by the continuous temperature keeping, and the fuel has been saved [11]." The first tunnel kiln restarted its operation in 1922 after stopping for two years. At the beginning it fired both table ware and sanitary ware, and could not exert its inherent high performance. After the market conditions recovered, the tunnel kiln also started to exert its original efficiency. The second kiln was introduced in 1923 and the third in 1926. In that process, technological improvement was attempted; for the second kiln, burner was reduced to one and the refractory material was improved. Prior to building the third kiln, Tsuboi was sent to Europe in 1925, and the latest Dressler kiln with three patents was introduced. Afterwards in 1931, The burner chamber of the third kiln was improved, an idea learned from high temperature firing of Carbo-radiant kiln[4], the solo burner was changed to multi burner, and the fuel was changed from coal gas to heavy oil the kiln furnace was improved to heavy oil fired, what enabled to abolish the gas producer. Such improvement process improved the technological capacity in the company. Okura confirmed that firing by heavy oil was more efficient when he visited the USA in 1929, and highly recommended the kiln improvement at the time to change the fuel to heavy oil [20]. Toyo Toki, producing also tableware at the time, made a small tunnel kiln of 34.5m for tableware in 1932. At the time, Noritake was also carrying out a large scale plan of introducing four tunnel kilns for porcelain tableware, using the method of firing in reducing atmosphere. Okura mediated these two parties with different opinions and helped realize such a small tunnel kiln construction [20]. It was the first tunnel kiln for tableware in Japan, prior to the introduction of Kerabedarf type kiln by Noritake in 1934. It was heavy oil fired and was built the year after Toyo Toki remodeled the third Dressler kiln to heavy oil fired; so the technology of that remodeling was utilized there. It was the tunnel kiln with high performance, equivalent of productivity of six round kilns [20].

B. Harrop type tunnel kiln

The harrop type tunnel kiln was developed by Harrop Industries, Inc. established in 1919. It is direct firing tunnel kiln of simpler structure compared to the Faugeron type; its bottom part of the side wall was designed to be wider so as to guide the combustion gas down.

Ezoe and Yoshida who visited the USA to study about tunnel kiln for the insulator in 1927, recommended the adoption of the Harrop type tunnel kiln. Even though Toyo Toki at the time was constructing the third Dressler type kiln, of which they obtained the exclusive right and found to be successful, Okura decided to adopt the efficient direct firing Harrop type kiln accepting the recommendation by Ezoe and Yoshida. An American engineer Perry directed the construction. It was started up using the American method of firing in oxidizing atmosphere and it was changed successfully to the firing method in reducing atmosphere later by Japanese engineer.

and he became the president of these three companies.

[4] Toyo Toki purchased the drawing of the kiln and constructed three kilns by themselves. It is square kiln with the combustion chamber covered by carborundum board, which has high heat conductivity; therefore high efficiency of firing was expected. It was brought into practical application in the UK and Toyo Toki was the first to adopt in Japan. [20]

Figure 2. Cross section of a Harrop type kiln owned by NGK Insulators, Ltd.
Photo by the author

It was the first Harrop type tunnel kiln introduction to Japan. Harrop type tunnel kiln was found to be very efficient: uniform firing improved fuel efficiency and reduced failure rate. It also improved operating efficiency. The Harrop type tunnel kiln increased to three by 1938. Tunnel kiln for saggers (43.43m) was also constructed at the same time as the third kiln [13]. In the mean time, the tunnel kiln for spark plug in Harrop type (31.7m) was also made in 1933 [13]. Harrop type maintained very high product yield ratio and became very competitive factor of NGK Insulators, Ltd. NGK Insulators, Ltd. diffused Harrop type by using their patent and through technical assistance. In addition, NGK Insulators continued to advance their technology and upgrade their facility, when building their new plant. Many technological improvements were added, such as injecting air from the position of the first burner of the firing zone so as to prevent the impact of excessive carbon monoxide to the pre-heating zone, and changing the burners' placement facing to each other, while they were placed alternately before [5]. NGK Insulators later made a foray into kiln manufacturing business, utilizing the technology accumulated in the company through such a development process of tunnel kiln and its operation.

C. Kerabedarf type tunnel kiln

It can be assumed from the past documents that Okura was searching for the tunnel kilns that can fire porcelain from the beginning; however, there were very lean success cases of firing porcelain in tunnel kilns also in Europe, as it was technically very difficult [6]. Okura refrained introduction of the kiln in 1913, on the verge of it, as stated earlier. In 1929 and 1933, Harada and Ishikawa of Noritake visited Europe and the USA and continued research on the kiln. Noritake, at this time, needed to be absolutely confident that the introduction of the tunnel kiln would result in a success, as they were implementing a great restructuring of production systems along with the introduction of the tunnel kiln; such as introducing conveyer systems before and after the firing process, based on a newly introduced scientific management system and IBM computer [14]. Harada and Ishikawa visited a Kerabedarf type kiln in Czech and examined the unsuccessful kiln closely; the inside of the kiln and also defective products. As a result, they became convinced that some modifications of the structure enables the realization of the practical application of the kiln [6]. They bought only the drawing and they built the kiln by themselves with some modification. At the same time, coal gas producer was also made as the first case in Japan[6]. Harada added two modifications to the kiln structure. First, by injecting fresh air between the pre-heating zone and firing zone, it prevented the reducing flame flowing into the preheating zone[7]. Second, the fresh air was injected to the end of cooling zone and it was taken out partially at the border to the firing zone so that the combustion gas never come back to cooling zone[8]. These two important improvements enabled more precise control of the gases flow in the kiln; oxidizing atmosphere in the pre-heating zone, reducing atmosphere in the firing zone, and clean oxidizing atmosphere in the cooling zone.

In addition, pressure control devices of Askania Werke AG[9] enabled a better control of the gas supply and also the pressure of inside the kiln by the air control in the exhaust channel. These improvements finally realized the stable control of reducing atmosphere of tunnel kiln for porcelain which had been sought for many years. As a result, a mass production plant of porcelain was established by 1938; following to the first tunnel kiln in 1934, four tunnel kilns for glost firing and three tunnel kilns for biscuit firing were established, and all 28 multi-layer round kilns were abolished. Noritake accumulated know-how from previous cases of Toyo Toki and NGK Insulators: they achieved a stable control of firing in reducing atmosphere, which was still not realized in Europe the advanced place of tunnel kiln, by adding their original modifications to the purchased drawing of the Kerabedarf, when introducing new tunnel kiln

[5] Source: hearing from Mr. Okada, the kiln expert of NGK Insulators.

[6] The first domestically designed and fabricated coal gas producer. The drawing was prepared by Ishi Iron Works Co., Ltd. in Tokyo, referring to the Power Gas type and the Wellman-Seaver-Morgan type.[6]

[7] The structure of tunnel kiln which realize the perfect combustion of CO by introducing the fresh air from the ceiling of the kiln at the position of atmosphere change, oxidizing to reducing. It prevents the combustion of CO in oxidizing zone which increase the temperature of preheating zone and it results in "yellow discoloration" [2]. This modification enables the combustion of CO and temperature drop at the same time by introducing the fresh air.

[8] This structure realizes the cleanliness of cooling zone by introducing the fresh air from the end of cooling zone. Part of the fresh air is exhausted right after the reducing atmosphere firing zone, and the excess air flows to the reducing firing zone and used as the combustion air. The air in the kiln flows one way from the cooling zone to the entrance; keeping the cleanliness in the cooling zone and improving the cooling effects.

[9] Askania Werke AG is a manufacturer of the optical instrument and the precision equipment. It is a fomer Bambergwerk, founded in 1871 at Berlin Friedenau by Carl Bamberg who learned under Carl Zeiss.

technology to their plants. Various technical improvements by their original technology for quality improvement continued even afterward, for example adding burners to the pre-heating zone and reutilizing the exhaust gas for stabilizing the reducing flame.

The basic technology of firing porcelain in reducing atmosphere established was utilized for the large tunnel kiln at Miyoshi Plant, which was the first kiln designed in-house in 1964. It was the state-of-art tunnel kiln at the time; for example, the kiln car movement was automated and temperature and supply and exhaust air control automation was also realized. The know-how that was accumulated, started from the first Kerabedarf type tunnel kiln and continued through trial and error, leading to the internal designing of the tunnel kiln of Miyoshi Plant, continued to be utilized for the tunnel kiln design of Noritake porcelain plants in Japan and overseas afterwards, and design of the next generation roller hearth kiln. Noritake, currently Noritake Company Ltd, also later expanded their business to kiln manufacturing business, utilizing such know-how accumulation.

D. Features of the technology introduction in the three companies

There are differences in the timing and means of tunnel kiln introduction at the three companies; Toyo Toki, NGK Insulators and Noritake. The features of introduction are summarized in the Table 3.

TABLE 3. COMPARISON OF THE TUNNEL KILNS INTRODUCTION AT THE THREE COMPANIES

	Toyo Toki	NGK Insulators	Noritake
Tunnel Kiln	Dressler (England)	Harrop (USA)	Kerabedarf (Germany)
Year	1920	1928	1934
Design Supervision	Dressler Rushton (England)	Harrop Perry (USA)	Kerabedarf Japanese
Kiln Length	107.5m	120m	78.7m
No of Burner	4	14	20
Fuel	Producer Gas	Heavy Oil	Producer Gas
Products	Sanitary Ware	Insulator	Porcelain
Heating	Indirect	Direct	Direct
Atmosphere	Oxidizing	Reducing	Reducing
Sagger	Without	Without	With Sagger

Referencece : [8]

In the case of Toyo Toki, Okura introduced it by his private expenses against the objections by the board members of Morimura Group. Because it was the very first introduction in Japan, it was discreetly prepared. At the introduction, design and direction of building and operation was relegated entirely to Dressler, and the engineer was sent from the UK to supervise the construction and the operation. After many trials and error throughout the process of the operation start, a great success was achieved: the second and the third kilns were introduced following to the first one. The third kiln was introduced in 1926 and remodeling was done in 1931; several burner chambers were added from only one pair at both sides of the kiln previously, and the fuel was changed to heavy oil. It shows that such know-how was gradually established.

In the case of introduction to NGK Insulators in 1928, they quickly learned about the success of the newly developed heavy oil fueled tunnel kiln in the USA, and they adopted that state-of-art Harrop type without fixating to the Dressler type, of that they held the exclusive right. While design and construction, and operation was directed by Harrop Industories Inc. by an American engineer, the final atmosphere control was conducted by a Japanese engineer, because insulator firing was carried out by oxidizing atmosphere in the USA and NGK Insulators employed the firing method in reducing atmosphere also at the time[5]. The initial start up went well and the kiln was run successfully from the beginning, as the know-how and experience were accumulated at Toyo Toki since their introduction of tunnel kiln a few years ago. Therefore, the second and the third kilns were introduced soon after.

Noritake was the last to adopt the tunnel kiln in 1934. There was no successful example of firing porcelain in tunnel kiln operated in reducing atmosphere also in Europe, where the technology was most advanced at the time. Besides, Noritake at the time was facing a great challenge to succeed in this new technology, in addition to designing it adoptable to the newly developed production line, as a part of the whole plant renovation into a mass production system. In such circumstance, they purchased only the drawing of the kiln: they were convinced by studying previous failures in Europe that the tunnel kiln operation in reducing atmosphere will succeed by adding some improvements to the basic structure of the original Kerabedarf type. Know-how and experience in introducing and operating tunnel kiln itself was accumulated in the Toyo Toki and NGK Insulators. In order to assure the cleanliness in the kiln, which is essential for firing the white porcelain, gasified coal was used as fuel. The coal gas producer was also designed and constructed in Japan, which was different from the case of Toyo Toki. Construction of the kiln, based on the drawing of Kerabedarf with some original technological improvements, and its operation including technology management and operation management were all managed by Japanese engineers. The complete porcelain production line using all tunnel kilns was established, by expanding the plant to 4 tunnel kilns for Glost firing and 3 tunnel kilns for biscuit firing instead of the existing 28 round kilns.

E. Mechanisms of the innovative technology transfer and the barriers in this project

In this technology transfer the most important technological components to be transferred was the continuous firing technology. The idea of tunnel kiln existed since the 18th Century in Vincennes France. However realization of its practical application has been difficult. In the meantime in Europe, the round kiln was improved

technically; heat homogeneity of the round kiln was improved by the invention of the down draught firing structure by Minton and that enabled to make the kiln bigger, and it supported to grow the ceramics industry to manufacturing at larger scale. The long-awaited tunnel kiln was realized around the early 20th Century. After the WWI, the industries in the USA were vitalized to go on to the mass production. The technology of the continuous firing by the tunnel kiln was a revolutionary innovation for the mass production.

As far as the transferring mechanism is concerned it was greatly due to farsightedness and strong will of Okura. He was confident that the tunnel kiln to be the most adequate technical component to start mass production early in Japan, a developing country at the time, at about the same time as diffusion in Europe and the USA had only just begun. Okura not only established the first modern ceramics production of Japan by introducing several latest round kilns, but also was confident about the value of tunnel kiln as a revolutionary technology for the future large scale production and was considering its early introduction to his companies consistently. He continued to visit various countries to research the tunnel kiln. In 2013 although he gave up the introduction due to technical difficulty, he tried to introduce the first tunnel kiln for the porcelain in Noritake. He set up the excellent engineers to make a decision of the validity of the tunnel kiln. 3 years before the establishment of Toyo Toki, in 1915, he saw the successful operation of the tunnel kiln for the sanitary ware in USA together with his engineer. Then the factory layout of Toyo Toki was prepared on the basis of the operation of the tunnel kiln. However the barriers for the introduction of the tunnel kiln were many. It requires the huge amount of money and there were strong oppositions among the managers in the group companies, they thought it was too drastic and too early considering the tunnel kiln was too big in production capacity at the time and also the actual achievement results in the world were rare. However Okura was strong enough in having confidence and eagerness to get the recognition of managers to introduce the first tunnel kiln at Toyo Toki with his own money. The excellent performance of the tunnel kiln was eventually recognized; not only Toyo Toki, but also NGK Insulators and Noritake introduced tunnel kilns one after the other and established mass production systems using tunnel kilns as technical core at an early stage.

Such an early introduction of tunnel kiln technology and its establishment became the technological base for the rapid diffusion of tunnel kiln at Japanese ceramics industry at the post WWII reconstruction period of Japan.

F. Tunnel kilns introduction cases of other companies

The tunnel kiln introduction before the Second World War (WWII) as summarized in the table 4, was initiated under the leadership of Okura, started at Toyo Toki, then followed at the large ceramics companies of Morimura Group. After that, other industries, such as refractory and tile also adopted tunnel kilns. Japan Iron & Steel Co., Ltd.[10] in 1933, adopted a 140.5m German Dressler type[11] tunnel kiln for refractory bricks (footnote 8). This was the first tunnel kiln in the refractory industry of Japan. Then Shinagawa Refractories[12], Osaka Yogyo[13], and Matsukaze Industry[14] followed in introducing tunnel kilns. In the tile industry, Tsukiboshi Kentosha constructed a Harrop type heavy oil fired tunnel kiln by their own design under technical guidance by NGK Insulators in 1934. In 1937, Saji Tile constructed direct flame type tunnel kiln for rigid tile and semi-muffle type tunnel kiln for glazed tile, in cooperation with the German Dressler. Ina Seito[15] also constructed a Kerabedarf type tunnel kiln with a coal gas producer in 1937. As for the tableware industry, even though Nagoya Seito[16] constructed German Dressler type kiln inviting a German engineer; the kiln was not used before making any success, because of the changing course of the war. There were about 50 tunnel kilns, for refractory and for ceramics in Japan before the WWII, while the number decreased after the War, to 32 in 1952 [5][7].

G. Tunnel kiln diffusion to ceramics industry

The tunnel kiln introduction by the precedent large scale manufacturers were realized ahead of other industries and achieved successful outcomes. The diffusion of tunnel kiln in ceramics industry mostly consist of small and medium sized manufacturers had to wait till the post WWII period. It was difficult for general small and medium sized ceramics manufacturers to adopt large scale tunnel kilns as they had excess production capacity and required a huge investment. The fuel supply was also limited at the post WWII period, relying on rationed firewood and coal. Climbing kilns and coal periodical kilns were also used. With such a historical background, Dachi Ceramics Industry Association[17] constructed an experimental tunnel kiln with a support by the National Industrial Recovery Public Corporation in 1948. For designing of this kiln, NGK Insulators offered an aid in design and technical aspects, who had accumulated

[10] Japan Iron & Steel Co., Ltd is a semi-governmental corporation established in 1934, from its governmental parent corporation Yahata Steel Works.

[11] The tunnel kiln in the direct firing structure, being produced by German Dressler was later introduced by Saji Tile and Nagoya Seito. It is different from the most well known Dressler type tunnel kiln which is indirect firing type.

[12] The manufacturer of the refractory bricks established in 1875.

[13] The manufacturer of the refractory bricks established in 1888.

[14] The manufacturer of the refractory bricks, insulators and the chemical porcelain, established in 1917. Fomer Matsukaze Toki & Co., Ltd .

[15] Ina Seito was established in 1924 as the Manufacturer of the ceramic tile of the Morimura Group. The former form of the company started its business in 1921, with a support by Kazuchika Okura, producing pottery pipe and tile.

[16] The manufacture of the table ware established in 1911. It became the base of Narumi Corporation after the WWⅡ.

[17] Dachi Ceramic Industry Association is the industry association of ceramics manufacturer in Dachi town in Toki city in Gifu prefecture, Japan.

know-how and experiences in large scale tunnel kilns introduction previously. This tunnel kiln was initially operated by producer gas ; however, it was changed to heavy oil, partly influenced by the post WWII fuel policy. This Harrop type small tunnel kiln fueled by heavy oil became the basic model of tunnel kiln widely diffused in the industry later on. In 1950, Funai Industry in Tokoname, Aichi, constructed a 25m tunnel kiln for mosaic tile mass production [5]. As such momentum for small tunnel kiln introduction was gathering, Suzuki[18] who participated in the planning and construction of the tunnel kiln at Dachi Ceramic Industry Association , founded Takasago Industry co., Ltd.[19] and started production of small tunnel kilns. Takasago constructed tunnel kilns at medium sized tile manufacture and tableware manufacturer cumulated in Tono Region[20]. Tunnel kiln was diffused in the region, as Takasago supported their clients after starting the kiln's operation until they succeed in products firing.

Takasago grew to the largest tunnel kiln producer in the post WWII Japan: since their first tunnel kiln production in 1953, they produced over 1,600 tunnel kilns within Japan, and over 300 overseas [19]. Takasago invented various types of tunnel kilns based on the Harrop type kiln and made the golden years of tunnel kiln. It grew to a specialized manufacturer of kilns, accumulating experiences and know-how through large number of tunnel kiln production in and out of Japan: it became the engine for the growth of Japanese ceramics industries domestically and internationally. The tunnel kiln diffusion lead by Takasago laid an important basis for the prosperity of Japanese ceramics industries in the post WWII period. The early introduction of large tunnel kiln, achieved through the Okura's leadership and effort, and the know-how accumulation in the pre WWII era also Contributed greatly. However the tunnel kiln completed its role at the end of mass production system period, and the major role was succeeded by the next generation kilns for the more flexible production system, such as Roller Hearth Kilns.

V. DISCUSSION

Tunnel kiln was introduced to the ceramics industry at the early 20th Century, when various industries started mass production. It then supported mass production and mass supply of fair-to-middling products as the core production facility. In such process, tunnel kilns were first rooted in the three Morimura Group companies of Toyo Toki, NGK Insulators, and Noritake: it became the base of the tunnel kiln diffusion in the post WWII period and contributed the prosperity and modernization of the ceramics industry later on. The Dressler type, the precedent for the tunnel kiln introduction to Japan, was adopted, based on his splendid foresight and insight, with a careful consideration and preparation. The Harrop type and Kerabedarf type following to it, were also introduced after a close investigation of the state-of-art production site overseas by the executive engineers, adhering the fundamental attitude of Okura, when adopting the latest advance technology of the world. Such philosophy lead to the introduction of the most suitable type of tunnel kilns production at the time for different type of products; such as sanitary ware, insulator, and porcelain. The each three of the different types of tunnel kilns was introduced from the UK, the USA and Germany; each was unique technology introduced to Japan for the first time. The Kerabedarf for the porcelain, which was the most difficult technology at the time, only the drawing was bought. Its construction with some modifications based on their in-house know-how and technology, by their in-house

TABLE 4. THE BEGINNING OF THE INTRODUCTION OF TUNNEL KILN IN JAPAN BEFORE WW **II** (1912-1940)
Referrence [5]

Year	Type of Tunnel Kiln Introduced
1912	Noritake : Tunnel Kiln (Decoration)
1920	Toyo Toki : Dressler (Sanitary Ware)
1923	Toyo Toki : Dressler (Sanitary Ware)
1926	Toyo Toki : Dressler (Sanitary Ware)
1928	NGK Insulators : Harrop (Insulator)
1931	Toyo Toki : Inhouse-made (Tableware)
1932	Toyo Toki : Inhouse-made (Biscuit)
1933	NGK Insulators : Harrop (Spark Plug)
	Japan Iron & Steel : German Dressler (Refractory)
	Fujimiyaki : Harrop (Tile)
	Tsukiboshi Kentosha : Harrop 2kilns (Tile)
1934	Noritake : Kerabedarf (Tableware)
	Noritake : Kerabedarf (Buiscuit)
	Ina Seito : Kerabedarf (for test firing for tile)
1935	NGK Insulators : Harrop (Insulator)
	Sone Jisoen : Harrop 2 Kilns (Tableware)
	Tsukiboshi Kentosha : Harrop (Tile)
1936	KyushuTaika: GermanDressler (Refractory)
	Tsukiboshi Kentosha Harrop 2 Kilns (Tile)
	Kamiyama : Kojima 2 Kilns (Tile)
1937	Toyo Toki : Inhouse-made (Sanitary Ware)
	NGK Insulators : Harrop (Insulator)
	Noritake : Kerabedarf (Tableware)
	Noritake : Kerabedarf (Biscuit)
	Nagoya Seito : German Dressler (Tableware)
	Nagoya Seito : German Dressler (Tableware)
	Nagoya Seito : German Dressler (Biscuit)
	Japan Iron & Steel : German Dressler (Refractory)
	Japan Iron & Steel : German Dressler (Refractory)
	Ina Seito : Kerabedarf (Tile)
	Saji Tile : German Dressler (Tile)
	Danto : Direct Heating Type (Tile)
1938	Noritake : Kerabedarf (Tableware)
	Noritake : Kerabedarf (Biscuit)
	Shinagawa : German Dressler 3 Kilns (Refractory)
	Thukiboshi Kentosha : Harrop (Tile)
1939	Shinagawa : German Dressler 2 Kilns (Refractory)
1940	Nippon Toki : Kerabedarf No.4 (Tableware)
	Sone Jisoen : Harrop No.2 (Tableware)
	Taisho Seitosho : Inhouse Design (Tile)
1944	Seto Toujiki Kumiai : Kojima (Tableware)
	Kamiyama : Kojima (Tile)
?	Matsukaze Industry : German Dressler(Insulator)

[18] The Founder of Takasago Industry Co., Ltd., born in 1912.
[19] The Manufacturer of the industrial kiln established in 1953.
[20] Tono Region is the area of ceramics industry located in the south-east of Gifu prefecture.

engineers, rejecting to receive the German engineers' support shows that tunnel kiln construction and operation know-how was accumulated and reached to the world standard.

Those three tunnel kilns, introduced in different years, were operated successfully from soon after the time of introduction. To use the tunnel kiln was the competitive factor for the ceramics mass production and many companies followed to introduce the tunnel kiln. Endeavor and pursuit for improvement and innovation by Japanese engineers brought out the inherent advantages of tunnel kiln. Related technologies and know-how learned through the process were nurtured and accumulated; those later grew to the technological competence in each company and developed to the kiln designing ability later.

VI. CONCLUSIONS

This paper reviewed the development process of tunnel kiln that was developed and realized its practical application in Europe in the early 20th Century that enabled mass production of ceramics by continuous firing for the first time in the history. Then the paper analyzed the introduction process to Japan. The following conclusion can be drawn from the review and discussion above:

(1) The realization of coal-fired tunnel kiln, capable of continuous firing greatly contributed the realization of mass production systems for the ceramics industry in the early 20th Century. Introduction to Japan was carried out by the three companies of Morimura Group at the early stage, not much delay from the Western countries. This early introduction with a great foresight laid a foundation for mass production of the ceramic industry of Japan.

(2) At the early stage of the tunnel kiln introduction to Japan, the introduction process was directed by the foreign engineers invited for technical guidance. Know-how on kiln construction and operation and related technology was gradually accumulated in the companies; those developed into the kiln designing ability. These technical advancement lead to not only kiln construction and operation technology advancement, but also the foundation for development and creation of related technologies.

(3) Okura's open mindedness and enterprise spirit based on his excellent foresight promoted the early introduction of tunnel kiln. Each of the three Morimuta Group companies succeeded in its introduction by choosing the most suitable tunnel kiln type. This introduction and rooting of different types of latest tunnel kilns not only contributed to the success and competitiveness of the companies, but also contributed greatly to the modernization and prosperity of the ceramic industry of Japan, laying the technological basis for the industry for many years.

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