Establishing R&D capability in the
prewar Japanese rayon industry:
The organization of technical staff and
institutionalization of R&D

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I. INTRODUCTION

THE RAYON industry was a newly emergent chemical industry in World War I, alongside dyes, fertilizers, and soda. Even though rayon's industrialization of Japan was behind that of the West, in 1937 Japan overtook America and became the top producer of rayon yarn. Rayon was developed with the aim of creating an artificial silk, and was also known as such. The development of rayon industry in the West posed a serious competitive threat to Japanese silk industry, which had been supporting the Japanese international balance of payments. As a strategic industry to acquire foreign exchange instead of silk, the Japanese rayon industry shouldered the burden to compensate the collapsed balance of payments resulting from setbacks in the silk industry and the advance of heavy industrialization. At the same time, it also mediated the structural transformation from the prewar structure focusing on the silk and cotton industry to the postwar structure focusing on civilian heavy industry. Several factors were behind the rapid development of Japanese rayon industry, including (i)

the introduction and assimilation of mature rayon technology of the West; (ii) the application of the highly developed market, distribution system and capital of the silk and cotton industry; (iii) the growth and support of zaibatsu general trading companies; and (iv) the downward tendency of prices of chemicals and electricity in the 1920s and wages and foreign exchange in the 1930s.¹ In particular, the paper focuses on the formation of research and development capability that made possible the rapid assimilation of foreign technology and further independent advances.

In addition to the rayon industry, the Japanese chemical and electrical industries also achieved rapid development during the interwar period. These were driven by the introduction of foreign technology and moved towards increasingly autonomous technological development, a process which is generally explained through the organization of technical staff and institutionalization of research and development.² However, in the case of rayon industry, a new industry based on new technology, young engineers graduating in the Showa period were appointed to important positions³ and the industry was supported “not only by their old school tie but through the master-pupil relations within laboratories”⁴. Consequently, we can hardly neglect the relationship between companies and institutions of higher education. These characteristics are also associated with the trend to apply science to industrial production. In American major companies of the early twentieth century, the first stage of that trend was the employment of trained engineers and creation of research laboratories for analysis, standardization, and quality

1. Hiroaki Yamazaki, *Nihon kasen sangyō hattatsu shiron* [The history of the development of Japanese chemical fiber industry] (Tokyo: Tokyo Daigaku Shuppankai, 1975), 5–6, 412–414.

2. For instance, see Hoshimi Uchida, “Gijutsusha no keisei to kigyōnai gijutsu hatten” [The formation of engineers and the advance of technology in companies] in Moriaki Tsuchiya (ed.), *Keieishi: seiyō to Nihon* [Business History: The West and Japan] (Tokyo: Yūhikaku, 1994); Shin Hasegawa, “Gijutsu dōnyū kara kaihatsu e” [From introduction to development of technology] in Tsunehiko Yui and Eisuke Daitō (eds.), *Nihon keieishi 3 daikigyō jidai no tōrai* [Japanese business history 3: arrival of the era of big business] (Tokyo: Iwanami Shoten, 1995).

3. The Showa period began in 1926.

4. Hoshimi Uchida, “Jinken ōgon jidai” [The golden age of rayon] in Hoshimi Uchida (ed.), *Gijutsu no shakaishi 5* [The social history of technology Vol.5] (Tokyo: Yūhikaku, 1983): 166.

control. The second stage was the separation of research and development functions of product and process from other laboratory operations, and the linkage of research in universities with industrial production. The foundation of an independent experimental or research laboratory that separated from the production floor became common, and the Japanese rayon industry followed much the same route.⁵

This paper aims to examine the formation of research and development capability in the rayon industry, taking into account the role and contribution of the institutions of higher education to the establishment and development of the industry. There were three patterns of technological development during the rise of the Japanese rayon industry: (i) original technology coupled with imported machinery and information (Teikoku Jinzō Kenshi K.K. (Teijin Ltd.)); (ii) technology introduction attended by capital participation and dispatch of executives (Asahi Kenshoku K.K. (Asahi Kasei Corp.)); and (iii) technology introduction coupled with the import of machinery and technical instruction (Tōyō Rayon K.K. (Toray Industries, Inc.), Nippon Rayon K.K. (Unitika, Ltd.), Tōyō Bōseki K.K. (Toyobo Co., Ltd.), and Kurashiki Kenshoku K.K. (Kuraray Co., Ltd.).⁶ The paper examines concretely the cases of Kurashiki Kenshoku and Tōyō Bōseki, which built up a close relation with Department of Industrial Chemistry at Kyoto Imperial University, a leading university of fiber chemistry in Japan. Though discussion focuses on the third pattern above, the organization of technical staff, the institutionalization of research and the relationship with institutions of higher education are common issues, and these points can be equally applied to the other two patterns.⁷

5. Alfred D. Chandler, Jr., "From Industrial Laboratories to Departments of Research & Development" in Kim B. Clark, Robert H. Hayes and Christopher Lorenz (eds.), *The Uneasy Alliance: Managing the Productivity-Technology Dilemma* (Boston: Harvard Business School Press, 1985), 60–61.

6. Nihon Kagaku Sen'i Kyōkai (ed.), *Nihon kagaku sen'i sangyōshi* [*The history of the Japanese chemical fiber industry*] (Tokyo: Nihon Kagaku Sen'i Kyōkai, 1974), 156–158.

7. The archives used in this paper are available in my papers "Sengo no Nihon kigyō no gijutsu sentaku to gijutsu hatten: Tōyō Bōseki no gōsei sen'i heno shinshutsu wo chūshin toshite" [The Technological Choice and Development of Japanese Firms during Postwar Period: A Case of the Advance to Synthetic Fiber of TOYOBO], *Keiei shigaku* [*Japan Business History Review*], Vol.42, No.3, 2007, and "Senji-ki / fukkō-ki no Nihon kigyō no gijutsu kaihatsu to saiteki shijō no sōshutsu: Kurashiki Reiyon no biniron

II. THE CASE OF TÖYÖ BÖSEKI

After the World War I, the major cotton spinning companies, with retained earnings from during the war, diversified into silk, wool and rayon, and proceeded the vertical integration of dyeing and processing. The first six companies to begin rayon production established a competitive monopoly over Japanese rayon market. They were Teikoku Jinzō Kenshi founded by Suzuki Shōten in 1918; Asahi Kenshoku by Shitagau Noguchi (Nippon Chisso Hiryo K.K.) / Nippon Menka K.K. / Vereinigte Glanzstoff Fabriken A.G. in 1922; Tōyō Rayon by Mitsui Bussan K.K., Nippon Rayon by Dainippon Bōseki K.K. (Unitika, Ltd.), Kurashiki Kenshoku by Kurashiki Bōseki K.K. (Kurabo Industries, Ltd.) in 1926, and in the same year Tōyō Bōseki advanced to rayon industry.⁸

As a natural fibers company, the conventional experience of Tōyō Bōseki in chemistry was nothing more than the testing of adhesives and other chemicals involved in cotton spinning in a small laboratory. Entry into the rayon business was an opportunity to incorporate chemistry into fiber production. Viscose rayon production consists of an initial stock-solution process (steeping, milling, aging, xanthation, dissolving, and ripening) and post-processing (spinning, winding, washing, bleaching, and drying). There was little difference between the latter process and the existing cotton spinning industry except the spinning machine, a peculiar equipment of rayon, but the former process required equipments employed in chemical industry and engineers trained in chemical engineering. When Tōyō Bōseki imported technology from the

kōgyōka wo chūshin toshite” [The Technology Development and the Creation of Optimum Market of Japanese Firms during War and Revival Period: A Case of the Industrialization of Vinyon of Kuraray], *Keiei shigaku* [Japan Business History Review], Vol.45, No.4, 2011. The trends and characteristics of the rayon industry discussed in this paper, considering the relationship between Sumitomo Kagaku Kōgyō K.K. and the Gen’itsu Kita laboratory, suggest that there were similar trends and characteristics in the chemical industry. However, in this regard, it remains unclear whether this was common to industries including the electrical industry that were technically behind their western counterparts and imported technology, or whether it was common more widely across industries in late-industrializing Japan.

8. Yamazaki, *op. cit.*, 296–297. In this paper rayon refers to viscose rayon, not including cuprammonium rayon of Asahi Kenshoku.

German company Oscar Kohorn & Co. and established their Katata plant in 1926, they had no chemical engineers. So they took on two graduates from the Department of Applied Chemistry at Tokyo Imperial University and one from the Department of Applied Chemistry at Hamamatsu School of Technology. Together with the in-house mechanical engineers they worked to master rayon production technology, but were unable to produce a good-quality rayon yarn. At the beginning of operation, as Tōyō Bōseki set focus on uniformity than tensile strength in industrial production, yarn had poor texture, a dry strength was just 1.2g/d, and a wet strength was just 0.5-0.6g/d.⁹ All things considered and in order to diversify risk, in March 1928, the newly completed Katata plant was separated as Shōwa Rayon K.K., an independent company. In addition, as the plant was being operated under the instructions of foreign staff despatched from Oscar Kohorn, executive director Keizō Seki requested the cooperation of his junior high school classmate Gen'itsu Kita, the professor of the Department of Industrial Chemistry at Kyoto Imperial University, and in April that year Rikimatsu Tomihisa, who had studied the chemical composition of viscose rayon in Kita laboratory, joined the company.¹⁰

After joining, Tomihisa, while accepting introduction of a Czech chemical engineer mainly on the control of chemical process, wrote up his previous studies as a doctoral dissertation titled “Viscose Research” and in March 1929, was awarded a doctorate in Engineering from Kyoto Imperial University. At that time, rayon yarn was strengthened by the Lilienfeld process, stretching it in a bath of concentrated sulfuric acid.

9. “‘100nen-shi Toyobo’ rēyon kankei shiryō” [100 year history of Toyobo: documents of rayon business], Held by Company History Office in Tōyō Bōseki K.K.. While cotton spinning companies had many graduate mechanical engineers, pioneers Teikoku Jinzō Kenshi and Asahi Kenshoku lacked mechanical engineers rather than chemical engineers. In any case, one of the major issues is the establishment of chemical engineers and of research activities, and the relationship with institutions of higher education was seen more conspicuously in chemistry too, so this paper focuses principally on the chemical aspects, while taking as precondition the role and contributions of mechanical engineers in such as the design and improvement of machinery and the improvement of yarn's quality.

10. Rikimatsu Tomihisa, “Seki-san to watashi” [Mr.Seki and me] in Tōyō Bōseki Kabushiki Kaisha-nai Seki Keizō-shi Tsuikairoku Kankōkai (ed.), *Seki Keizō-shi tsuikairoku* [Reminiscences of Keizo Seki] (Osaka: Tōyō Bōseki Kabushiki Kaisha-nai Seki Keizō-shi Tsuikairoku Kankōkai, 1965): 259–260.

After the Czech chemical engineer returned to his country in 1930, acting on the basis of his doctoral research, Tomihisa altered the angle of the yarn guide and achieved an increase in yarn dry strength to 1.8g/d and wet strength to 0.8-1.0g/d.¹¹ Texture was improved by adding an olive oil emulsion, and the use of glucose in the spinning bath was abandoned as its effect was doubtful and its use at high concentrations was adding 10 yen per hundred pounds to the cost of the yarn. Additionally, on the foundation of his basic research experience in university and with the cooperation of mechanical and chemical engineers, Tomihisa introduced improvements in the imported technology. He connected the steeping and pressing processes by introducing a steeping press machine, linked up the xanthation and dissolving processes with a vacuum kneader, cut out the reeling process through cake scouring, increased spinning speed by improvements in pot-motors, and recovered sodium hydroxide (caustic soda) through a precipitation method. Altogether these efforts reduced production cost vastly, which had risen to more than 100 yen per hundred pounds, to 58 yen per hundred pounds by 1932.¹²

Tomihisa's joining the company was a turning point, after which rayon plants, which had been run on the basis of shop-floor experience, began to be run on scientific principles. Though the chemistry in Japan was then just beginning to develop a theoretical understanding on the nature of the sticky cellulose which was employed in rayon, the relationship between the quality of rayon yarn and temperature, quantity, time, degassing and so on of the chemical reagents was not yet to be fully elucidated. Tomihisa, talking about the new technology introduced, said "I could introduce changes with confidence because of my basic research at university ... [Top management] let me do as I

11. "'100nen-shi Toyobo' rēyon kankei shiryō." In his thesis he suggested that surface friction resulted in a stronger thread, but in fact it was due to the tension applied by changing the angle of the yarn guide.

12. Nihon Kagaku Sen'i Kyōkai, *op. cit.*, 158–159; Bōshoku Zasshisha (ed.), *Nihon bōshoku taikan [Japanese textiles overview]* (Osaka: Bōshoku Zasshisha, 1934), 25. The production cost in 1932 was 57.0 yen/hundred pounds for Teikoku Jinzō Kenshi, 60.0 yen/hundred pounds for Tōyō Rayon and Nippon Rayon and 67.0 yen/hundred pounds for Asahi Kenshoku. The precipitation process devised by Tomihisa added diatomite to alkaline waste as a precipitation accelerator, causing the precipitation of β-cellulose and permitting the recovery of sodium hydroxide from the supernatant liquid.

pleased.”¹³ Managers had limited understanding on chemistry and consequently engineers’ opinions carried great weight, so he was able to attempt a variety of changes on the scientific basis.¹⁴ The presence of one leading engineer contributed to the establishment of rayon technology, but with the expansion of the Katata plant and establishment of the Tsuruga and Iwakuni plants and subsequent business expansion, there was a limit to the ability of one individual. In order to conduct production management and research organizationally, Tōyō Bōseki increased recruitment from universities and higher technical schools and organized the chemical engineers. Kyushu Imperial University and Osaka Imperial University graduate chemical engineers were also employed at Tōyō Bōseki, but the largest group were Kyoto Imperial University graduates. As shown in Table 1, almost every year from 1931 to 1937 graduates were recruited from the Department of Industrial Chemistry at Kyoto Imperial University, and from the Kita laboratory in particular (12 of 17 recruits, 15 of 17 including the associated Ichirō Sakurada laboratory), the relationship with the Kita laboratory growing ever stronger after the employment of Tomihisa.

Meanwhile, by its nature the rayon industry was dependent on chemical research, and the continued recruitment of engineers from the institutions of higher education contributed to the establishment of research activities and organization within the company. “Chemical research, invention and investigation contribute to the improvement of product and reduction of production cost ...research on chemistry is [requested] for fundamental improvement in product quality and research into recovery of waste chemicals by the nature of chemical industry.”¹⁵ Consequently, the Shōwa Rayon Chemical Laboratory was established within the Katata plant in 1930, and Tomihisa took charge of rayon research at the laboratory as research director. The number of chemical engineers at this laboratory was initially limited and they concentrated on research closely related to improving production, including improvements in the spinning bath and chemical recovery. As the number of in-house engineers increased, however, they were able to

13. Rikimatsu Tomihisa, *Kagyū zuisō 6* [*The memoirs No.6*] (Osaka: Tōyō Gomu Kōgyō Kabushiki Kaisha, 1970), 93–94.

14. Uchida, “Jinken ōgon jidai,” 169.

15. “‘100nen-shi Toyobo’ rēyon kankei shiryō.”

Table 1: Chemical engineers who graduated department of applied

Name	Graduated year	Joined company date	Laboratory	Position (as of November 1937)
R. Tomihisa	1923	Apr 1928	Kita	Manufacturing department, rayon section manager
S. Nakajima	1926	May 1936	Kita	Science research laboratory, chemistry leader
J. Onohara	1928	Jan 1931	Kita	Iwakuni plant, acting plant manager
S. Masuda	1928	Mar 1933	Kita	Science research laboratory staff
T. Uchida	1931	Feb 1932	Kita	Manufacturing department, rayon section staff
F. Fujita	1931	Apr 1931	Kita	Science research laboratory staff
K. Yoshino	1932	Mar 1933	Kita	Science research laboratory staff
E. Noguchi	1932	Apr 1932	Kita	Tsuruga plant, manufacturing staff
T. Sakano	1933	Mar 1933	Kita	Iwakuni plant, manufacturing staff
T. Furukawa	1933	Mar 1933	n.a.	Science research laboratory staff
S. Nomura*	1934	n.a.	Kita	Manufacturing department subsidiary, Osaka Keori K.K.
S. Morimoto	1934	Mar 1934	Sakurada	Iwakuni plant, manufacturing staff
T. Kitahata	1934	1934	Sakurada	Science research laboratory staff
J. Tōbara	1934	1934	Nakazawa	Science research laboratory staff
H. Takada	1935	1935	Kita	Katata plant, manufacturing staff
Y. Kikuchi	1936	Mar 1936	Kita	Iwakuni plant, operation trainee
S. Kawada	1937	Mar 1937	Sakurada	Science research laboratory trainee
(Above, graduates of the Department of Industrial Chemistry at Kyoto)				
T. Ōta	1926	1926	n.a.	Tsuruga plant, acting plant manager
H. Ōhashi	1926	1926	n.a.	Died
S. Yamamoto	1934	Mar 1934	n.a.	Iwakuni plant, manufacturing staff
H. Ōe	1936	Mar 1936	n.a.	Science research laboratory trainee
W. Mokudai	1937	Mar 1937	n.a.	Science research laboratory trainee
(Above, graduates of the Department of Applied Chemistry at Tokyo)				
K. Saitō	1922	n.a.	n.a.	Science research laboratory staff
Y. Ōtsu*	1935	n.a.	n.a.	Nagoya plant, manufacturing staff
(Above, graduates of the Department of Applied Chemistry at Kyushu)				
M. Naka	1934	n.a.	n.a.	Katata plant, manufacturing staff
(Above, graduate of the Department of Applied Chemistry at Osaka)				

Source 1: Ryūtarō Akiyama (ed.), *Osaka Kōgyō Kurabu kaiin meibo* [Directory of Osaka Industrial Club] (Osaka: Osaka

Source 2: Kyoto Teikoku Daigaku Kōgakubu Kōgyō Kagaku Kyōshitsu Kōkakai (ed.), *Kōkakai kaiin shimeiroku Showa Kōkakai*, 1937).

Source 3: Tokyo Teikoku Daigaku Kōgakubu Ōyō Kagakuka Kyōshitsu (ed.), *Tokyo Teikoku Daigaku Kōgakubu Ōyō Department of Applied Chemical, School of Engineering, Tokyo Imperial University* (Tokyo: Tokyo Teikoku

Source 4: Tōyō Bōseki Kabushiki Kaisha (ed.), *Shokuinroku* [Directory of staff] (Osaka: Tōyō Bōseki Kabushiki Kaisha,

Source 5: Yoshihiro Watanabe, Hideaki Uemura and Tomotake Kinoshita (eds.), *Kyushu Teikoku Daigaku Kōgakubu* (Fukuoka: Kyushu Teikoku Daigaku Kōgakubu Dōsokai, 1941).

Note 1: Yoshio Nakazawa held the chair of industrial electrochemistry (electrochemistry, chemical fertilizers, inorganic from 1918 and the chair of industrial organic chemistry of dyes, fibers and paper) from 1933; and Ichirō Sakurada

Note 2: Order of allocation in plant or laboratory is marked as ①, ②, ③.

Note 3: Names marked with an asterisk (*) were employed on business other than rayon as of November 1937.

chemistry at university employed by Tōyō Bōseki as of November 1937

Company activity			
	Plant	Laboratory	Research area
	①	②	Rayon (1930–1936)
	×	①	Synthetic organic chemistry (1936–)
	①, ③	②	Rayon (1931–1933)
	×	①	Regenerated silk (1933–1936), Rayon (1936–)
	×	①	Regenerated silk (1932–1933), Pulp (1933–)
	×	①	Tire (1933–)
	×	①	Regenerated silk (1933–1935), Acetate (1935–)
	②	①	Regenerated silk (1932–1936)
	①	×	-
	①	②	Fiber acetylation (1936–)
	-	-	-
	②	①	Rayon (1934), High-temperature aging (1934–1937)
	×	①	Synthetic dyes (1935–)
	×	①	Electrolysis of sodium sulfate (1935–)
	①	×	-
	①	×	-
	×	①	n.a.
Imperial University)			
	①	×	-
	①	×	-
	①, ③	②	Rayon (1934–1936)
	×	①	Substitute fibers for hemp (1936–1937), Tire cord (1937–)
	×	①	n.a.
Imperial University)			
	×	①	Dyeing
	-	-	-
Imperial University)			
	①	×	-
Imperial University)			

Kōgyō Kurabu, 1939).

13endo [Directory of Kokakai in 1938] (Kyoto: Kyoto Teikoku Daigaku Kōgakubu Kōgyō Kagaku Kyōshitsu

Kagakuka sotsugyōsei, shokuin oyobi gakusei meibo [Directory of graduates, faculties and students of Daigaku Kōgakubu Ōyō Kagakuka Kyōshitsu, 1940).

multiple years).

Dōsōkai kaiin meibo [Directory of alumni association of Faculty of Engineering at Kyushu Imperial University]

chemicals) from 1914; Gen'itsu Kita held the chair of organic natural chemistry (oils and fats, petrochemistry) held the chair of industrial biochemistry (yeast, coal gas) from 1933.

conduct research on full-line production of fine denier yarn, dull fiber, multi-filament yarn, and hollow yarn products, development of staple fiber, research on high temperature aging methods of alkali cellulose, research on electrolysis of sodium sulfate, and from about 1932 began carrying out research on the creation of new rayon products and process technologies. The university graduate engineers took the responsibility of the research on high temperature aging methods and electrolysis of sodium sulfate, and they moved to the new Iwakuni plant to incorporate and operate the results of their efforts.¹⁶

In January 1931, the Tōyō Bōseki Chemical Laboratory was established within the Katata plant, Tomihisa holding research director concurrently, to carry out research on materials other than rayon. Forseeing that the profitability of cotton spinning business would continue to decline, after rayon technology had been well established and with the aim of promoting new research, the Shōwa Rayon and Tōyō Bōseki Chemical Laboratories and the materials testing room of the headquarters research section were merged in September 1933, forming the Shōwa Chemical Research Institute. The institute was established with funding of one million yen, and its equipment and staff allocation were entrusted to Tomihisa. When Tōyō Bōseki merged with Shōwa Rayon in June 1934, it was reconstituted as the Tōyō Bōseki Science Research Laboratory. In addition to rayon, research related to existing products and technologies commenced in 1931, including research on regenerated silk from waste thread left over from the silk spinning process, on tire deriving from cotton tire code and on cotton thread on the base of twisted yarn technology. However, there were no in-house engineers capable of conducting research into regenerated silk, so as he had for rayon, Keizō Seki contacted Gen'itsu Kita and employed four graduates from his laboratory who were carrying out research in that field. This research was discontinued by his successor when Tomihisa promoted to company headquarters as technical manager

16. My paper, "Sengo no Nihon kigyō no gijutsu sentaku to gijutsu hatten," 40. Sodium sulfate electrolysis is a process by which sodium hydroxide and sulfuric acid are recovered from sodium sulfate, a byproduct of the spinning process. High temperature aging is a method by which aging is achieved through high temperature at the grinding stage of alkali cellulose, and by pneumatic transportation to the xanthation / dissolving stage, aging time was reduced by 2-3 hours.

in May 1936. While research activities were reduced in scale, engineers changed the focus to research on rayon, its base materials of pulp and acetate, and consequently to strengthen the Tōyō Bōseki research staff concentrating on chemical fiber research.¹⁷

Tomihisa's joining, with his experience in chemical research in university, research at Tōyō Bōseki had a relatively early start. Research was maintained by further employment of chemical engineers, took root within the company due to the indivisibility of chemical research and rayon production, and was promoted with the formation of a research organization. Laboratory staff increased from 7 in 1932 to 28 in 1937 and 45 in 1938. Table 1 shows that of 23 university graduate chemical engineers working on rayon-related business, 17 (74%) were engaged in laboratory research and 12 (52%) had experience of production management in plants. The transference between plants and the laboratory was usually conducted for such reasons as the commencement of new research, application of research results and abandonment of research projects, and the emphasis of staff allocation gradually shift to research. In the laboratory, the engineers of university graduate were at the center of efforts to implement the scientific knowledge of the universities in company production. Meanwhile, regarding plant production management, the number of university graduate was reduced and higher technical school graduates were made central to management at the Tsuruga and Katata plants where production was stable, while university graduates were deployed in the new Iwakuni plant where the latest technology was being introduced.¹⁸ In the 1930s, with the flow of people and knowledge from institutions of higher education to companies, companies gained the scientific basis of rayon technology and established rational process, scientific management of operations and the structure of research and development, and actively incorporated science into manufacturing, all of which provided a major stimulus to independent development of rayon technology.

17. Ibid, 38–40.

18. As far as can be confirmed in 1937, the Katata plant employed as least two university graduates and four higher technical school graduates, Tsuruga plant employed two, and Iwakuni plant four university graduate engineers. In addition, many higher technical school graduates were also engaged in research at laboratories.

Further, the Taniguchi Kōgyō Shōreikai Foundation, founded by Tōyō Bōseki's director Toyosaburō Taniguchi, provided 20,000 yen to fund Gen'itsu Kita's "basic research into industrial raw cellulose" in 1936–1938 and 1940–1944 with the aim of promoting research and education.¹⁹ The grant was originally targeted at pulp research, but it also led to the study of rayon and synthetic fibers, focusing on cellulose. In this way Tōyō Bōseki made significant contributions to institutions of higher education.

III. THE CASE OF KURASHIKI KENSHOKU

In January 1926, Kurashiki Bōseki decided to enter the rayon industry, and the company established Kurashiki Kenshoku in June the same year. A large part of the management maintained a cautious stance, given the strict secrecy of the rayon industry, and because even if they could introduce foreign technology there were no chemical engineers in the company to take on those skills. Therefore, Kurashiki Bōseki requested the cooperation of Ikuzō Fukushima, the professor of the Department of Industrial Chemistry at Kyoto Imperial University, and in May 1925, Toyosaburō Ueba of the health section of Kurashiki Bōseki was dispatched to Fukushima laboratory, and at the recommendation of Fukushima, Kenzō Negoro, Shigeichirō Takagi and Michio Nakamura joined the company. In late September, the Kyōka Laboratory for rayon research was established in Kyoto under the instruction of Fukushima, and with staff of ten technicians and funding of over 200,000 yen, started basic research on rayon production.²⁰

The Kyōka Laboratory initially lacked even the most basic knowledge such as the need to raise the temperature of the spinning

19. Zaidan Hōjin Taniguchi Kōgyō Shōreikai 45 Shūnen Kinen Zaidan (ed.), *Taniguchi Zaidan 70nen no ayumi: gakujiutsu kenkyū to kokusai shinpojiumu* [70 years of the Taniguchi Foundation: academic research and international symposium] (Osaka: Zaidan Hōjin Taniguchi Kōgyō Shōreikai 45 Shūnen Kinen Zaidan, 1999), 164.

20. Kabushiki Kaisha Kurare Shashi Hensanbu (ed.), *Kurare 60nen-shi (miteikō)* [The 60 year history of Kuraray (unfinished manuscript)] (Osaka: Kuraray Co., Ltd., 1987), 18. Toyosaburō Ueba had acquaintance with Ikuzō Fukushima and so requested his assistance. Fukushima provided assistance while retaining his university position, but resigned from the university in 1933 and took up a position as director at Kurashiki Kenshoku.

bath, yet by June 1926, they were able to produce 50 to 60 reels of rayon yarn per day, even though it was only 1.2g/d of strength and eight denier. Plant construction required acquisition of machinery from the West and Lampose process of the French company Soieries de Strasbourg S.A.'s was chosen. However, at the Kurashiki plant, instead of foreign engineers they relied, from installation of machinery to production management, on the technical skills nurtured at the Kyōka Laboratory.²¹ However, the pot motor, the main characteristic of the Lampose process, could not achieve the speed of 7,200rpm, and production was low, both of which resulted in high cost of 150 yen/hundred pounds with poor quality. At Kurashiki Kenshoku, the technical improvements of processes proceeded throughout the 1930s, the mechanical and chemical engineering university graduates playing the central role. These included achievement of a 7,200rpm pot motor, Tsukumo Tomonari's stretchfixing method of viscose spinning by the introduction of roller guides, Negoro's invention of the vertical spinning method, and the introduction of Heibig type and Cerni type dialyzers for recovering sodium hydroxide. In addition to abolishing the pre-drying process between the winding and scouring processes and stopping the addition of glucose to the spinning bath, processes with limited scientific basis were rationalized and continuous process was attempted through the introduction of steeping press machines and vacuum kneaders. As a result, production costs fell to 59.2 yen/hundred pounds and the weak yarn's wet strength improved from 0.3g/d to 0.6–0.7g/d.²²

21. Kurashiki Reiyon Kabushiki Kaisha Sōmubu, "Kurare monogatari (1) reiyon sōgyō heno michi" [The Kuraray story (1) the road to establishing the rayon business], *Kurare jihō* [Kuraray news], Vol.16, No.3, 1967: 17. At that time, the fastest Japanese pot motor was that of Teikoku Jinzō Kenshi at 4,500rpm while that of Oscar Kohorn was capable of 5,400rpm.

22. Nihon Kagaku Sen'i Kyōkai, *op. cit.*, 156, 159; Bōshoku Zasshisha, *op. cit.*, 25; Kurashiki Reiyon Kabushiki Kaisha Sōmubu, "Kurare monogatari (3) reiyon no sōgyō kaishi" [The Kuraray story (3) the start of rayon production], *Kurare jihō* [Kuraray news], Vol.16, No.5, 1967, 11. Many mechanical engineers had transferred from Kurashiki Bōseki, but Tomonari joined in 1927 when he graduated from the Department of Mechanical Engineering at Tohoku Imperial University, and contributed to the establishment of rayon technology mainly through mechanical design. However, Tomonari also had an interest in chemistry and studied in Germany from 1930 to 1932, at which time he engaged in fiber chemistry research and deepened his friendship with Ichirō Sakurada. In July 1937, Tomonari received a doctorate in engineering from Tokyo Imperial University for his thesis, "Research on the mechanism and characteristics of

Fukushima's direction and the employment of his pupils made possible the smooth assimilation of imported technology as well as its independent development, which was the ground to establish rayon technology. Additionally, these early engineers supported the expansion of business; for example, Nakamura acted as manufacturing section manager during the establishment of the Niihama plant, then transferred to the Saijo plant as plant manager for the establishment.²³ However, the "plants dispersionism" advocated by President Magosaburō Ōhara required even more chemical engineers to promote "the technological competition, discovery by engineers and technological advance through utilizing the particularities in each [plant's] technology and creating new contraption by criticism."²⁴ As detailed in Table 2, after 1931 Kurashiki Kenshoku increased employment of higher technical school graduates and graduates of Fukushima laboratory, in particular until 1933, while Fukushima was at Kyoto Imperial University (5 of 13 employees were from the Fukushima laboratory).

Meanwhile, the establishment of research activities and organization can be observed even in Kurashiki Kenshoku. Fukushima said, "I believe firmly and have been advocating from start to last that the most important thing for chemical fiber companies is nothing other but research,"²⁵ and a research laboratory was established early at the Kurashiki plant. In April 1933, as a part of organizational reconstruction of headquarters and plants, a research section was established and its research subjects expanded to include the whole chemical fibers, and in October the following year, the research section was separated as an independent laboratory from Kurashiki plant, broadening the area of research from fiber to chemistry. Behind of this was that eyes' sickness

nitrication of cellulose." Later, Tomonari, as a leading figure in the technical and philosophical aspects within Kurashiki Kenshoku, promoted the industrialization of the synthetic fiber Vinyon (polyvinyl alcohol fiber) which was developed in Japan. My paper, "Senji-ki / fukkō-ki no Nihon kigyō no gijutsu kaihatsu to saiteki shijō no sōshutsu," 6, 25.

23. Kabushiki Kaisha Kurare Shashi Hensanbu, *op. cit.*, 17, 26, 51, 59, 64.

24. Magosaburō Ōhara, "Kuraken 13nen no kaiko" [Reminiscences of thirteen years in Kurashiki Kenshoku], *Kuraken Sangyō Hōkokukai shokuin renraku geppō* [Monthly report of Kurashiki Kenshoku], December issue, 1941, 7.

25. Sōichirō Ōhara, "Chōji" [Eulogy], *Kurashiki Reiyon jihō* [Kurashiki Rayon news], Vol.5, No.10, 1956: 2.

among spinning operators had been a problem since autumn 1928, and Ōhara, entrusted with improving working conditions, ordered strongly the laboratory to find out how to prevent the emission of carbon disulfide gas in rayon production, or to work on chemical fibers that did not utilize carbon disulfide.²⁶ Responding to this request, research was commenced into acetate in August 1931, but until the establishment of the laboratory most research had been on process continuance and shortening and on chemical recovery, areas directly related to production. Looking at the period up to September 1937, when Fukushima was laboratory director, research was conducted into acetate and pulp. However, while dealing with problems that emerged as the business expanded, the engineers, with Tomonari at the head, began to conduct rayon-related research and development with little relation to production, including the development of full-line rayon products and staple fiber, high temperature aging, and electrolysis of sodium sulfate. Among these developments was a revolutionary new method of rayon production developed by Masao Horio in August 1936, the two bath stretchfixing method of viscose spinning. Laboratory research discoveries were implemented at the new Saijo plant and the Okayama plant, such as the high temperature aging method of alkali cellulose and commercialization of cone product through cake scouring.²⁷

At Kurashiki Kenshoku, independent research had been carried out from before the introduction of technology, and were reinforced by organizing the technical staff and broadening the research organization in the charge of Fukushima and Tomonari, the former with research experience in university and the latter with experience of overseas study.

26. The cause of the eye problems was insufficient ventilation, and sulfide gas generated by the reaction of sulfuric acid with viscose in the spinning bath attacked the mucous membranes of the eye causing acute conjunctivitis. This issue was resolved with the introduction of an airtight system of spinning machine in 1936.

27. My paper, "Senji-ki / fukkō-ki no Nihon kigyō no gijutsu kaihatsu to saiteki shijō no sōshutsu," 5-6; Shigeharu Onogi, "Horio Masao sensei: parupu to reiyon no kenkyū wo chūshin ni" [Professor Masao Horio: focusing on pulp and rayon research] in Shadan Hōjin Kōbunshi Gakkai (ed.), *Nihon no kōbunshi kagaku gijutsushi* [*The history of polymer science and technology in Japan*] (Tokyo: The Society of Polymer Science, Japan, 2005), 26. Kurashiki Kenshoku's high temperature aging method was a method of rapidly aging alkali cellulose in a high temperature vacuum kneader. In addition, the two bath stretchfixing method of viscose spinning employed a second high temperature bath (the spinning bath) in which the fibers were stretched in order to increase strength.

The laboratory expanded to employ a staff of 41 by 1939, and other than the search for new fibers, including synthetic fibers, its activities were limited to rayon-related research. While there are many unknowns, Table 2 shows that of 17 university graduate chemical engineers, ten were engaged in research (58.8%, six unknown), five had experience of production (29.4%, six unknown). According to Kurashiki Kenshoku, we can deduce the following staff allocation policy. That is in the infancy the engineers took charge of the production and cooperated in the setup of new plants, among whom the main were higher technical school graduate engineers with several university graduate disposed, as in the case of other companies, and university graduate engineers were engaged in research. Kurashiki Kenshoku acquired scientific knowledge and staff from institutions of higher education and establish the rational process, scientific production and operations management, and the organization of research and development. Centered on the research activities of Ōhara and Fukushima, Kurashiki Kenshoku actively pursued independent proprietary improvements and cutting-edge advances and ultimately established the independent development of rayon technology.

IV. FEATURES OF THE RAYON INDUSTRY AND TRENDS AT OTHER COMPANIES

Below, I will summarize the main features of the establishment of research and development capability within Tōyō Bōseki and Kurashiki Kenshoku, comparing with trends at other companies.²⁸

First, companies formed partnerships with particular institutions of higher education when establishing technology. Until the mid 1920s, other than Katsumoto Atsugi at Tokyo Imperial University and Gen'itsu Kita and Ikuzō Fukushima at Kyoto Imperial University, very few were engaged in rayon research, even including higher technical schools, so

28. For details of pioneer company Asahi Kenshoku see Kenji Kamide, *Regenerated Cellulose Fiber Industry: A History of Technological and Economical Advances* (Fukuoka: Kyushu University Press, 2006); for Tōyō Rayon see Tsunehiko Yui, "Senkan-ki nichio kan no gijutsu iten to ruisekiteki kakushin: Tōyō Rēyon no jirei ni tsuite" [Technology transfer between Europe and Japan and accumulative innovation during interwar period: a case of Toyo Rayon] in Hidemasa Morikawa and Tsunehiko Yui (eds.), *Kokusai hikaku kokusai kankei no keieishi* [Business history of international comparison and relations] (Nagoya: Nagoya Daigaku Shuppankai, 1997).

Table 2: Chemical engineers who graduated department of applied chemistry at university employed by Kurashiki Kenshoku as of November 1937

Name	Graduated year	Joined company	Laboratory	Position (as of November 1937)	Company activity		Research area
					Plant	Laboratory	
I. Fukushima	1909	1933	-	Director	x	①	Rayon
K. Negoro	1922	Jun 1926	Fukushima	Planning section	②	①	Rayon (1925–1927)
S. Takagi	1925	Jun 1926	Fukushima	Osaka branch office (under head office)	②	①	Rayon (1925–1927)
M. Nakamura	1926	Jun 1926	Fukushima	Saijo plant, plant manager	②	①	Rayon (1925–1927)
Y. Takamatsu	1927	n.a.	Kita	Central research laboratory staff	x	①	n.a.
M. Horio	1928	Jul 1935	Fukushima / Kita	Central research laboratory staff	x	①	Two bath stretching method of viscose spinning (1936–)
Y. Saitō	1928	n.a.	n.a.	Central research laboratory staff	x	①	Acetate (1931–)
Y. Moriwake	1930	n.a.	Nakazawa	Saijo plant, manufacturing section manager	①	x	-
M. Shinohara	1931	n.a.	n.a.	Okayama plant	○	n.a.	n.a.
S. Nomura	1932	Apr 1932	Fukushima	n.a.	n.a.	n.a.	n.a.
K. Watanabe	1933	n.a.	n.a.	Central research laboratory staff	n.a.	○	n.a.
T. Horie	1933	n.a.	n.a.	Planning section	n.a.	n.a.	n.a.
T. Osugi	1936	Apr 1936	Sakurada	n.a.	n.a.	n.a.	n.a.
S. Kohyuga	1937	Mar 1937	Kita	Central research laboratory staff	x	①	n.a.
(Above, graduates of the Department of Industrial Chemistry at Kyoto Imperial University)							
S. Takehara	1935	n.a.	n.a.	Central research laboratory staff	n.a.	n.a.	n.a.
N. Shimada	1937	1937	n.a.	Central research laboratory staff	x	①	n.a.
(Above, graduates of the Department of Applied Chemistry at Osaka Imperial University)							
H. Imamura	1932	Mar 1933	n.a.	Osaka branch office (under head office)	n.a.	n.a.	n.a.
(Above, graduate of the Department of Applied Chemistry at Tohoku Imperial University)							

Source 1: Ryūtarō Akiyama (ed.), *Osaka Kōgyō Kurabu kaimi meibo* [Directory of Osaka Industrial Club] (Osaka: Osaka Kōgyō Kurabu, 1939).

Source 2: Kuyōkai (ed.), *Kuyōkai kaimi meibo* [Directory of Kuyōkai] (Sendai: Kuyōkai, 1937).

Source 3: Kyoto Daigaku Daigaku Kōgakubu Kōgyō Kagaku Kyōshitsu Kokakai (ed.), *Kōkakai kaimi shimeiroku Showa 13nendo* [Directory of Kokakai in 1938] (Kyoto: Kyoto Teikoku Daigaku Kōgakubu Kōgyō Kagaku Kyōshitsu Kokakai, 1937).

Note 1: Ikuzō Fukushima held the chair of industrial organic chemistry (chemistry of dyes, fibers and paper) from 1914 to 1933.

Note 2: See note 1 in Table 1 for details of Yoshio Nakazawa, Gen'itsu Kita, and Ichirō Sakurada.

Note 3: Order of allocation in plant or laboratory is marked as ①, ②.

the limited personal relationships were utilized. Looking at the pioneer companies, Teikoku Jinzō Kenshi collaborated with Atsugi and Itsuzō Hata, the professor of Yonezawa Higher Technical School, Asahi Kenshoku with Kōjū Asahina, the professor of Osaka Technology School, Tōyō Rayon with Atsugi, Kōtarō Tanemura, graduate student of Tokyo Imperial University, and Takeshi Ozawa, the professor of Kiryu School of Technology, Nippon Rayon with Kiyohiko Hagiwara, the professor of Kyoto College of Industrial Arts and later with Kita, who each contributed to the establishment of rayon technology as external advisors or as leaders after joining those companies. In addition, because they had research experience of in institutions of higher education, they also contributed to transferring research to and establishing research within the companies, and additionally each company had already started independent research from before the establishment of research laboratories in the 1930s. Even in the expansion stage, each company continued the employment of engineers through the personal network. Because they continued to hire engineers from particular institutions of higher education, “they were all close in age, there were no awkward organizational issues ... everyone was from the same narrow school with a close senior/junior feel,”²⁹ making it possible to develop a well-organized technical staff. However, in Nippon Rayon, about a dozen engineers including Hagiwara left the company in 1930 due to the delay in organization of a technical staff and internal conflict, and because of further delaying the establishment of rayon technology, the company sought the help of Kita to reorganize its technical staff. After that Nippon Rayon and Dainippon Bōseki continued employing from the Kita laboratory and by 1937, the former employed six graduates from that laboratory and the latter eight. It has been said that Japanese rayon industry took advantage of the expiry of the basic viscose process patent in Europe and favorable developments in the rayon machinery industry and further advanced their technology by leveraging the import of superior equipment. However, in addition the role of Japanese institutions of higher education was highly important in establishing companies’ absorptive capacity, which made it possible to assimilate smoothly the new technology coupled with

29. Uchida, “Jinken ōgon jidai,” 169.

machine and led to independent development.³⁰

Second, companies supported research and education in those institutions of higher education by donations and other means. Each company was quite aware of the importance of the institutions of higher education in creating an academic understanding on rayon and educating highly skilled chemical engineers who would conduct production management and research. It is difficult to estimate informal contributions, and while it cannot be confirmed for Kurashiki Kenshoku, Tōyō Bōseki was providing donations to the Kita laboratory through the Taniguchi Kōgyō Shōreikai Foundation, and even during the World War II provided donations to the Kita laboratory in support of synthetic organic chemistry research. Meanwhile, in March 1932, Nippon Rayon donated 1,000 yen to the Institute for Chemical Research at Kyoto Imperial University for a new building to house a fiber-related research laboratory in the name of director Sashichi Ōsaka; in April they established the Nippon Rayon Scholarship with 2,000 yen, as “funding for research related to the fiber industry at Kita laboratory in the Institute for Chemical Research,” and in December the following year with Dainippon Bōseki established the Kikuchi Scholarship with 10,000 yen, as “funding for research and the improvement of facilities in the Department of Industrial Chemistry in Faculty of Engineering.”³¹ Because the limited space, the article focus on Kita laboratory, which had turned out many competent engineers. The reasons for this were (i) while being an applied chemistry laboratory in the faculty of engineering, the Kita laboratory also attached great importance to basic research and had been directing pupils strongly not to be inferior to pure chemistry in scientific level, and (ii) they did not limit themselves to basic chemistry and small-scale experiments, but had sufficient funds to

30. Yamazaki, *op. cit.*, 249-250. Group unity and the technical level of foreign temporary staff was one factor affecting the outcome of technology transfer. In the case of Tōyō Rayon and Tōyō Bōseki, their staff included excellent chemical engineers with a comprehensive knowledge of rayon and group cohesion was reasonable, but this was not the case at Nippon Rayon. In addition, while Tōyō Rayon, Tōyō Bōseki and Kurashiki Kenshoku prepared for technology transfer by dispatching engineers to foreign companies, Nippon Rayon's preparations were lacking in this respect.

31. Kyoto Daigaku Jimukyoku Shomuka (ed.), *Kyoto Daigaku ichiran: ji Showa 18nen shi Showa 28nen* [Kyoto university overview from 1943 to 1953] (Kyoto: Kyoto Daigaku, 1954), 407-408.

employ the latest laboratory instruments, equipment and pilot plants in their research.³² By 1937, 92 graduates from the Department of Industrial Chemistry at Kyoto Imperial University, and from the Kita laboratory in particular, were working in fiber companies (31.7% of graduates of this department worked in the mining and manufacturing industry, and 27 of the 92 graduates were from the Kita laboratory, 42 from unknown laboratories for the archives were unavailable), and the university provided many chemical engineers to the fiber industry including the rayon.³³ For the enterprises, it was possible to employ chemical engineers who had the base knowledge of engineering and had absorbed the fruits of high-level scientific research and education, and at times that companies faced difficult problems in production, they turned to the laboratories to find clues by the contact of the engineers.

Third, in addition to university graduate engineers the companies employed a large number of higher technical school graduates too. While many rayon companies increasingly used higher technical school graduates both in research laboratories and at their plants, there was a trend to appoint university graduate engineers to such affairs as management and oversight both headquarters and plants as senior-level

32. Shinjirō Kodama, *Kenkyū kaihatsu heno michi* [The road to research and development] (Tokyo: Tokyo Kagaku Dōjin, 1978), 6–8; Masao Horio, “Kita Gen’itsu sensei to sen’i kagaku” [Professor Gen’itsu Kita and fiber chemistry] in Shadan Hōjin Kōbunshi Gakkai, *op. cit.*, 20–21. For Gen’itsu Kita’s impact in the academic world see Yasu Furukawa, “Kita Gen’itsu to Kyoto gakuha no keisei” [Gen’itsu Kita and Kyoto School’s Formation], *Kagakushi kenkyū* [The Journal of the Japanese Society for the History of Chemistry], Vol.37, No.1, 2010.

33. Kyoto Teikoku Daigaku Kōgakubu Kōgyō Kagaku Kyōshitsu Kōkakai (ed.), *Kōkakai kaiin shimeiroku Showa 13nendo* [Directory of Kokakai in 1938] (Kyoto: Kyoto Teikoku Daigaku Kōgakubu Kōgyō Kagaku Kyōshitsu Kōkakai, 1937). As of 1940 there were 39 graduates working in the fiber industry from Department of Applied Chemistry at Tokyo Imperial University (while 8.1% of graduates from the same department worked in the mining and manufacturing industries) and as of 1939 there were 23 graduates from Department of Applied Chemistry at Osaka Imperial University (while 19% of graduates from the same department worked in the mining and manufacturing industries, after its precursor Osaka Technological College promoted to university). Ryūtarō Akiyama (ed.), *Osaka Kōgyō Kurabu kaiin meibo* [Directory of Osaka Industrial Club] (Osaka: Osaka Kōgyō Kurabu, 1939); Tokyo Teikoku Daigaku Kōgakubu Ōyō Kagakuka Kyōshitsu (ed.), *Tokyo Teikoku Daigaku Kōgakubu Ōyō Kagakuka sotsugyōsei, shokuin oyobi gakusei meibo* [Directory of graduates, faculties and students of Department of Applied Chemical, Faculty of Engineering, Tokyo Imperial University] (Tokyo: Tokyo Teikoku Daigaku Kōgakubu Ōyō Kagakuka Kyōshitsu, 1940).

engineers, launching new plants and adopting new technology, research leaders and new or high-level research at research laboratories, and at the case of newly-employed engineers some were in research laboratories from the beginning and some were appointed to production management in plants. One the other hand, higher technical school graduates were often appointed to production management positions in plant as mid-level engineers or to general research activities. As shown in Table 3, while entering late into the rayon industry, Kanegafuchi Bōseki K.K., for which I have been able to obtain archives, employed university graduate engineers as plant managers for plant-level management and oversight in every rayon plant, while most processes were in the charge of higher technical school graduates, and at the research laboratory, while the university graduate engineers were at the center, many higher technical school graduates were involved in research activities concurrently. However, this was not a fixed staff allocation policy. There were many cases where university graduate engineers spent long periods on plant-level production management, and higher technical school graduate engineers were entrusted with plants' management and promoted to executive officers later or were involved in new research and development at laboratories. As a young organization, it was to some extent managed flexibly responding to internal circumstances and personal stature. The increase of engineers in the companies, relying more heavily on the employments of higher technical school rather than that of university graduates, supported the activities both at the plants and at research laboratories. At the plants level, it made possible technical improvements and scientific and efficient production management, and at the laboratories level, it supported the establishment and reinforcement of research, leaded by university graduate engineers, and turned to the development of new products and processes related to rayon, which were beyond technological improvements, and research on areas other than rayon such as synthetic fibers.

V. CONCLUSION

The relationship between companies and institutions of higher education seen from the establishment period to the development period

Table 3: Numbers and average ages of staff by educational background at rayon plants and research laboratory in Kanegafuchi Boseki as of September 1937

September 1937

(Units: persons, years, %)

Takasago Rayon Plant											
	Rayon filament plant		Rayon staple plant		Soda plant		Soap plant		Common section		
	Number	Average age	Number	Average age	Number	Average age	Number	Average age	Number	Average age	Total
University	2 (1)	33 (38)	3 (1)	32 (34)	2 (1)	40 (49)	1 (1)	53 (53)	-	-	8
Higher technical school	8	26	5	25	3	29	2	34	4	38	22
Other	4	33	1	28	-	-	2	28	2	33	9
Unknown	2	41	-	-	-	-	-	-	3	48	5
Total	16	30	9	27	5	33	5	35	9	40	44
											100
Takasago Rayon Plant											
	Rayon filament plant		Rayon staple plant		Common section		Total		Muto Physics and Chemistry Laboratory		
	Number	Average age	Number	Average age	Number	Average age	Number	Average age	Number	Average age	Total
University	2 (1)	37 (40)	2 (1)	29 (34)	-	-	4	12.50	11	40.74	31
Higher technical school	5	26	4	25	3	38	12	37.50	14	51.85	33
Other	7	32	1	38	3	45	11	34.38	2	7.41	37
Unknown	4	37	-	-	1	52	5	15.63	-	-	-
Total	18	32	7	28	7	43	32	100	27	100	32

Source: "Eigyōbu oyobi honshiten jimu, kōmuin meibo: dai 4 kyū shain oyobi senmon gakkō jō shushinsha Showa 12nen 9gatsu 4ka genzai" [Directory of white-collar employees of sales department and headquarters office: including over the fourth grade employees and graduates of institutions of higher education, dated 4 September 1937], Kanegafuchi Boseki K.K., 1937. Held by 'Kanebo Collection' at Kobe University, 407-480.

Note 1: As there is no record of department or faculty of origin except university graduates, totals group together mechanical and chemical engineers.

Note 2: Numbers in parentheses show numbers of plant managers (included in total).

Note 3: Nagahama plant (weaving) employed 16 engineers, of which 6.25% were university graduates, 25.00% were technical school graduates, average age 36 years old.

Note 4: Hyogo plant (spinning and weaving) employed 45 engineers, of which 6.67% were university graduates, 26.67% were technical school graduates, average age 37 years old.

Note 5: Sumoto plant (spinning and weaving) employed 30 engineers, of which 0% were university graduates, 20.00% were technical school graduates, average age 40 years old.

of the rayon industry had been supporting the rayon companies to assimilate imported technology rapidly, by providing with the scientific basis and engineers with the requisite chemistry knowledge, and translating relevant research from universities. Thereafter, on this foundation, each company devoted itself to pursuing improvements and applied research to the limits of the technology, which contributed to the international competitiveness of the Japanese rayon industry.

On the other hand, while it is said that synthetic fiber research started late, in 1938 when information about industrialization of Nylon arrived from the United States, companies had enough time and resources to dedicate to new fibers post-rayon, for the establishment of chemical research staff and the organization of research and development had already proceeded on, rayon technology reached to maturity and the expansion of rayon industry was over. Moreover, the companies not only acquired the technology and operation knowhow of chemical industry through rayon production, but were approaching to high polymer chemistry on the research front too, research turning from improvement and applied research centered on rayon and pulp towards cellulose chemistry pursuing the structure, qualities, and rules governing transformation of fibers. Rather than saying that Japanese rayon companies were late starters, it would be more accurate to say that they did not have sufficient time, technological and personnel resources to bring to bear on synthetic fiber research at that time. In the late 1930s, rayon companies began to develop their own original research, going beyond the simple application of scientific knowledge from academia.³⁴

However, as research took off in synthetic organic chemistry including synthetic fibers, the companies reached the limitations on human and technological resources and as a solution to supplement the research and development capability, began to dispatch engineers to universities and to collaborate with universities lying on the relationship that had been built up between them. In addition to companies' research and development capability, the relationships built up during the establishment and development of the rayon industry became an

34. Though several fiber companies had undertaken the beginning research on synthetic fiber before 1938, the full-scale development didn't proceed until the end of the 1930s.

important precondition supporting university-industry collaboration in wartime, and also contributed significantly to the research and development and the industrialization of the synthetic fiber industry in the postwar period.³⁵

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35. For details of collaboration between the rayon industry and universities, see Naoyuki Inoue, *Nairon hatsumei no shōgeki: nairon ga Nihon ni ataeta eikyō* [The impact of the invention of nylon: the influence of nylon on Japan] (Nishinomiya: Kwansai Gakuin Daigaku Shuppankai, 2006); Chikayoshi Kamatani, "Nihon ni okeru sangaku-renkei: sono sōshiki ni miru tokuchō" [Industry-university collaboration in Japan: features of the initial period], *Kokuritsu kyōiku seisaku kenkyūjo kiyō* [Bulletin of the National Institute for Educational Policy Research], No.135, 2006.

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