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Development of Manufacturing Technology of Viscose Rayon Fibers in Japan Since 1930s (Part 1) Pre-War Prosperity (1930～1937)*

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SYNOPSIS :

First, whole history of Japanese viscose rayon industry was divided into eight stages: Stage I (embryo), Stage II (introduction), Stage III (un-aided development), Stage IV (mid-war ordeal), Stage V (post-war reconstruction), Stage VI (post-war expansion), Stage VII (long-term recession) and Stage VII (reformation). In the previous studies the technological advance at Stage II was studied comprehensively. In this article, study on the development of manufacturing technology in Japanese viscose rayon industry at Stage III (1930～1938) was attempted in systematic manner.

1. INTRODUCTION

In 1993, Kamide wrote a brief overview of development of regenerated cellulose fiber industry including three processes (nitrate, cuprammonium and viscose) in his book on history of textile industry[1]. Then, comprehensive historical study on invention and commercialization of regenerated cellulose fibers was made on Chardonnet process[2,3] and cuprammonium process[4,5]. Technology transfer of cuprammonium process from Germany (J. P. Bemberg A. G.) to Japan (Asahi) and further advance of technology by Asahi after the transference to Japan were studied in detail[6~8]. As far as viscose rayon industry in Japan is concerned, catch-up of European technology by Asahi Kenshoku (AKS, or simply Asahi) after technology transfer from Verinigte Granztoff Fabriken A. G. (VGF) to Asahi was surveyed in detail[9] and also career inventry[10] as well as research and development activity[11,12] of white-color senior technical staff employed once by Asahi were investigated.

Kamide[9] showed that the expansion of production capacity of AKS Otsu Factory during 1924～1928 can be classified into three terms: Term I; stage of learning, Term II; stage of imitation,

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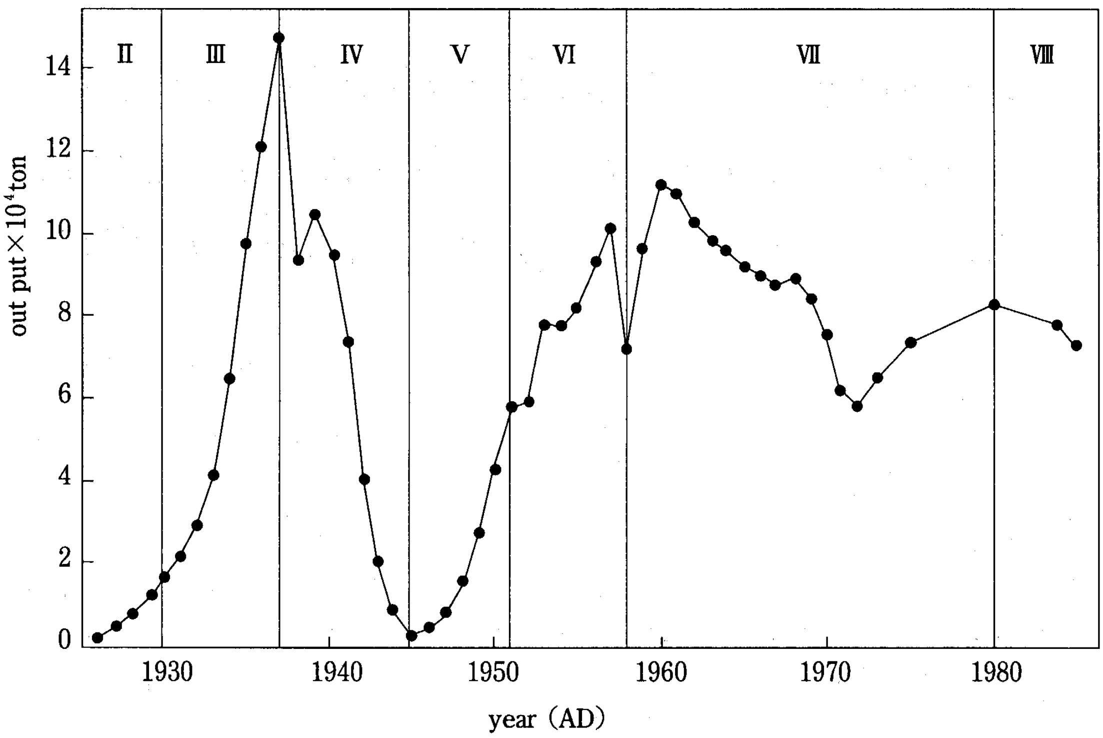


Fig. 1 Out put of viscose rayon yarns in Japan

Term III; stage of mastering. After Term III Asahi modified considerably the original operation conditions of VGF's viscose process to produce the high-tenacity rayon fiber and development of machines was also made by Asahi.[9] In this and successive papers, attempts will be made to clarify the history of technological development in Japanese viscose rayon industry in 1930～1990.

2. STAGE OF DEVELOPMENT (RISE AND DECAY) OF JAPANESE VISCOSE RAYON INDUSTRY

Figure 1 illustrates the output of viscose rayon yarn in Japan. The data points in the figure were cited from ref. 13.

Table 1 shows the stages of viscose rayon industry in Japan. In the table some explanations characterizing the stage are given. The whole history can be divided into eight stages. In Figure 1, the stages are shown as fine lines for comparison. The last column of the table shows analogy of life cycle corresponding to the stages. Stages IV and V are the war-time ordeal and the post-war recovery periods, respectively. These stages are extraordinary stages, inserted into a normal life cycle.

Stage III:

During 1930～1937 Japanese rayon industry had improved by themselves the foreign technology, which had already been transferred in Stage II, and imported not systematically the machines based

Table 1 Viscose rayon industry in Japan

Stage	Year	Period	Remarks	*Analogy*
I	1905～1921	embryo	un-aided imitation: failure by numerous ventures	*Conception*
II a	1922～1925	introduction (learning) of foreign technology	advance two companies (Teijin and Asahi)	*Birth*
II b	1925～1929	to Japan and its establishment	four manufactures got into business later	
III	1930～1937	unaided development prosperity	improvement and rationalization of foreign technology	*Growth*
IV	1938～1945	mid-war ordeals	reduction and closure	—
V	1946～1951	post-war reconstruction	repair of production equipment	—
VI	1952～1956	post-war expansion	licensed production of USA technology	*Growth*
VII	1957～1979	long-term recession and rationalization		*Decay*
VIII	1980～	reformation		—

on the most advanced technology or installed the machines manufactured domestically.

The rayon business expanded remarkably in this period (see Fig. 1): Owing to embargo of gold export, and stoppage of the convertibility of the bank note, both planned and ordered by the financial minister Korekiyo Takahashi of Inukai Cabinet and fall in the foreign exchange rate yen/dollar (¥2～3/$), caused by the above embargo and stoppage, the export expanded greatly. This export booming induced a large expansion of rayon industry. For example, in 1929 Japanese rayon filament yarns production increased by 11.98 times from 12,300 tons in 1929 to 147,304 tons in 1937.

Accordingly, this term (1930～1937) can be regarded as the rayon yarn expansion period. Is further technological innovation necessary even at the time when routine operation of rayon yarn production becomes possible by installing a set of machine? (this is a general situation of Japan in 1928).

Rayon filament yarn industry is basically a kind of chemical industry[14] in which no fully-matured technology, which gives no room of further progress, is practically nonexixtent. For improvement of yarn quality and reduction cost it is indispensable the limitless improvement of operation

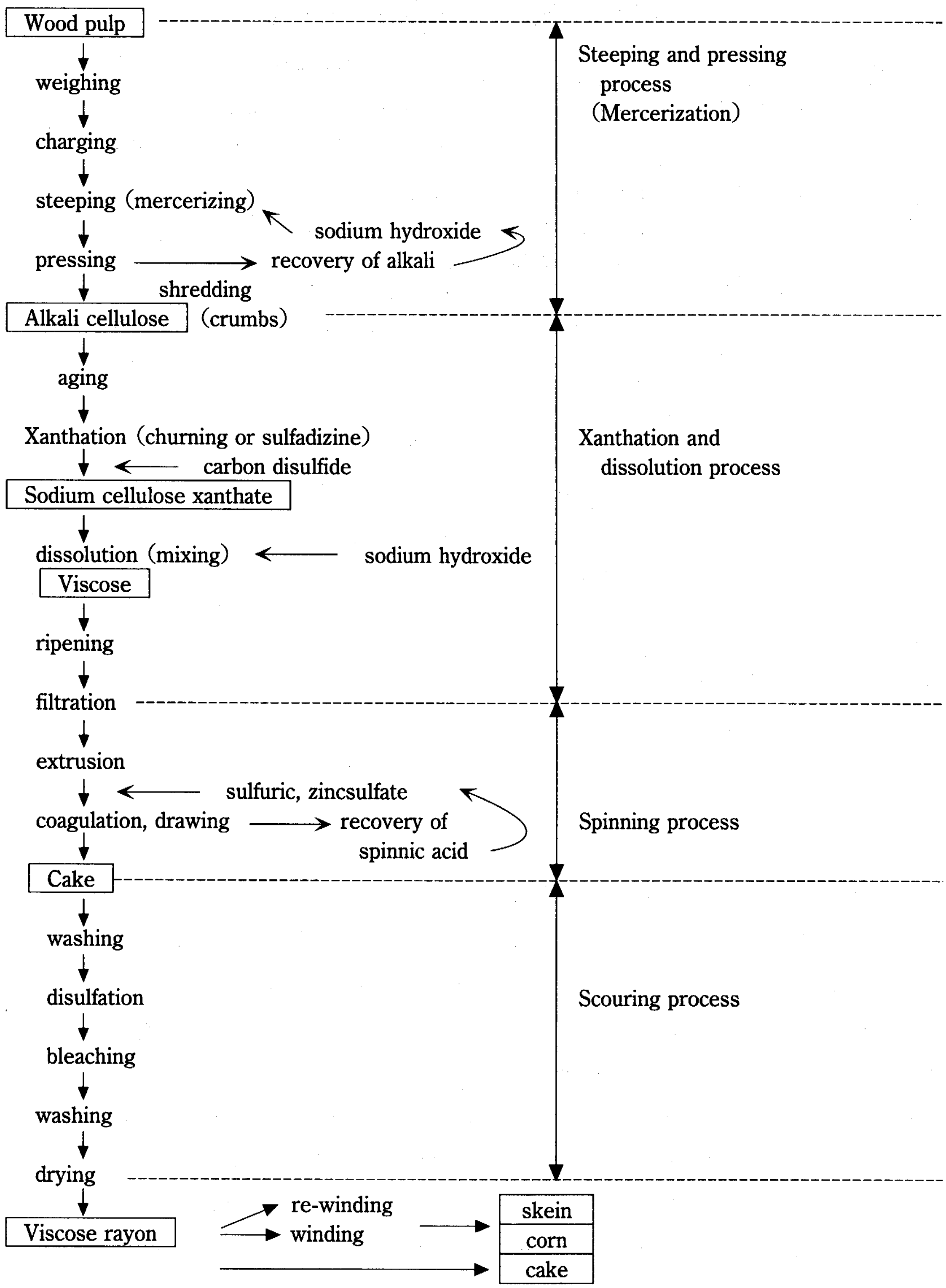


Fig. 2 Manufacturing process of viscose rayon

conditions and the respective replacement of outdated machines with higher-performance much sophisticated equipments. As soon as new investment is suspended decrepit ageing of the instruments may start rapidly[15].

3. MANUFACTURING PROCESS AND GENERAL TECHNOLOGICAL TRENDS DURING 1930～1937

Figure 2 illustrates the typical manufacturing process of viscose rayon filaments.[16～21]

Until 1929 the manufacturing technology had been transferred from Europe to Japan by technical guidance of European engineers.

Here, note that, as Kamide pointed out before[22], even Teikokujinzokenshi (Teijin), which was said to have established so-called 'National technology' by themselves, imported all principal equipments at their main plants from Europe or USA[23] and invited foreign engineers to inspect or to instruct the plant operations[7], and also tried to obtain contemporary European technical informations from the engineers, who quitted off, for example, from Asahi Jinzokenshi (Asahi), to reform the plant.[24]

Thereafter, four companies (Nihon Rayon (Nichi-ray), Toyo Rayon (Toray), Kurashiki Kenshoku (Kura-ray), Toyo Bouseki (Toyobo)) entered later than Asahi and Teijin into a new market, introducing directly the German technology. Note that the process of Emil Bronnert, who was one of creators and once been senior executive of Vereinigte Glanzstoff Fabriken (VGF)[5] and after the world War I dispatched from VGF because his native place (Atsas) returned to France, should be regarded as the German-based technology.[25]

After technology transference, the copies of foreign-made apparatus, not licensed, were installed as nation-made machines in plants.

During 1930～1937 attempts of improvement of the rayon yarn quality and reduction of the production cost were made by modifying the imported foreign technology and up-grading of performance of the manufacturing apparatus.

Table 2～3 collect the manufacturing apparatus equipped in viscose rayon filaments in Japan during 1927～1940. The tables were constructed by using the data of ref 26～29.

4. STEEPING AND PRESSING

Steeping and pressing were at early stage the separated sub-processes. In 1924 when Asahi introduced German technology, it employed steeping press[44] (Mercerisier-Tauchpresse[57]), which was first invented in Sydowsaue plant of Vereinigten Glanzstoff Fabriken.[58, 59] Amalgamation of steeping and pressing sub-processes enabled to save time and man power required to transport of the products between the processes and loss of chemicals.

In 1927, in addition to Asahi, Toray, Toyobo and Nichi-ray had employed this machines.[60] However, even in 1927 some Japanese companies, Teijin and Kura-ray[5] both introduced foreign

Table 2 Change of manufacturing apparatus of viscose rayon filaments in Japan during 1930～1937 (I)

Process	Apparatus and operating conditions	Effects
Steeping	steeping machine + vertical-hydraulic press (traditional) ↓ (steeping dipping-press) machine (1924) (Asahi)[30] holizontal-hydraulic press (sheet)[31] ↓ extruding from front door (1927) ↓ open-and-shut type front door (1933)[32]	continuation or scaling-up of batch
Schredding	Werner pfleider type crusher (traditional)[33,34] (degree of crashing 160 g/ℓ) ↓ continuous type schredder (1936) (Kura-ray) (JB grinder)[35] (degree of crashing 70～100 (g/ℓ) ↓ Eirich shredder (1938) (Nichi-ray)[36,37]	continuation of steps from alkalicellulose preparation to crushing
Ageing	ageing box (traditional) ↓ (17～18 ℃, 70 hr) large scale ageing box (Asahi,1948)[38] ↓ ageing in xanthation reactor or in crusher	shorting of aging process
Transportation of alkalicellulose to xanthation process	transportation by hand (traditional) ↓ pneumatic transportation (1934) (Teijin)[27]	
Xanthation (churning) and	churn[39,40] ⇓ vacuum kneader (1929) Werer-Pfleider Z type[41,42] (1931～1934)[43] ⇓ kneader with safety device against explosion	continuation of sulfation dissolution processes

Table 3 Change of manufacturing apparatus of viscose rayon filaments in Japan during 1930～1937 (II)

Process	Apparatus and operating conditions	Effects
Spinning	spool (bobbin) spinning	
	⇓	
	centrifugal (cake) spinning (1927) (Asahi)[44]	increase in spinning rate
	↓	
	high speed rotation of pot-motor (1927～1936)	improvement of yarn quality
	↓	
	duble-godet type (1933)[27,45]	control of tension on running filament
	↓	
	cover of spinning machine[46] (1940)	increase in amount of spun yarn
Scouring	discontinuous hank-scouring	
	⇓	
	discontinuous hank-scouring (washing＋desulfation/bleaching)	increase in scouring speed
	↓	
	abolition of stretch drying (1930)[47]	lowering of production cost
	⇓	
	cake-scouring (1938) (Toyobo)[48,49]	
Recovering alkali in dipping liquid	non-recovery	
	⇓	
	dialyzer (1929) (Asahi)[50] (Heibig Co.[51,52] and Cerini Co.[53]) Asahi type dialyzer	lowering of production unit of sodium hydroxide
	↓	
	wide diffusion to other rayon makers	
Spinning acid	non-recovery	environmental protection and cost down of acid
	⇓	
	Kestner type acid recovering equipment (evaporator)[55] (Teijin,1929)[27]	
	⇓	
	drum crystallizer (1930,Teijin)[27], (1940,Asahi)[56]	

technology, and Toyobo (Showa-rayon)[61], had employed the above traditionally separated systems.[60] The pressing was done by pressing piled wood pulp[62] sheets with the vertical hydraulic press.

These companies adopted mercerizer-hydropress in 1930 (Teijin)～1933 (Kura-ray). The machine was improved from horizontal-hydraulic press[31] to extrusion type[63] from front door

1927	Steeping → Pressing → Shredding → Ageing → Xanthation → Dissolution
1930s	Steeping • Pressing → Shredding • Ageing ⇒ Xanthation • Dissolution → Hand-transportation ; ⇒ Pneumatic • transportation

Fig. 3 History of amalgamation of spinning dope manufacturing processes of viscose rayon in 1920s～1930s.

(Showa)[61] (1927) and to open-and-shut front door type[63] (Kura-ray)[61] (1933).

In addition, capacity (pulp) of batch unit of steeping press machine increased from 100kg (about 1925)→120 kg or 150 kg→ 200 kg→ 250 kg→ (→ 2,000 kg (about 1945)), resulting in reduction of the production cost[64～67].

Uniform pressing of steeped pulps under higher pressure yields an improvement of higher quality. Typical conditions are as follows: steeping time, 100 min; press ratio, 3.0.[68]

At the beginning (～1924) German-made Werner-Pfeiderer type crusher[69] was imported and then (1933) the same type crusher manufactured by Kotobuki Seisakusho[68] was used (Asahi).

Replacement of Werner-Pfleiderer type crusher with a high speed rotating hammer type continuous crusher, J. B grinder[35] (after 1937～38)[70] (1936, Kura-ray) shortened the crushing time to 1/3 of the original treating time. Degree of crushing was about 160g/ℓ by J. B grinder.[71] By the latter the crushing can be achieved to greater extent. JP grinder is relatively simple in construction and is not readily to break down except abrasion of hammer[71].

In this manner, introduction of mercerization press and JP grinder mechanized fully the process covering pulp steeping to shredding.

In 1938 a rotating disc-crusher[72] (Eirich crusher)[36], which had higher performance than J. B grinder, was installed in Nichi-ray et al.[73] Asahi equipped Eirich crusher in 1948.[72] Eirich crusher had larger capacity and attained better degree of crushing.

Figure 3 demonstrates history of amalgamation of spinning dope manufacturing sub-processes of viscose rayon in 1920s～1930s.

5. AGEING

In the past, for the purpose of adjustment of the degree of polymerization (DP) of alkalicellulose (i.e., reduction of DP), which was produced in steeping step, ageing of alkalicellulose was performed by placing alkalicellulose without agitation in the ageing box normally at 22～24℃ (in winter at 18～19℃)[74] for 24～72hr[75]. This sub-process needed a large number of the ageing boxes and then, a huge land, on which the ageing boxes were set. Later (1948), the size of the box was enlarged.[27, 74]

Table 4 Time of adoption of high temperature-aging method

	Company	
year	ref. 76	re. 77
1936	Kurashiki	Kurashiki
1937	Toyobo	–
1938	Toray	–
1938	Teijin	–

In order to overcome the shortages in the above sub-process (longer time and larger space, necessary for the treatment), ageing (depolymerization) was attempted to carry out in shredder or/and in xanthation machines. This new techniques did not require the ageing boxes and wide land. Additionally, in 1935 in Kura-ray[76] and in 1939 in Toyobo, for examples, the time of treatment was shortened by continuous high temperature-ageing method from 48hr to 8hr[77].

Table 4 collects the time of adoption of high temperature-ageing method.

6. XANTHATION

Alkalicellulose was conveyed by hand to the xanthation process (Fig. 2). In 1934, the transportation method was improved by employing pneumatic method, by which alkalicellulose was conveyed by air in pipe (Teijin)[27].

Xanthation of alkalicellulose and successive mixing sub-process had been done in German-made 'baratte'[78] (churn?) in 1924 at Asahi plant.[79] Baratte was less dangerous, being suitable to homogeneous xanthation as compared with kneader.[79] However, workers had to scrape with oak spalita the viscose (mixture of xanthate and aq. alkali) adhered to the wall of baratte's vessel and the remained xanthate unscraped became loss.[79] If this testimony is right, baratte is considered to have the function similar with kneader and different from dry churn, in which only xanthation occurs.

In 1932 (three vacuum) kneader machines[80] were imported from Germany to Asahi[79] (Otsu plant), in which 12 baratte machines were in operation.[79]

In 1933 nine vacuum kneader made by Kotobuki were equipped at Nobeoka.[81]

According to Ref. 82 Asahi adopted vacuum kneader in 1929, then Showa (1930), Toray (1931), Kurashiki (1933), Nichi-ray (1933), Teijin (1934), Mitsubishi (1934) and Daiwa-bo (1935) followed. Okamura[27] stated that Teijin imported vacuum kneader in 1931～1933.

Table 5 summarizes the time of adoption of vacuum kneader. It can be concluded that ref 79 and ref 77 are the most reliable.

After the xanthation reaction was completed the reaction products (sodium cellulose xanthate) in the churn was transferred into dissolver and mixed with aq. sodium hydroxide, but the reaction

Table 5 Time of adoption of vacuum kneader

Year	Company			
	ref. 79	ref. 27	ref. 82	ref. 77
1929	–		Asahi	–
1930	–		Showa	–
1931	–		Toray	Toray
1932	Asahi	Teijin	–	Asahi
1933	–		Kurashiki & Nippon	Nippon
1934	–		Teijin & Mitsubishi & Daiwa	Kurashiki & Teijin

products in the kneader could be dissolved in situ into sodium hydroxide solution. In this case, toxic manual labor (such as sweeping out the xanthate from reactor putting into the dissolver) was not required and the excessive unreacted carbon disulfide, reminding in the kneader could be removed by sucking it from inside of the kneader. This resulted in not only a significant improvement of carbon disulfide consumption, but also dramatic betterment of working circumstances.

Thereafter, explosion-proof equipment was attached to the cap of kneader and then, security of working was improved.

Capacity of the reactor was expanded from 2,800ℓ to 5,800ℓ. Adoption of kneader enabled amalgamation of xanthation and dissolution sub-processes.

7. WET SPINNING

In 1930s there existed two types of wet-spinning: Bobbin (or Spool)- spinning and cake (or pot)-spinning.

Bobbin spinning :

The filaments of rayon emerging from the coagulating bath are wound without twist onto the bobbins[83]. Viscose yarn spun on the spool (bobbin) is called as spool-spun (or bobbin-spun) yarns.

Merits and demerits of the spool wet-spinning are summarized in the previous paper[9]. Lieser distinguished 'Spulen spin mashinen' from 'Walzen (cylinder) spin verfahren'[84]. Walz was originally made of glass and Spul (spool) was made of paper clay. VGF used aluminum cylinder coated with acid-resistant Bakelite resin.[84] Ozawa[85] and Oka[86] also discussed briefly advantage and disadvantage of the bobbin-spinning. Note that Oka's comment is the same as that of Ozawa.

Table 6 Some mechanical properties and yarn qualities of viscose rayon yarns produced by spool (bobbin) spinning and cake spinning (120d, multifilament)[1]

Yarns	Tensile elongation (%) dry	Tensile elongation (%) wet	Yield of 1st grade yarn (%)	Fuzz rate (%)
Spool type	20.9	31.0	93.0	4.2
Cake	20.6	31.9	93.5	2.0

* : calculated using the records (July 1937～December 1937) shown in History of Asahi Kasei Rayon Factory p41.[91]

Cake (or Pot)-spinning:

The filaments extruded from each spinneret is led out of the coagulation bath and around a glass wheel, whose surface has regular detaches in order to reduce slippage of fiber and wheel (Godet wheel or Godet roller; Galette) (the first or bottom godet). Then, fibers pass around a second wheel (top godet). The stretching is applied to the running yarn between two godets (if double godets system is adopted). After stretching the godets lead the fibers, by change of direction of running filaments, into a pot (Topham box), which is a hollow container. The fibers are twisted (about 2.5 turns per inch of yarns) and flung against the wall side by centrifugal force, formed by rotation of a pot (6,000～10,000 rpm), and build up into a 'cake' of filaments inside the box.[87～89] The fibers wound in cone-shape in pot is often called as cake, in which decomposition of cellulose xanthate is not yet complete.[90] Godet acts as a controller of filament denier, because the denier is determined by the balance of pulling power due to centrifugal force into a rotating pot and the rotation velocity of the godet. The viscose yarn spun on the centrifugal system in the cake form is called as centrifugal type yarn or cake-spun viscose yarn.

Table 6 collects comparison of some mechanical properties and yarn qualities of spool yarns with those of the centrifugal yarns.[91] Although there is no significant difference in average mechanical properties and the first class yarn yield between two methods, the occurrence of fuzz of the spool yarn is about twice of that of the centrifugal yarns, indicating that the cloth quality is apparently superior in the centrifugal yarns.

Since in the bobbin spinning the yarns are untwisted additional twisting sub-process is needed (see, Fig. 4). On the other hand, in the cake-spinning the yarns, extruded from die, are twisted between godet and pot (in the spinning step) and do not need to be twisted further in the later stage.

Table 7 lists the labor force required in the twisting and the re-winding sub-processes in two types spinning procedures. The table was reproduced from Table 9 of ref. 7.

Conversion of the spool spinning to the cake spinning can reduce the labor force in twisting and

Table 7 Labor force required of twisting and rewinding processes*

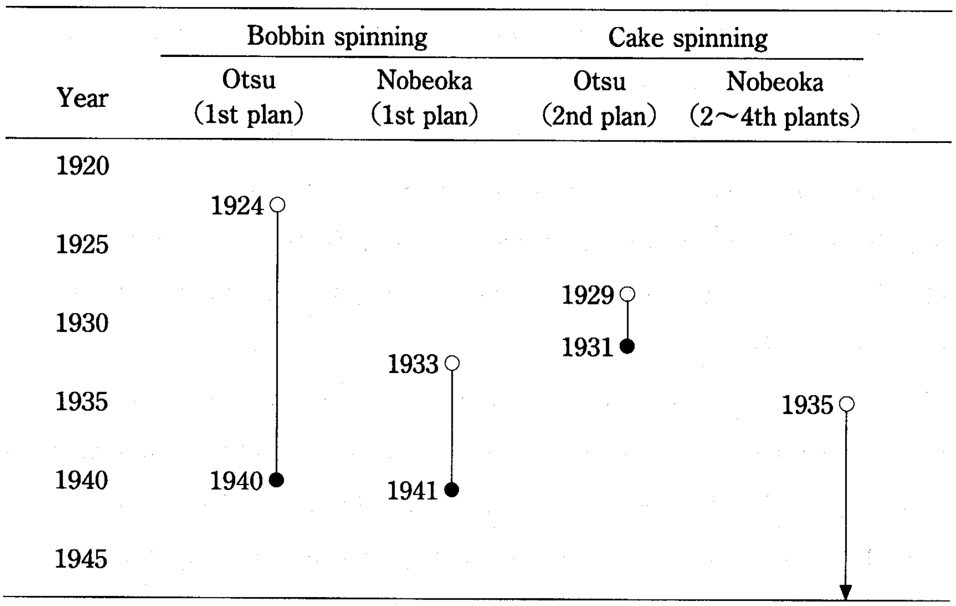
	Spool	Centrifugal
Production (case)	75,543	122,656
Twisting		
total	216,236	–
per case		2.86
Rewinding		
total	334.20	480,705
per case	4.42	3.92

* : calculated from Table in p40 of History of Asahi Rayon Factory[92]

rewinding processes by a factor of 1/1.19. In 1930 the factory cost per one case was ¥52.38 for spool yarns and ¥52.63 for cake yarns, respectively.[92] Then, we can conclude that in spite of significant difference in labor expenses between the two methods, the production costs, which contain of course labor costs, are almost the same.

Table 8 summarizes the period of plant operation of the bobbin spinning and the cake spinning at Asahi. It is interesting to note that the bobbin-spinning method was introduced to the first plants in both factories (Otsu and Nobeoka) although the introduction of method was made at different years (1924 at Otsu and 1933 at Nobeoka). In 1933 the cake-spinning method had already been established at Otsu Factory. Nevertheless, Asahi chose the bobbin-spinning method at new Nobeoka

Table 8 Period of plant operation of two kinds of spinning methods at Asahi



○ : start of operation, ● : suspension (or abolition) of operation

Factory. Stoppage of the plant operation was not decided based on the principal of purely economical competitiveness, but on its adaptability to the numerous war-time requests and limitations.

As noticed before[1], the table indicates that the outstanding performance of the rewinding sub-process (advantage (6) in the previous paper[7]) is not true merit of the bobbin spinning, but the high labor cost in twisting sub-process (disadvantage (1) in the previous paper[7]) is a demerit of the method. The poor fiber quality was fatal blow to the bobbin spinning. In an earlier stage a centrifugal type spinning machine had 90 spinnerets (=spindle) each. Capacity of the machine was later scaled-up: The following machines were developed: machine with 90 spindle→150 spindles →200 spindles. In this case, the winding tension varied from the outer layer of cake (spun at initial stage of spinning) to the inner layer (spun at later stage of spinning), limiting the size of cake.

The variation of winding tension along the spun yarns brings about the deterioration of uniformity of yarn quality.

The original machine had a single godet, inserted between the die and the centrifugal spinning pot.[93, 94] In 1933 the double-godets system was installed by Teijin[27] in a centrifugal type machine.[95~98] The tension of running yarn in the spinning sub-process by usage of the double-godets system, (and then the yarn weight of a cake) could be increased (i.e., enlargement of cake size and long time spinning).[99]

In order to increase the spinning velocity the pot motor was rotated at high rate of rotation. During 1929~1936 the operational rotation rate of the pot motor was increased from 6,000 rpm to 8~9,000 rpm and finally to 10,000.[100] Kura-ray (before war) 9,000 rpm; Nichi-ray (1936), 8,000~9,000 rpm; Toyobo, 8,000 rpm. The take-up velocity (i.e., the spinning velocity) reached up to 95~97 m/min by pot motor rotating with 9,000 rpm.[100]

In 1940 cover was put on the spinning machine and the working circumstance were remarkably improved.[2]

Comparatively large phenol-formaldehyde resign pots have the following characteristics.[102]

Advantage:

(1) lower frequency of change of the pots → lower man power cost in spinning sub-process.

(2) smaller loss of fibers at initial and final stages of the spinning per unit weight of product.

(3) smaller fluctuation of denier of the fibers wound at inner and outer sides of a pot (compared at the same weight of spun filaments).

Disadvantage :

(1) high power consumption

(2) higher frequency of damage → increase in repairing costs.

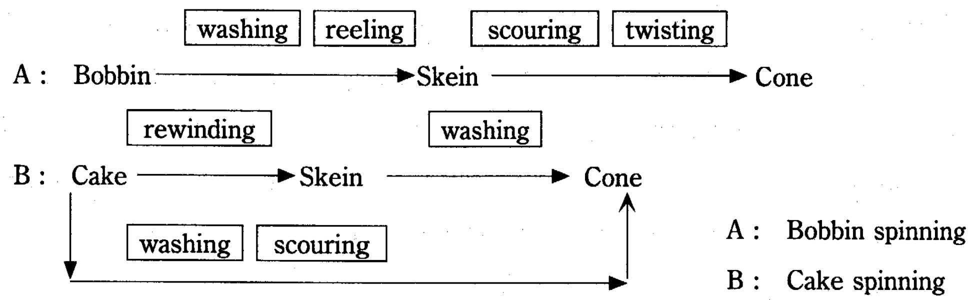


Fig. 4 After-treatment of viscose filament yarns

8. WASHING, SCOURING AND BLEACHING

Figure 4 shows steps of after-treatment of viscose filament yarns.

Cake was rewinded to skein (Fig 2). The skein were, at early stage, scoured non-continuously (batch). That is, the scouring was carried out through three steps: skein washing, drying (machine) and scouring and bleaching (machine). The above system was thereafter substituted by the continuous skein scouring. In a new system washing and bleaching were carried out inside of a machine, resulting in an increase in the scouring velocity.

In 1930s the stretch-drying operation was entirely abolished[47], leading to reduction of the production expenses[1]. In 1938 cake-scouring system was introduced.[48, 49]

9. RECOVERY

Until about 1928 bi-products, produced in the viscose rayon process, for example alkali component contained in the steeping liquid and sodium sulfate in the spinning liquid, were not in the least recovered. Alkali in steeping liquid was (1) abandoned, or (2) mixed with scouring liquid in the scouring process, or (3) sold to paper mill or soap mill at cheaply low price. Since about 1929 the dialysis method had been started to be applied for alkali recovery. At first, dialyzers, made by Heibig[51, 52] and Cerine[53], had been successfully imported from Europe. Sodium hydroxide consumption per fiber unit weight was reduced by dialyzer from about or above 1 to 0.85～0.90[103].

The production cost was decreased by recovery of alkali with by hydrolysis by 0.2×10 = ¥2/100 ℓb yarns. According to Artificial silk 1939 almanac[104], the production cost at that time was ¥about 67/100ℓb yarns. Then, sodium hydroxide waste correspond to about 3% of the total cost. (see, also Table). Benefits in 1939 are estimated as selling price－production cost－selling cost＝86.5－66.6－6.0＝¥13.9/ℓb rayon. Therefore, the recovery of alkali brought maximum 21% increase in the benefits.

Asahi type dialyzer, which is based on the same principle as that of Heibig type dialyzer, was

Table 9 Comparison of performance of three dialyzers

	Heibig		Cerni		Asahi
Capacity:					
waste liquor (ℓ/day)	735	≈	740	<	3000
waste liquor/membrane (ℓ/day・m^2)	15.24	>	45	≤	36.36
Alkali recovery (%)	86.5	<	90	<	95
Hemicellulose conc in recovered liquor (%)	0.03	<	0.1~0.2	>	0.02
Life time of membrane (day)	30	<	300	>	18
Working time for replacement of membrane (hr)	24	≫	2	<	12

invented by Tachikawa in 1929[105] ~1930[106] and completed in 1929(June)[107]. Asahi dialyzer was adopted by Nichi-ray (1930) and Kura-ray(1931)[107].

Table 9 summarizes the performance of three major dialyzers.[108] The table was constructed by Hirakawa using ref. 109~113. It is obvious that Asahi type dialyzer has the largest capacity (per unit apparatus), the highest efficiency (when expressed by waste liquor/membrane (m^2), day), the highest rate of alkali recovery (the weight ratio of recovered to input sodium hydroxide), giving the most pure recovered alkali.

Its disadvantage is the shortest life time of membrane. Note that in Asahi type the pressure applied the both sides of separating membranes should be strictly balanced in order to avoid to give the possible damage to the membrane[114].

Asahi dialyzer had been manufactured by Kotobuki Seisakusho. At that times, among many 'made-in-Japan' viscose manufacturing apparatus only Asahi dialyzer had been successfully exported world wide (mainly to USA).

At early stage the spinning acid waste (often called 'waste acid') (dilute sulfuric acid and sodium sulfate) in spinning bath had been disposed without any further treatment. In 1930 for purpose of acid recovery Kestner type evaporator[55] was installed by Teijin(1929), Showa(1930), Toray(1930) and KuraKen(1930)[115]. Here, the concentrate sulfuric acid thus recovered was again reused as the spinning acid. Furthermore, about in the same year (1930[115] or 1931[27]) drum type crystallizer was used by Teijin et al.[115] to eliminate sodium sulfate by crystallization from the waste acid and the sodium sulfate crystals were sold. Asahi started the plant operation of drum crystallizer at

Nobeoka in 1940[116]. In this manner the spinning acid waste was recycled in the viscose rayon process to realize the circumstance protection and the reduction of the production cost.

Note that in this period (1930~1937) the viscose rayon manufacturing apparatus were first imported from Europe, and then, their copies or modified machines of the European-made, were manufactured in Japan for domestic use, except for Asahi dialyzer.

10. MISCELLANEOUS TECHNOLOGICAL ADVANCES FOR COST REDUCTION

(1) Abolition of addition of glucose into coagulation bath:

In earlier times glucose was added to the coagulation bath to make 10% solution. It has been said that glucose may prevent crystallization of sodium sulfate inside the filaments (or yarn), which brings about occurrence of fuzz of the finished fibers.[117] Then, the function of glucose was often questioned and the concentration of glucose was gradually diminished, finally to zero (that is, addition of glucose was stopped): Kura-ray (before 1930)[118], Nichi-ray (before 1930)[118], Toray (about 1931)[119], Teijin (1931~32)[118], and Asahi (1941)[120]. In this respect, Asahi was the most faithful disciple of the German technology. The cost of glucose addition was estimated to be about ¥10/100 lb-fiber[117], which was more than 10% of the total production expenses (see Table 12). Therefore, the stoppage of addition of glucose made a significant contribution to the cost reduction.

(2) Self-sustenance of sulfuric acid and carbon disulfide:

Asahi established first the sulfuric acid plant with capacity of 20,000 ton/year in 1933[2] and the carbon disulfide plant with capacity of about 400 ton/month[3] in its Nobeoka viscose rayon factory.[122, 123]

(3) Substitution of imported parts with domestic ones:

In addition to replacement of imported major machines, as described before, some parts of the machines and tools were also substituted by domestic goods. several examples are shown below:

(a) Spindle motor was first imported from Siemens (Germany), then the motor made by Kobe Seiko was used.[124]

(b) Spinning pump was first imported from Italy, then, from USA and was gradually replaced by domestic pump.[124]

(c) Pot was made by Japan Bakelite and the price was down to 1/20 of the imported pot.[124]

(d) Godet, designed by Toyobo and manufactured by Shimada Glass, was utilized. The price was diminished from ¥30/piece for an imported godet to ¥0.2/piece for a domestic one.[124]

(4) Life time of the spinning machine increased from 3～4 years to 10～13 years by covering all apparatus, including the coagulation bath and trough, which might be exposed to acid spray of coagulation liquid, with lead plate.[125]

(5) Home generation station of electricity was installed in order to avoid instantly power failure[126, 127], often occurred at that days in Japan[128]: Asahi (1933[126])

11. QUALITY IMPROVEMENT AND REDUCTION OF PRODUCTION EXPENSE

Following endeavors were done to improve fiber quality and to reduce manufacturing expenses.

(1) Improvement of quality of pulp and chemicals:

Utilization of high α-cellulose (i.e., high molecular weight cellulose) and low resin wood pulp and improvement of purity of sodium hydroxide. For this purpose, the resources which meet the above criterion were domestically produced. Improvement of quality of resources allowed simplification of the subsequent steps (see, Fig.2) (for example, increase in solubility of sodium cellulose xanthate into aq sodium hydroxide resulted in lowering of filtration pressure (of viscose dope)) and brought about lowering of production expenses per unit weight of the product and also leaded to improvement of the fiber quality.

(2) Uniform xanthation:

Both choice of the reaction conditions and improvement of xanthation vessels (churn and kneader) decreased the portion of unreacted or lowly reacted materials.

(3) Complete dissolution of xanthate:

Preparation of spinning dope, in which xanthate is completely dissolved and no undissolved materials is included, from even reaction products (see (2)) by improving the dissolving method such as agitation method.

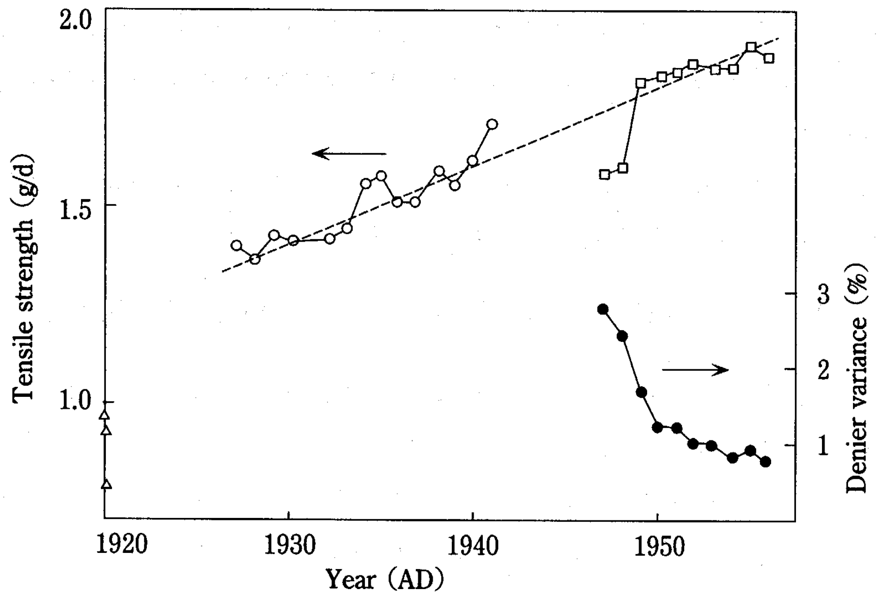
(4) Purification of spinning dope (completely dissolved spinning dope):

Preparation of colorless, transparent viscose liquid by thorough going of filtration (precise filtration and filtration equipment, which permits precise filtration) (in addition to (2) and (3)). Completely dissolved spinning dope resulted in cut down of frequencies of occurrence of blockage in spinneret holes and also made long-time operation possible. As result, this leaded an improvement of the fiber quality as well as the operation efficiency.

(5) Increase in spinning velocity:

With help of (4) and improvement of spinning machine (for examples, adoption of double godet and pot motor) the spinning velocity was increased. Note that speed-up of spinning contributed significantly to lowering of the production cost, but not to improvement of fiber quality.

(6) Scale-up of batch operation unit:



△ ; Kamide, History of Textile Industry, p293[130] ○ ; History of Japan Text. Ind., p613, Table 5[131]
● , □ ; History of Japan Text. Ind., p601, Table 20[132]

Fig. 5 Tensile strength (TS) and variance of denier of viscose rayon filaments.

Decrease in fluctuation of fiber quality was realized by installment of large capacity equipments.

(7) Shortening of the reactions such as mercerization, ageing and xanthation: Installment of steeping press, ageing tower (high temperature ageing) and kneader.

(8) Simplification and amalgamation of individual process:

Amalgation of (steeping and pressing), (shredding and ageing) and (xanthation and dissolution) (Fig. 3).

Unevenness of filament denier is one of parameters representing the yarn quality. Fluctuation of denier of the filament emerged from a given spinneret was influenced by the following factors[129].

(1) fluctuation of viscose out-put of the pump

(2) adhesion of a filament flowed out from the adjacent hole or reversely running of a filament from a given hole to adjacent yarns.

(3) loose of the godet and slipping of the pot.

(4) winding of a filament or coming out of a filament

(5) lowering of pressure of the viscose

(6) closure of spinning nozzle or candle filter

(7) weak hole or blind hole

(8) inadequate composition of the viscose components.

Figure 5 plots the variance of yarn denier of Japanese viscose rayon during 1920～1960. The

Table 10 Diversification of viscose rayon products

Yarn	Brands of product (description)	Remarks
1925	fine denier (90d) artificial silk yarn (A)[133, 134]	
1926	fine denier (75d) artificial silk yarn (A)[133, 134]	
	and heavy (300d) artificial silk yarn (A)[133]	
1927	multi-filaments yarn (A) : 150d/40f[133]	1929, Te[135] ; 1934, To[136]
1930	dull (delustred) fibers (Te)[137]	1926, UK
1929	hollow rayon fiber (To)[138]	
1931	viscose staple fibers (Te[139], N[140])	1937, A (Otu)[141]
		1938, A (Nobeoka)[141]
1934	dull multi-filament (A) ; 120d/50f[142], To[143]	1920, UK,
		1934, (Courtaulds)
1935	ultra-dull (matt) yarn (To)[143]	
1937	super multi-filament yarn (To)[145]	
	110d dull-filament (A)[146]	
1937	crimped rayon staple fiber[147]	1932 Swizz
1938	wool-like (Gimo) yarn (To)[148]	
1940	high molecular weight staple fiber (A)[149]	
1940～41	high tenacity rayon (ToB)[150]	1937 UK (Courtaulds)
1942	Tire cord (A) 1.2～1.5 g/d→1.8～2.0 g/d[151]	
1943	Toramomen (A)[9]	

A; Asahi, Te; Teijin, To; Toray, ToB; Toyobou, N: Nihon-rayon

yarn uniformity was improved remarkably.

The tensile strength (TS) (g/denier) is another parameter of average fiber quality. Figure 5 shows also change in the tensile strength of the viscose rayon yarns.

Stronger yarns could be produced at the later years. Change in uniformity of yarn denier and TS with the year of production imply the steady progress of the viscose rayon technology in Japan. The data in 1927～1941 correspond to those of 'A' company, whose name was not described[131]. In the figure, the data for after-war were cited also. Except for the recovery period, immediately after the world war two (data for 1947 and 1948), the TS data in post war years (1949～1956) are on the line extrapolated from the pre-war (1927～1941) TS data.

12. DIVERSIFICATION OF RAYON PRODUCTS

Improvement of rayon yarns, especially an increase in the tensile strength (TS), made the development of new brands possible. Table 10 exemplifies new brands commercialized in Japan during

Table 11 Production of viscose rayon yarns with different deniers

	Relative out-put of fiber(%)				Total (case)	Table 1 Remarks
	>100d	120d	150d	>200d		
1934/Sept	0.13	69.0	19.4	110.3	120,852	8 companies
1937/June	2.1	73.2	14.2	10.4	278,794	8 companies
Grows ratio	3.87	2.45	1.69	2.33	2.31	—

* calculated from Table1, p101 of ref.152.

1925 ~1944. The last column of the table shows the first manufacturer of similar brand in the world. All brands, shown in Table 10, had been developed by themselves except for 90 denier yarn by Asahi (1925), which had been commercialized by introducing VGF's technology. Note that all these brands had been originally invented in Europe and come into market several~ten years earlier than Japanese companies did (see the last column). Then, in this period(stage III) Japanese rayon industry attained to the level ,which enabled them to catch-up or imitate new European technology some years behind Europe, although they could not invent a thoroughly new brand. Then, the new brands in the table can be considered as the achievements due to a kind of imitation or modifications. Any way, exploration of new brand of rayon fiber enabled rapid spreading of rayon commodity in the case of woven cloth field.

Table 11 collects relative the out put of viscose rayon yarns with different deniers at September 1934 and June 1937, respectively[152]. The data were taken from eight major companies. Numerous new viscose manufactures, which were established during 1934~1937, produced 120denier yarns, but their records were not taken into account.

In the table out-put of yarns within approximately three years the total out put increased about 2.3 times. The growth of production is concentrated in the fine denier fibers.

Figure 6 illustrates the history of diversification of viscose rayon products. The figure was constructed on the basis of ref. 153~155.

Table 12 illustrates the items of the production expenses of viscose rayon yarns during 1926~1988. In the table the production costs are shown as yen per 100ℓb fiber (1926~1937) or per 1 kg fiber (1952~1988). The Table was constructed from various sources[156~160], in which the detailed items are different from source to source: 1926~1930: ref. 156; 1932,1934: ref. 157,158; 1937: ref. 159; 1952, 1956: ref. 160. For example, business packaging cost was classified as production cost, but business cost was regarded as general administration expenses. It is not clear whether operation cost is included in general administration expenses or not. Note that some data do not satisfy the condition: Factory cost price = (1) + (2), but the table was reproduced as it was.

braid cord (predominant product in 1917～1918)
↓ ← improvement of tenacity (1925)
braid sash (obi) and shawl cloth (1919～1921)

mixed-weave fabric (1919～1921)
↓
cloth (from 1922 onwards)
(Habutae artificial silk : heavy, easy to wrinkle, excessively luster and cool touch)
↕
non-twisted yarn cloth
↓
plain weave (plain fiber)
↓
jacquard stain weave (plain fiber)
↓
striped twill (plain fiber)
↓ ← improvement of tenacity by using twisted yarn
silk crepe : georgette
↓
artificial silk (both the warp and weft are viscose rayon) (1933～1935)
(golden age of crepe)
↓ multi-dull filament
improvement of cloth handling (feeling)
↓ ← usage of twisted yarn and specialized yarn
(high class weave, mixed weave of rayon and silk)
kimono, pongee, crepe (for domestic market) (1939)

satin mix (for Chinese market) (1939)

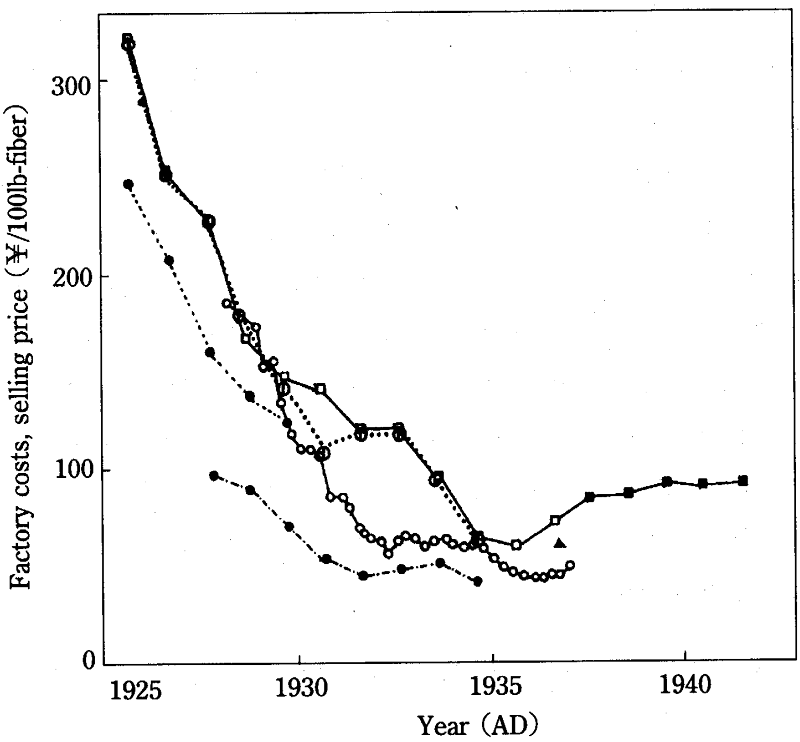
Fig. 6 Evolution of service rayon commodity in Japan during 1917～1939

Figure 7 shows the factory cost and the selling price of viscose rayon yarns in Japan. Selling price was continued to decrease with year quickly from 1920 down to 1935 and this long-term trend turned over in about 1936. The lowering of the price was very effective to expand a new market of viscose rayon yarns. The production costs also decreased remarkably with year from 1926 down to 1932～1933. Since then, lowering of the costs stopped almost (Teijin) or became gentle (Nihon rayon): Since 1932～1933 further lowering of raw material costs had ceased an only reduction of wages owing to rationalization of the process and mechanization contributed notably to the total cost reduction.

The difference of the production cost between two companies (Teijin; a pioneer, or a

Table 12 Production cost of viscose rayon

Item	Cost ¥100ℓb fiber									¥/kg fiber		
	1926	1927	1928	1929	1930	1932*	1933	1934	1937	1952	1956	1988
(1) Resource Raw materials cost												
(i) pulp						9.80	17.00	12.50	17.25			
(ii) chemicals { alkali	100	80	60	50	47	15.40	20.00	18.20	19.07	111.80	82.80	174.3
other												
(2) Manufacturing cost												
(i) wages						17.50	10.00	5.80	7.00	27.01	22.30	167.9
(ii) power costs { fuel						7.70			3.50			
electricity						6.30	8.00	3.50			16.80	60.0
water	125	105	80	68	61	2.80		0.90	3.85			
(iii) other expenses										19.66		
business and packing						10.50	4.50	5.10	13.00			
(iv) deduction										△2.3	△0.50	
(v) repairing cost												57.2
(vi) depreciation	25	23	22	20	18	5.60				72.5		
Factory cost price (≡(1)+(2))	250	208	162	138	126	70.00	59.50	46.00	69.27	160.67	135.80	642.9
(3) Administration expenses												
(i) general administration cost										12.00	16.80	94
(ii) interest payment										2.50		
(iii) operation cost												
Total cost price (≡(1)+(2)+(3))										175.17	152.60	719



⊙ ; factory costs (120d fiber)[161], ● ; factory costs (Teijin)[162], ○ ; factory costs (Nihon-rayon)[163], □ ; selling price[164], ■ ; selling price[165], ⦶ ; selling price[166], △ ; factory costs (Teijin Hiroshima)[167], ▲ ; factory costs (regular rayon)[168]

Fig. 7 Factory costs and selling price

Table 13 Relative factory expenses in the end of 1933*

	Factory expenses ¥/case of yarn**				
Item	USA	UK	Germany	Italy	Japan
Pulp	0.96	0.96	0.98	1.00	1.00
Chemical	2.09	2.05	1.88	1.61	1.00
Wage	5.03	4.56	3.38	1.63	1.00
Energy	3.33	2.00	1.52	1.77	1.00
Administration	4.87	3.46	3.21	1.13	1.00
Total	2.58	2.47	2.08	1.37	1.00

* constructed from Table 3, p614 of History of Japanese Textile Industry[169].
** 1 case = 100ℓb yarn

manufacturer which started the rayon production earlier and Nihon rayon; a manufacturer which got into the business later or successor) is estimated to be ¥90/100ℓb of fibers in 1928 and ¥(about) 50/100ℓb of fibers in 1930. Thereafter, the gap shrinked down to ¥10 in 1934~1935. It is clear from the figure that for ten years (1925~1935) viscose rayon business enjoyed extremely profitability, especially to the manufacturers who commercialized the production at early stage. The factory expenses in Japan can be compared with those in the advanced countries. The results, estimated at the end of 1933, are summarized in Table 13. The table was constructed using the data in ref.169.

The factory expenses in Japan was only 0.39, 0.41, 0.48, and 0.68 of those in USA, UK, Germany and Italy, respectively. The pulp cost was the highest in Japan, where the pulp was imported almost entirely from Europe (mainly, Norway) and USA: Portion of imported pulp was 100% up to 1930, 96% in 1931[170] and 75% in 1936[171]. The wage in Japan was 1/3～1/5 of those in European countries, except Italy. In addition to the wage, other items such as chemicals, energy and administration cost in Japan are 1/2～1/3 of those in Europe and USA, except for administration cost in Italy. Self-sustenance rate of sodium hydroxide increased from 54% (in 1931) to 75% (in 1932) and finally to 100% (after 1933).[172] It is clear from the table that in 1930s Japan rayon industry had the strongest international price competitiveness.

13. JAPANESE VISCOSE RAYON INDUSTRY AT PRIMACY IN 1937

In 1937 Japan enjoyed to hold top out-put of rayon yarn over the world, implying that Japan had gained (even if, temporal) the biggest capacity in regenerated cellulose fiber industry in the world. Soon (next year) Japan rayon industry slipped down the summit due to the war-time restriction against rayon production and had never restored its primacy afterwards. Our simple question is: 'Had Japanese chemical fiber industry the best constitution in the world at that time for rayon production?'

Yamazaki wrote (in japanese) that until these days (1933) Japan catched-up to the technological level and the factory production scale, both of world first class[173]. Report of Chemical Fibers Technical Committee, dated on Jan. 1948, was briefly cited by Yamazaki as 'technical power strength, which allowed Japan to establish the world-widely recognized chemical industry from zero base'[173]. Ref. 174 commented (in japanese) that 'Chemical fiber industry in Japan had made a remarkable progress and its absolute level of technology and production scale had attained to the same level as that of some European countries and USA, keeping relative superiority' and 'for woven fabrics as finished goods Japanese relative superiority became utterly absolute'. Japan kept the top position in fabric export among ten countries (1937～1955)[175].

However, it should be noted that Japanese viscose rayon technology intended only to make an approach to European technology through technology transfer (including imitation) and we can never say that 'Japan had succeeded to catch-up to the level of world first class'. That's why at the moment when the predominantly one way flow of technology from Europe and USA was suspended (1937～1945) the gap of technology level between Japan and the advanced countries, at that times, expanded significantly[176].

14. CONCLUSIONS

(1) Stage III (1930 ~1937) is a period of prosperity for Japanese rayon industry.

(2) The manufacturing process was up-dated by amalgamation of some sub-processes (steeping and pressing; xanthation and dissolution), by continuation of sub-processes (pneumatic transportation of alkali cellulose from press to churn) and by recovery of wastes (alkali waste by dialysis; sodium sulfate by crystallization; acid waste by evaporation). These improvements reduced the cost remarkably.

(3) First, European-made most sophisticated machines were imported. Then, the machines were made by Japanese machinery manufacturers. Some machine parts were also made in Japan. This also contributed to reduction of the production expenses.

(4) Fiber qualities such as the evenness of denier and the tensile tenacity of yarns were improved. The high quality fibers including multi-, fine denier-, and full-dull- filament yarns were produced.

(5) The rayon commodity expanded, according to the improvement of yarn quality, into various branches from braid to kimono of 100% rayon.

(6) The pulp cost was the highest, but the total production cost was the lowest in Japan among Europe, USA, and Japan, indicating the strongest international price competitiveness of Japanese rayon fiber industry.

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33. *History of Asahi Rayon Plant*, p44.
34. See, for example, E. Oka, op.cit., p37. Fig. I .20.
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36. See, for example, E. Oka, op.cit., p38, Fig. I .23.
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112. Osaka Regional Court, Judgment No.1405 (File of Prohibition of Conduct of Infringement of Patent Right and Demand for Composition for Damages), Evidence A of Asahi Kenshoku, 24, June, 1932.
113. *History of Japanese Chemical Fiber Industry*, p155.
114. See, foe example, T. Ozawa, op. cit., p109-111.
115. *History of Japan Textile Industry*, p.616.
116. *History of Asahi Rayon Plant*, p50.
117. *History of Japanese Chemical Fiber Industry*, p155.
118. *History of Japanese Chemical Fiber Industry*, p156.
119. *History of Toyo Rayon*, 1926-1953, Toray, 1954, p84.
120. *History of Asahi Rayon Plant*, p64.
121. *History of Asahi Rayon Plant*, p60.

122. *History of Asahi Rayon Plant*, p61.
123. *History of Japanese Chemical Fiber Industry*, p157, Table 7: The date of plant establishment was erroneously written as 1993.
124. *History of Toyo Rayon*, p83..
125. *History of Japanese Textile Industry*, p615.
126. *History of Asahi Rayon Plant*, p28.
127. *History of Japanese Textile Industry*, p614.
128. K. Kamide, *History of Textile Industry*, p361.
129. T. Ozawa, op. cit., p205.
130. *History of Textile Industry*, p293.
131. *History of Japanese Textile Industry*, p613, Table 5.
132. *History of Japanese Textile Industry*, p601, Table 20.
133. *History of Asahi Rayon Plant*, p77.
134. *History of Japanese Textile Industry*, p614.
135. *History of Japanese Textile Industry*, p615.
136. *History of Toyo Rayon*, p89.
137. *History of Asahi Rayon Plant*, p41.
138. *History of Toyo Rayon*, p90.
139. *History of Japanese Chemical Fiber Industry*, p213, Table 2.
140. *History of Japanese Chemical Fiber Industry*, p214.
141. *History of Asahi Rayon Plant*, p10, p48.
142. *History of Asahi Rayon Plant*, p87, Table.
143. *History of Toyo Rayon*, p89.
144. *History of Toyo Rayon*, p90.
145. *History of Toyo Rayon*, p89.
146. *History of Asahi Rayon Plant*, p79.
147. *History of Japanese Textile Industry*, p613.
148. *History of Toyo Rayon*, p90.
149. *History of Asahi Rayon Plant*, p66.
150. *70 years History of Toyoboseki*, p299.
151. *History of Asahi Rayon Plant*, p66, p79.
152. *History of Japanese Chemical Fiber Industry*, p101, Table 1.
153. K. Kamide, *History of Textile Industry*, p374-375.
154. K. Kamide, *History of Textile Industry*, p375.
155. K. Kamide, *History of Textile Industry*, p293.
156. *History of Japanese silk and artificial silk textiles*, Fujin Gahosha, p281.
157. *History of Japanese Textile Industry*, p614, Table 3.
158. *History of Japanese Chemical Fiber Industry*, p131, Table 22.
159. *History of Japanese Chemical Fiber Industry*, p183, Table 1.
160. *History of Japanese Chemical Fiber Industry*, p447, Table 2.

161. *History of Japanese Chemical Fiber Industry*, p110, Table 15 (cited from Artificial Silk Year Book 1938).
162. *History of Japan Artificial Silk*, p281, Table.
163. *History of Japanese Chemical Fiber Industry*, p110, Table 4.
164. Data of Company 'A'.
165. *History of Japanese Chemical Fiber Industry*, p183, Table 1.
166. *History of Asahi Rayon Plant*, p101.
167. *History of Japanese Chemical Fiber Industry*, p214, Table 3.
168. *History of Japanese Chemical Fiber Industry*, p131, Table 21 (Data of Teijin are the same as those of ref 162).
169. *History of Japanese Textile Industry*, p614, Table 3.
170. *History of Japanese Chemical Fiber Industry*, p184.
171. *History of Japanese Chemical Fiber Industry*, p186.
172. *History of Japanese Chemical Fiber Industry*, p189.
173. H. Yamazaki, *History of Japanese Chemical Fiber Industry*, p357.
174. *History of Japanese Textile Industry*, p245-246.
175. *History of Japanese Textile Industry*, p246, Table 6.
176. See part II of this study.