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Development of Manufacturing Technology of Viscose Rayon Fibers in Japan Since 1930s (Part 2) Mid-War Ordeals and Post-War Reconstruction and Development (1938～1956)*

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SYNOPSIS :

Historical development of manufacturing technology of viscose rayon fibers at Stages IV, V and VI, defined in the previous paper (This journal, **20**, 1 (2005)), was studied. In particular, since Stage V was the time of social turbulent the study was made in close connection with social background. As supplement to the previous paper, details (causes and cut-off rate) of the operational curtailments with a golden age sandwiched between them in Stage III was surveyed. Conversion of autonomic control system (Stage III) to governmental compulsory control system (Stage IV) was studied on the basis of acts, royal ordinances, ministerial ordinances and notices. The first～fifth order national plans of reduction of production and the corresponding Asahi's achievements were examined. Numerous difficulties, such as shortage of resources, energy, and man-power, encountered by Japanese rayon producers in Stage IV (1938～1945) were investigated. Technological advance (if any) in Stage IV was studied: R & D activity of Asahi men (in comparison with that in Stage III), some key technology developments continued from Stage III, and Toramomen. The route of invention and commercialization of Tramomen at Asahi in Stage IV and at Tachikawa Research Institute in Stage V and evolution of Toramomen were surveyed. New concept of high-wet-modulus rayon (Toramomen, Polynosic rayon) and the worldwide evaluation of Toramomen (polynosic) were disclosed in detail. History of some restoration plans, approved by GHQ, in Stage V (1946～1951) was surveyed together with Asahi's restoration work. During Stage VI (1952～1956) the USA's technology, directly licensed to Japanese machinery manufactures, was introduced to Japanese viscose rayon producers. Characteristics of the technology at Stage VI were discussed.

1. INTRODUCTION

In the previous paper[1] whole history of Japanese viscose rayon industry was divided into eight stages. The advances in manufacturing technology at Stages I (embryo), II (introduction), and III (pre-war prosperity) were studied in detail before.[2～5] This article as the second part of the study

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deals with Stages IV (mid-war ordeal), V (post-war reconstruction) and VI (post-war expansion).

2. Stage III: PRE—WAR PROSPERITY (Supplement)

The output of viscose rayon filament yarn in Japan had attained maximum in 1937 (see, Fig. 1 of ref. 1). However, this does not mean that rayon manufacturers enjoyed the booming with full operation of their equipments, but drastic fall of selling price occurred often due to serious imbalance of production capacity and domestic and overseas market demands. In order to improve these social and economic situations the first operational curtailment was decided at a meeting of Artificial Silk (or Rayon) Manufacturers Association, which was established on 20 March 1927 by the five rayon manufacturers (i.e., all manufacturers at that time), and the curtailment was carried out during December~November 1932.

Fig. 1 demonstrates the course of the first operational curtailment of viscose rayon filament yarns in Japan.

Table 1 summarizes cutoff rate of rayon filament output during 1929~1945.

The first curtailment ended on November 1932. The period of December 1932~June 1935 (in total 31 months), locating between the two curtailment periods, was 'Golden Age' for Japanese viscose rayon manufacturers.

Fig. 2 shows the causes of the secondary operational curtailment of rayon filament output in Japan during July 1935~July 1938.

3. STAGE IV: MID—WAR ORDEAL

3. 1 Compulsory reduction of output of viscose rayon

Autonomic control aiming to prevent fall of selling price due to overproduction could not attain the perfect achievements. Then, on April 1936 Japan Artificial Silk Association decided to strengthen control on rayon fiber output by introducing restriction of increase in number of spinning machines, in addition to cut-off of rayon out-put.[6] After then, in the period of Japan—China War (1937~1941) the national economic system was converted to the war—time system.

Japanese rayon industry was not an exception, and it was put into under governmental control, which was based on the following laws:

(1) Act on 'Temporary measure against exported and imported products' (promulgation, 10 Sept. 1937; enforcement on the same day)[7,8]: Based on this law various ordinances and notices, attempting the restriction of textile industries, were promulgated.[9]

(2) Act on 'Temporary fund adjustment (promulgation, 27 Sept. 1937)[7,10,11]:

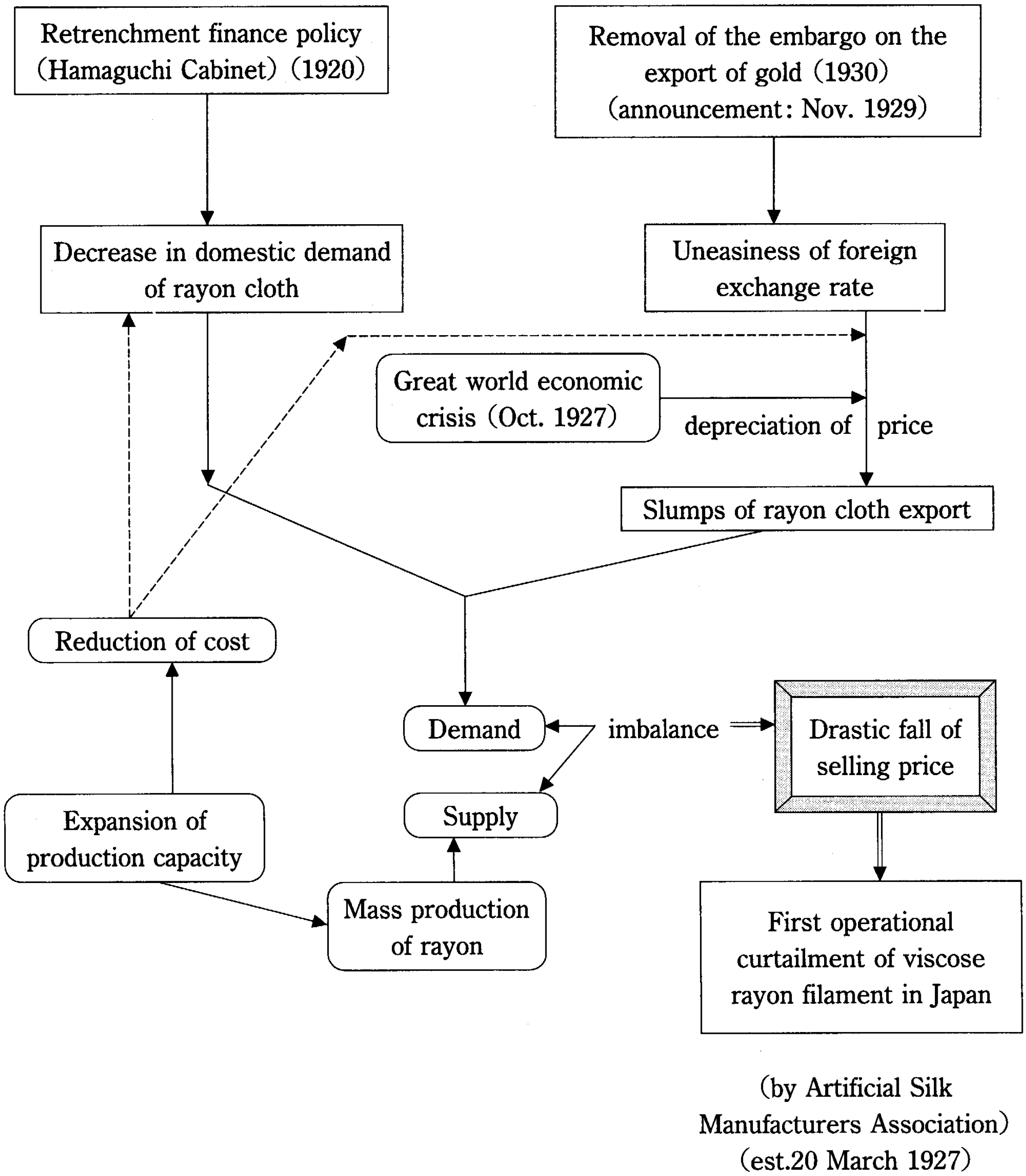


Figure 1 Causes of the first operational curtailment of rayon filament output (production) in Japan

New establishment or capital increase of company, new installment or expansion or remodeling of the apparatus needed the governmental permission or approval.[12]

Artificial silk manufacturers was classified as the third (or lowest) category among three, which had excessive production equipments, being inadequate to permit new establishment or further expansion of them and in addition loan was allowed only in the special case.

(3) Ministerial Ordinance (12 Feb. 1938)[13~15] No. 5 of the Ministry of Commerce and Industry:

Table 1 History of cutoff rate of rayon filament out put in Japan during 1929～1945

Year	Month	Cutoff rate (%)	Remarks	
1929	Dec	5%	1st period of out put curtailment (by suspension of machine operation)	Stage III
1930	July	20%		
1931	Jan	15%		
	Feb	10%		
	Oct	20%		
	Nov	30%		
1932	Jan	25%		
	Nov	10%		
1933	Dec	0%	Golden age	
1934	:	:		
	:	:		
1935	Jun	0%		
	July	20%	2nd period of out put curtailment (by suspension of machine operation)	
	Aug	30%		
	Nov	20%		
1936				
1937	Mar	30%		
	July	35%		
	Dec	55%		
1938	Mar	71%		
1939	Aug		Out put allocation system	Stage IV
1940				
1941				
1942	Sep			
	Oct		Artificial Silk Control Association	
:				
1945				

Manufacturing equipments of textile industry.

Person, who intends to install manufacturing equipments or to extend capacity of the existing equipments for production of artificial silk or staple fiber, spun yarn, cloth or knitting should obtain the permission by prefectural governor. The equipments concerned was specified later by a following Notice of the Ministry of Commerce and Industry.

(4) Notice No. 32 (Feb. 1938)[16]

Equipments specified in the Notice included the ageing tank and the spinning machine.

(5) Ministerial Ordinance (23 Feb. 1938)[16]

Person, who intends to newly install equipments or to enlarge their capacity of production, or to

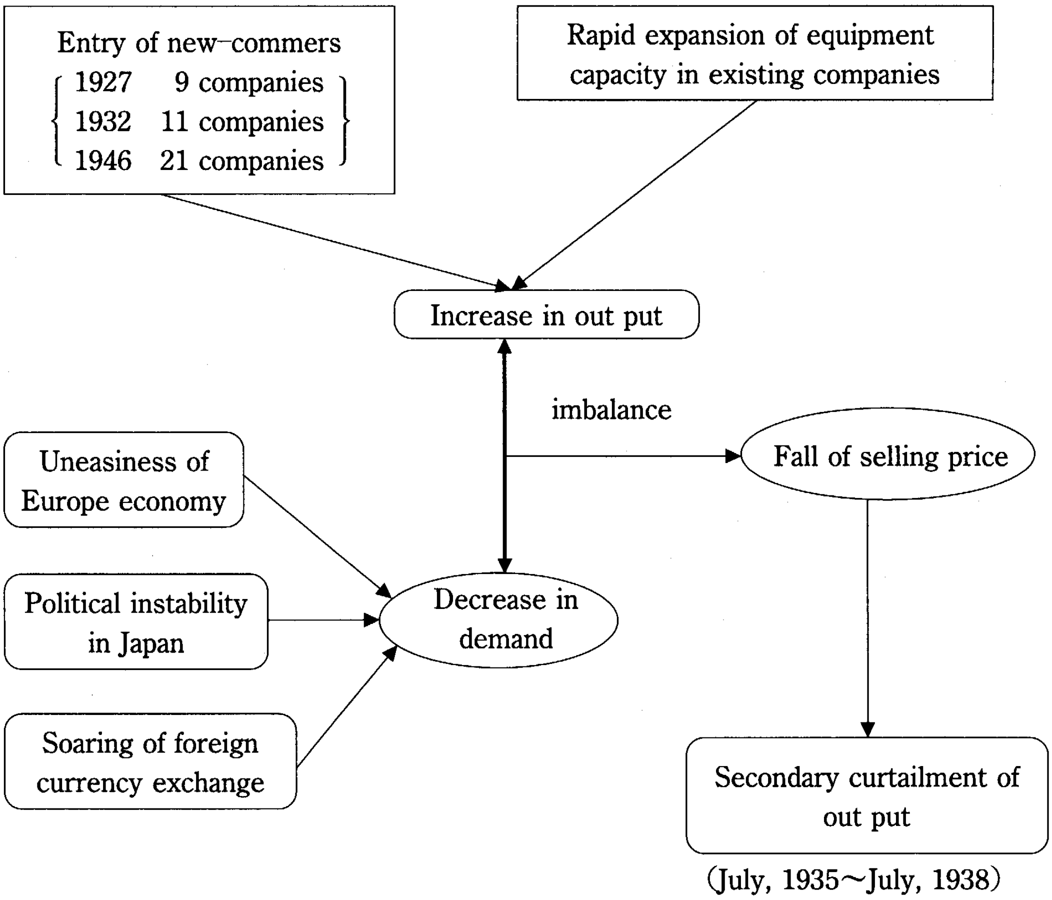


Figure 2 Causes of the secondary operational curtailment of viscose rayon filament output

remodel or to alienate or to borrow equipments for manufacturing the followings (term 6: artificial silk or its product), should get the permission of prefectural governor.

On August 1938 output allocation system, together with import (pulp)~export (rayon yarn) link system was introduced by Artificial Silk Manufacturers Association (Table 1). This system had continued until 1942.

On 12 October, 1942 Artificial Silk Control Association was established, according to Royal Ordinance No. 831: Important Industry Association Act (30 Aug. 1941)[17,18], as acting organization of the government, for which the powerful controlling right over the viscose rayon manufacturers had been authorized.[19,20] Artificial Silk Manufacturers Association was absorbed on that date into the new control association together with Japan Staple Fiber Manufacturing Industry Association.[21] Artificial Silk Control Association was amalgamated on 14 November 1943 to form Textile Control Association with other five control associations.[22,23] On the other hand, on 13 May 1942 Royal Ordinance No. 831: Preparation and Maintenance of Enterprise (i.e., essentially, compulsory abolish-

Table 2 Reduction of viscose rayon filament production equipments

Order	Date of completion	Total number of factories (companies, block)	Capacity (ton/day) Total	Asahi[25]
1st	Oct. 1941	27(12)	717.0871[25~27]	50.526
2nd	May. 1942	17(5)	556.322[25, 28~30]	45.644
3rd	Jan. 1943	9	327.315[25, 28~30]	39.386
4th	Aug. 1943	7	138.760[25, 26, 32]	16.724
			(104.573)[*a 33, 34]	(22.602)[*a]
5th	Jan. 1944	6	181.580[*b 25, 26, 35~37]	33.288[*b]

*a holding capacity
*b summation of operation and holding capacities

ment act) was promulgated.[24]

Table 2 summarizes compulsory reduction, planned by Textile Control Association, of viscose rayon filaments in Japan during 1941~1944. The second column of the table means the date of completion of the plan. The parenthesis of the next to the bottom line indicates the holding capacity and the bottom line means the summation of the operation capacity and the holding capacity. Concentration of viscose production was attempted to factories equipped with superior apparatus.

3. 2 Output of rayon filament yarns at Asahi

Table 3 lists the output of viscose rayon fibers at Asahi Nobeoka rayon factory during 1938~1945.[38] The last column indicates the relative ratio of output, which decreased approximately linearly with year, approaching to almost zero in 1946.

3. 3 Shortage of resource, energy and man—power

During Stage IV shortages of various essential resources and labor power were unavoidable and resulted in serious deterioration of fiber quality.[39]

(1) Domestically produced pulp was totally utilized in place of imported pulp. Quality of pulp became worse. In particular, uniformity of quality of large mass pulp remained unsolved problem for domestic pulp to the very end. The price soared in 1932~1936 and import became difficult more and more in 1940, finally stopped in 1941.

(2) Shortage of sodium hydroxide, which was synthesized from overseas salt (sodium chloride), deduced reduction of its consumption at viscose step. Up to Stage III solid sodium hydroxide was imported from England.[40] Home-made products were not used due to high impurity contamina-

Table 3 Output of viscose rayon filament at Asahi Nobeoka Viscose Rayon Plant during 1938～1945[38]

Year	Output(c/s)[*a]	Ratio
1938	209,115	1.00
1939	200,189	0.957
1940	169,991	0.812
1941	129,349	0.619
1942	105,218	0503
1943	73,567	0.352
1944	45,084	0.216
1945	20,267	0.097

*a c/s＝case（＝1,000 lb＝453.6 kg）

tion.[40] Titan dioxide for delustering use was first imported from France (cosmetic grade).[40]

(3) Shortage of labor power, caused by conscription of skilled male laborers by army, was in part compensated with mobilized students, who were, of course, not skilled.

(4) Shortage of electric power and steam became serious. The latter was partly caused by lowering of coal quality.

(5) Decrepit apparatus could not be fully repaired.

Following difficulties encountered at Asahi Nobeoka viscose rayon factory were recorded[41].

(1) July. 1939; low spinnablity of viscose → sudden fall of the first grade yield and rapid rise of portion of down-graded fibers.

(2) June. 1940; use of unpurified sulfuric acid for spinning bath (throughout Stage IV after that).

(3) Aug. 1940; cutback of amount of sodium hydroxide consumed at steeping and dissolution steps (throughout Stage IV after that).

(4) Oct. 1941; lowering of glucose concentration, finally to zero.

(5) Nov. 1941; decrease of zinc consumption in spinning bath by 50% (throughout Stage IV after that).

(6) Oct. 1943; lowering of spinning velocity by 4% (throughout Stage IV after that).

(7) Oct. 1943; numerous troubles due to shortage of labor force.

3. 4 Yield of first grade yarn

Table 4 lists the yield of the first grade rayon filaments at Asahi Nobeoka Rayon Factory during 1934～1944[42]. The yield is a measure representing the technological level of manufacturing. The yield had a tendency to decrease roughly linearly with large scattering until 1943, but it dropped

Table 4 Yield of the first grade filament (Asahi)[*a]

Year		Yield of the first grade filament(%)	Year		Yield of the first grade filament(%)
1934	first half	93.8	1940	first half	89.4
	second half	92.3		second half	83.3
1935	first half	95.9	1941	first half	86.5
	second half	94.2		second half	84.0
1936	first half	91.4	1942	first half	86.6
	second half	94.2		second half	89.1
1937	first half	93.4	1943	first half	86.6
	second half	90.2		second half	–
1938	first half	87.5	1944	first half	–
	second half	88.8		second half	–
1939	first half	87.4	1945	first half	52.8
	second half	88.9		second half	

*a: Constructed from Asahi Nobeoka Rayon Plant(ed.), *History of Asahi Viscose Rayon Factories,* Asahi Chem. Ind. Co. Ltd., p 64, Table, 1951[41]

markedly down to 52.8% in 1944.

3. 5 Rise in production cost and aggravation of producer's profit

Fig. 3 illustrates various factors, leading to conspicuous rise in cost and aggravation of producer's profit, from which a strong motive force was formed accelerating concentration of production to larger scale factories with high efficiency (Table 3).

3. 6 Technological advance (if any) in Stage IV

It has widely been said that 'under the (above) wartime system any improvement or development of machinery or the process of viscose rayon production was not made utterly[43], and that although a few documents written in wartime on technical progress were left the ten years were the time of void from technical point of view.[44, 45] The above conclusive needs more careful and comprehensive examination.

The technology at the wartime can be identified as the manufacturing technology, under severely limited conditions such as shortage of resources and labor power, to keep the output of the product with better quality. Followings, although not very innovative, were considered to be invented (unfortunately details were not left on record.):

(1) Usage of low quality domestic pulp in place of imported high quality pulp.

(2) Usage of smaller amount of sodium hydroxide than ever used.

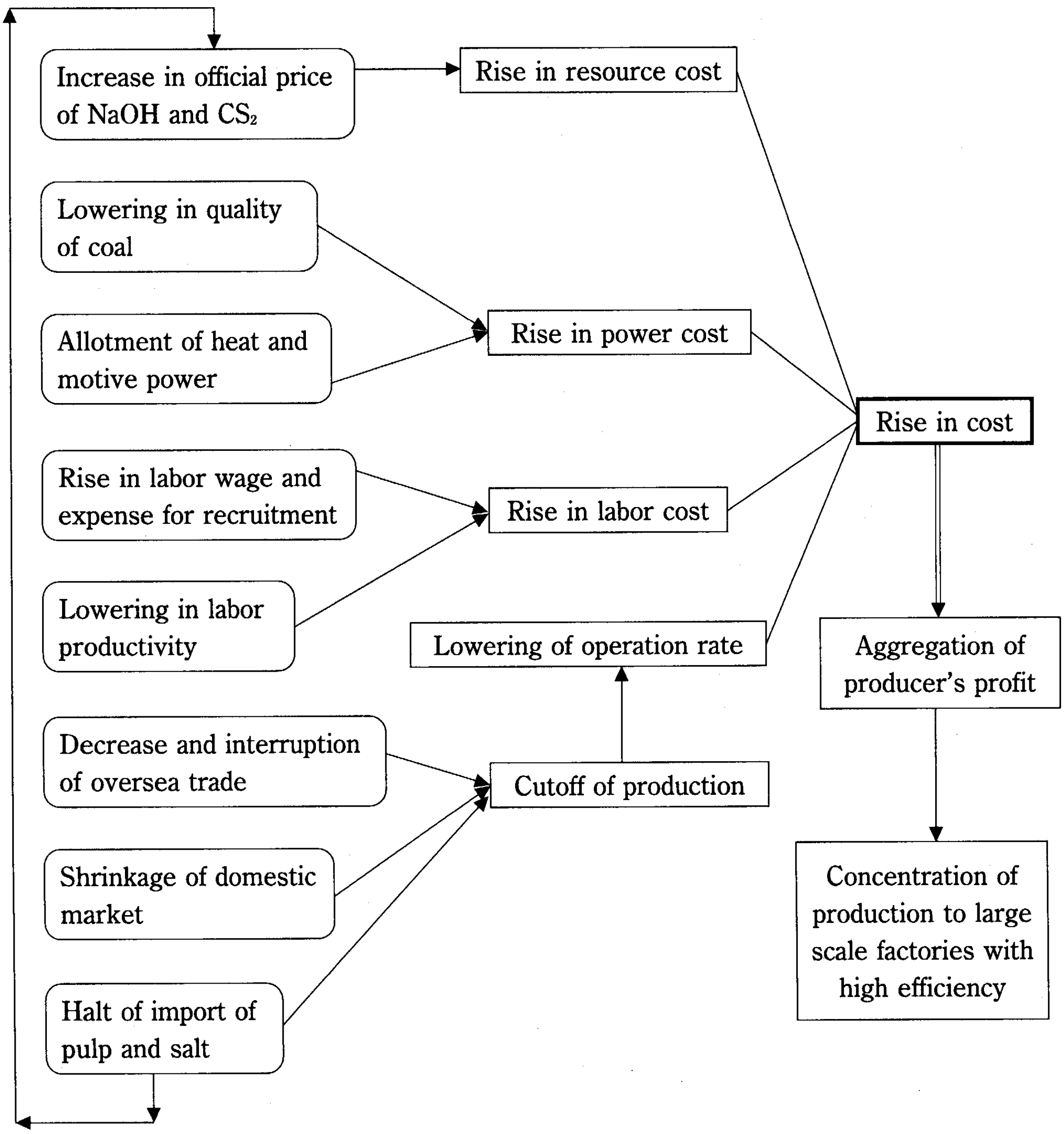


Figure 3 Rise in cost of viscose rayon filaments during Stage IV

(3) Usage of crude sulfuric acid in place of purified acid.

(4) Production technology to supplement lowering of laborer's skill (because numerous skilled male laborers were conscripted in the army and only female (often house wife) or students were replaced).

(5) Technology of keeping out-dated machines far beyond the period of their durability still operative by reuse of various parts of the disposed machines.

Above endeavors to make decrease rate of yield of the first class tarns as small as possible afford some limited success.

Was there not any noticeable technological development in the viscose rayon method during

Table 5 Comparison of R&D activity at Asahi

	Stage III (1930-1937)	Stage IV (1938-1945)
Duration	8 years	8 years
Total number of papers and patents	51	39
Number of engineers	14	10
Average number of papers and patent per individual	3.68	3.9

Table 6 Some illustrations of key technology development during Stage IV

Process	Company
Slurry steeping	Asahi (1942)
Cake scouring	Kura-ray, Toyobo

Stage IV? This question could be reasonably answered by comparing research and development activity in Stage IV with that in Stage III if possible. The comprehensive list of publications and patents of senior technological stuff, once employed by Asahi (Asahi Jinzokenshi, Asahi Kenshoku, Asahi Bemberg etc.)[4] is useful for this purpose.

The results of analysis are summarized in Table 5. Here, when papers or patents were published or applied by plural individuals, the first author or first applicant was counted in the table. In this case, attention was paid to individuals and not to the company. The parameter, expressed as the total number of papers and patents per year per person 3.68/8 (=0.455) in Stage III, is almost the same with 3.9/8 (=0.489) in Stage IV. This means that surprisingly, there is no evidence indicating that Stage IV was less active in R&D than Stage V. At least as far as Asahi man (including ex-Asahi man) is concerned, they could keep their activity throughout Stages IV and V.

As will be demonstrated in later section, in Stage VI new technology was grafted from USA into Japan. Here, we should be careful to conclude simply discontinuity of technological development in Stage IV~V in Japanese rayon industry. As exemplified in Table 6 leading viscose rayon manufacturers had attempted even in Stage IV to develop some key technologies. Detailed information is unfortunately unavailable. Their attempts were not well developed up to successful commercialization, but it is clear that the strategy, planned at Stage IV was not in the mistaken direction.

Note that German companies tried to innovate some essential steps in viscose rayon manufacture (see below), but they could not develop further up to the level of full commercialization. For examples:

(1) Slurry steeping;

(a) roll type continuous steeping machine[46]

(b) Fritz Müller's screw press type slurry steeping machine (7.2ton/day)[47]

(c) vacuum filter for separation of alkali cellulose from slurry[48] (This was used during the war.)

(2) Continuous spinning: J. P. Bemberg operated the machines for spinning direct to warping beams, produced about 1,000 ton of warps until the end of the war.[49]

(3) Wet xanthation: During the war wet churn was used to improve the efficiency of large size vacuum kneader (ex. Rheinische Kunstseide, Krefeld Plant; Lenzinger Zellwolle Fabrik, Lenzig Plant).[50]

It seems interesting to note that embryo of new technology emerged in 1930～1931 in Europe and USA were also reported by Japanese engineers: Yutaka Yoneda (ex Asahi man; code no. 4 in ref.3) watched continuous pressing machine (France)[51], which was just the same as those proposed in post—war Japan, continuous pulper (France)[51], which he had bought, cake scouring machine (proto type (France)[52] and commercial type (USA))[53].

3. 7 Toramomen and polynosic rayon: A Japanese technology developed during Stage IV～V

(a) For-running element innovation of the process

Exceptional, epoch-making technology in Stage IV is the high—tenacity rayon, which was invented by Shozo Tachikawa on Dec. 1942[54, 55]. Note that the date of invention, cited in ref. 54 and 55, seems lacking the evidence and the application date of the fundamental patent[56] is July, 1943 and before the application (since about 1938) Asahi had commercialized the invention of high-tenacity (high molecular weight) staple fiber under the trade name of Toramomen although the fiber was not yet fully evolved at that time. For example, we can find an article, introducing Tramomen in a journal, 'Artificial Silk World'[57]. In the chronological tables of *History of Japanese Textile Industry*[58] and *History of Japanese Chemical Fiber Industry*[59], only Tachikawa's invention was cited as technological advance made in Japan during Stages IV～VI.

Tachikawa's invention is described originally in Japanese Patent No. 172,865 (1946)[56]. After then, the technology developed ahead to 'Polinosic rayon'[60, 66]. Fig. 4 illustrates research and development route at Asahi Otsu plant, leading to innovation of 'Tachikawa's' Toramomen during Stage III～IV. The figure was constructed by referring to Hasegawa's memoirs[67～70].

Tachikawa's associate, Goichiro Hasegawa (Code no. 26 in ref. 4) got ideas on elements (a)～(d) in the figure, carrying out a bench-scale test operations at Asahi in 1920～1930[71]. Then, the

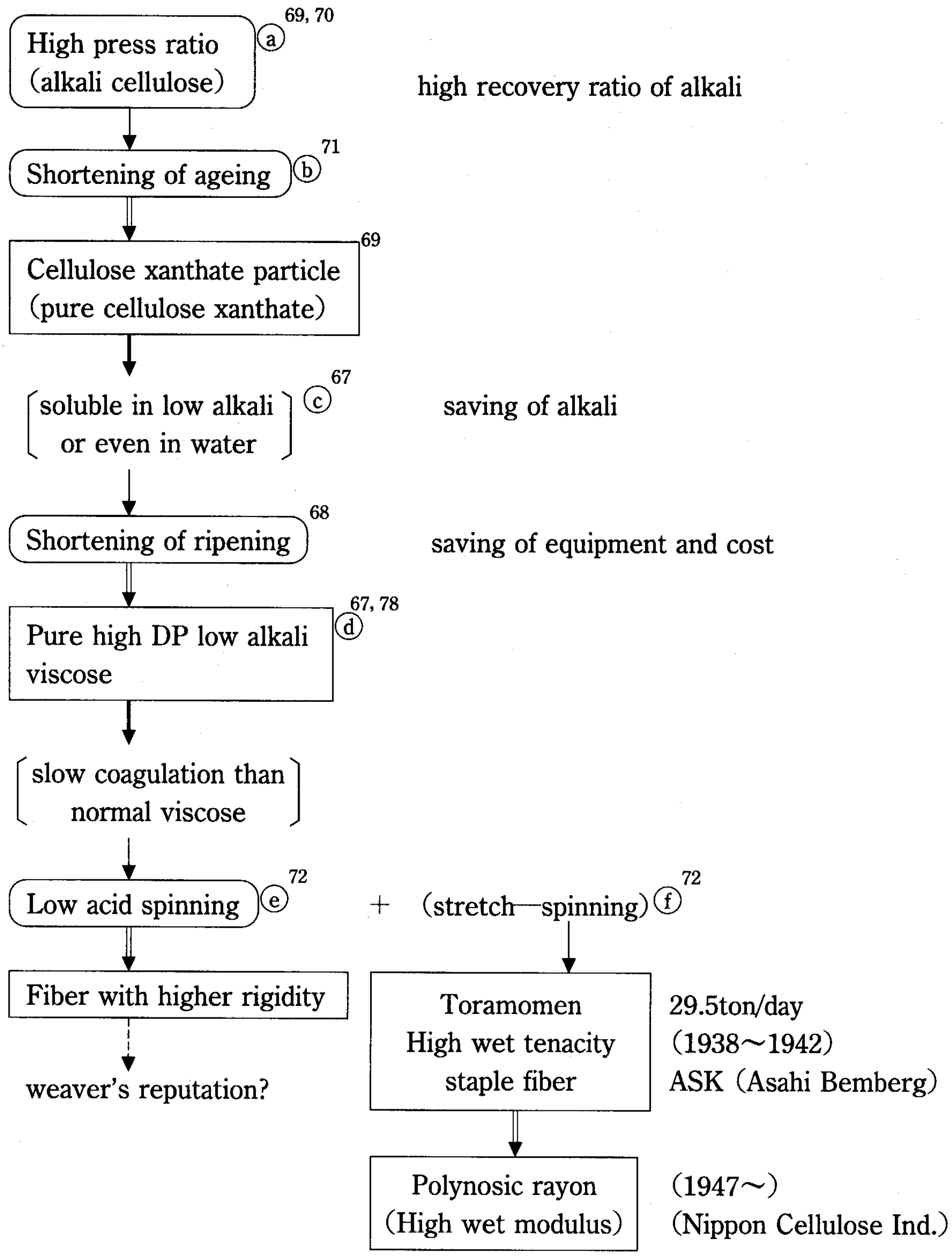


Figure 4 Route of invention of Toramomen (Asahi)

elements (a)~(d) were gradually practiced at the plant of viscose rayon filament during about 1930 ~1939.[68] High-tenacity viscose rayon, Toramomen is principally a combination of the elements (a) ~(d) and elements (e) and (f). The latter (low acid and stretch-spinning) were completed 10 years after Hasegawa's bench research by others[72]. Then, we can conclude that basic foundation of Tacikawa's Toramomen had been formed by many engineers in Stage III~Stage IV at Asahi Otsu plant.

Table 7 summarizes comparison of the operating conditions, first (in 1924) instructed by VGF

Table 7 Comparison of original VGF (Germany) technology with Asahi technology (Japan)

Process	Item	Operating conditions: VGF (1920s)	Operating conditions: Asahi (R&D) (1920s-1930s)	Ref.
Steeping	press ratio	3.2～3.0	2.7～2.8	60
	conc. of alkali	na*	18→18.5%	70
Alkali cellulose	cellulose content	na	>30%	70
Aging	time	96hr	short-ageing	71
			↓	
			non-ageing	74
	temperature	room temperature	35℃→53℃ (crashing)	
Viscose	cellulose content	8%	5%	75, 76
	aq alkali (for dissolution)	7%		75
	dissolving temp.	no instruction	low	77
	viscosity	30～32 sec	ex. 300 sec	78, 79
	repetition of filtration	3	5→3	80, 74
	ripeness	9±0.1	(high γ value)**	69
	level		(moderate or low ripeness level)	
	time	72hr		74
Spinning		Müller	low acid (4～6%)	72
			stretch-spinning	72
			low temperature 4℃ (5～35℃)	81

*: not available

**: The number of moles of carbon disulfide bound as xanthate per 100 moles of $C_6H_{10}O_5$

(Germany) and those developed afterwards at Asahi Otsu plant. Inspection of the table leads us to the conclusion that Asahi technology was doubtless by far beyond VGF instruction and not on the extrapolated line of VGF instruction. Then, it is a miracle that such great innovation was realized in an atmosphere that many Asahi engineers felt sure that the VGF technology of viscose rayon manufacture, transferred from Germany, was absolutely perfect.

(b) Early Toramomen process

As mentioned in (a), a typical great invention in Japan of the viscose rayon process during Stage IV～V may be high-wet-modulus, high-tenacity rayon, Toramomen, based on Tachikawa's invention[56], which claims the high molecular weight fiber characterized by (1) less ageing of alkali cellulose, (2) less ripening of viscose, and (3) low-alkali viscose, and (4) spinning bath of low coagulation power and reasonable regeneration power. Note that Tachikawa's process is a compilation of small inventions of each elements, which were made at Asahi Otsu plant in 1930s～1940

Table 8 Physical properties of 'Early' Toramomen

	Tensile strength			Tensile elongation		
	g/d		ratio	%		ratio
	dry	wet	(%)	dry	wet	(%)
Toramomen						
CP[*a] 1941[82]	3.8	3.0	87	8.5	10.8	127
1941[83]	3.8	3.3	87	8.0	10.0	127
1942[84]	3.80	3.29	87	11.4	13.2[*c]	116
Ultra Toramomen						
Lab[*b] 1942[84]	4.20	3.96	94	8.7	9.2	106
Cotton[84]	3.42	3.29	96	8.2	8.7	106
Ordinary rayon staple fiber						
CP (single bath)[84]	2.74	1.48	54	24.3	32.1	132
CP (double bath)[84]	3.01	2.12	70	18.4	31.2	170
Duraflax[84]						
CP (VGF)	3.11	1.98	64	22.4	27.4	122

*a CP: commercial product *b lab: laboratory scale
*c in ref. 84 (Table 1) 1.32 should be read as 13.2

(Fig. 4).

Early Tachikawa's process is, for example, as follows:

(1) Alkali cellulose is produced by steeping the cellulose in aq. sodium hydroxide solution, followed by pressing and shredding homogeneously as in the production of regular viscose. The concentrations are carefully controlled to ensure that the temperature does not rise above 20℃, and the process is completed within 2 hrs and without subjecting to ageing.

(2) Carbon disulfide more than 45% in weight of cellulose is used in xanthation, where xanthation velocity is controlled.

(3) Sodium cellulose xanthate is dissolved in water to provide a solution with the ratio of alkali content to cellulose less than 0.6. The ripening of viscose should be as short as possible.

(4) The solution is spun by extrusion into a bath of very dilute (less than 50g/l) sulfuric acid and sodium sulfate (50g/l~trace) at 25℃. The filaments are stretched to four times their spun length.

Table 8 lists some physical properties of 'Early' Toramomen manufactured by Asahi Bemberg during 1941~1942.

In the table corresponding data for cotton and ordinary rayon staple fiber are included for comparison. 'Ultra' Toramomen is ultra high molecular weight fiber produced at Asahi's laboratory. Toramomen has high-wet-tenacity, comparable or superior to cotton and large ratio of wet-tenacity to dry-tenacity (i.e., wet-to-dry ratio), a little smaller than cotton, but significantly larger than ordinary rayon staple fibers.

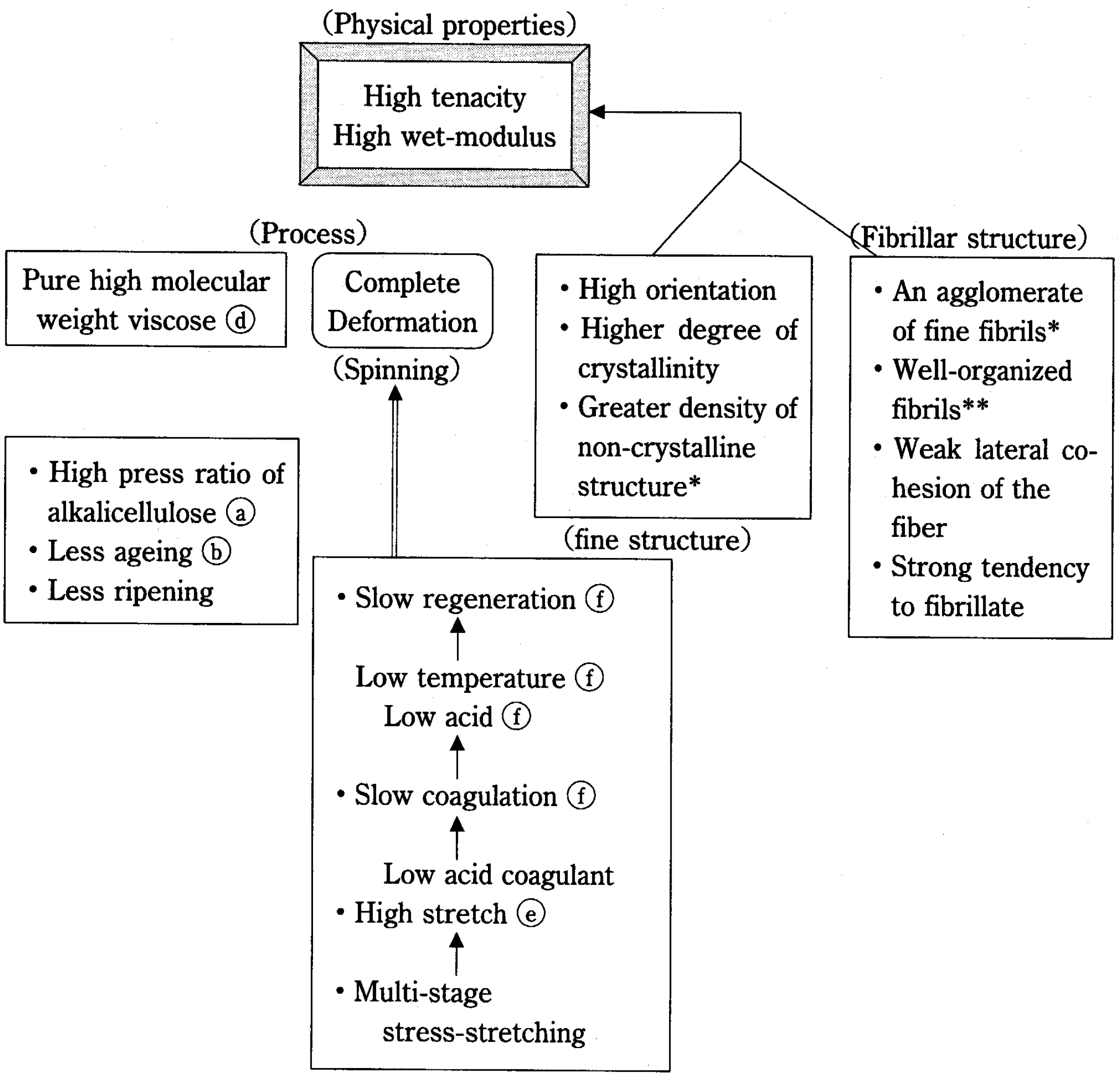
(c) Concept of Toramomen

Fig. 5 illustrates the fundamental relations between yarn performance, structures (fine and fibrillar) and manufacturing process of Toramomen and polynosic. The figure indicates theoretical basis of designing yarns with desired performance. At the time when Toramomen had been invented (1938~1943) the concept of the molecular weight of cellulose had not been widely accepted yet by ordinary cellulose engineers and the method of determination of fine structure had not been known in any sense. Then causal relations had not been obtained between pure high molecular weight viscose (i.e., viscose consisting of high molecular weight cellulose xanthate and aq. alkali) and the yarn performance and between the yarn structure and the yarn performance. Note that the former relations are even now only phenomenological correlations. Tachikawa considered that pure high molecular weight viscose (in other words, molecularly dispersed cellulose xanthate (degree of substitution=3) solution in aq. (rather dilute) alkali) stretched to the maximum extensibility should form the fiber with superior performance.

Tachikawa's work contributed significantly to establishment of the new concept of polynosic rayon. Polynosic rayon fibers are defined as: A manufactured cellulose fiber with a fine and stable microfibrillar structure which is resistant to the action of 8% sodium hydroxide solution down to 0℃, which structure results in a minimum wet strength of 2.2 grams per denier and wet elongation of less than 3.5 per cent at a stress of 0.5 grams per denier[85]. The term 'Polynosic' was restricted to the fibers of the high modulus type produced by techniques similar to that described in the Tachikawa patent[86].

(d) Commercialization of Toramomen

The original innovations had not been applied totally to the viscose rayon filament process, because new type fibers had somewhat different feeling from that of ordinary rayons[87] and weavers at Fukui, a famous rayon cloth manufacturing center rejected, after examination of the test samples, to use new type rayon because of its low extensibilty and too fine denier.[88] When the viscose rayon filament process was closed down by the second order plan (Table 2), converting to the viscose rayon staple fiber process (1937) the principal innovation, consisting of the high molecular weight viscose (than ordinary viscose) and stretch-spinning, was commercialized on large scale (29.5ton/



*; similar to cotton, **; straight and strictly parallel to the fiber axis
ⓐ~ⓕ, see, Fig. 4

Figure 5 Yarn physical properties, fine and fibriller structures and process of Toramomoen and Polynosic rayon

day)[89] to produce new staple fiber under the trade name of Toramomen (Tiger cotton)[90, 91]. This is an 'early' Toramomen. Note that, at that time (~1937), the specification (quality) of viscose rayon staple fiber suitable for spinning had not been established and the co-operational work of fiber manufacturers with spinning companies was not satisfactory. Cut fibers of rayon filaments were initially supplied to spinners as staple fibers, with worse market reputation, resulting in over-stocking. In particular, in wool spinning, rayon staple fiber was called as 'dead wool' and estimated to be 'unspinnable'[92].

Asahi was successful to produce the sturdy staple fiber. But, finally, Asahi Otsu Plant was closed in July 1943 due to The 4th Order Arrangement. Tachikawa and his associates spun out Asahi and

Table 9a Specifications of three fundamental patents of Toramomen

Items	Early Toramomen JP 172,865 (1956)[*a] [1943][*b]	Toramomen (Polynosic)		Super Toramomen (Super Polynosic) Belg. 593,672 (1960) [1959]
		USP 2,592,355 (1952) [1949]	USP 2,732,279 (1956) [1951]	
A. Raw material pulp DP		》 800		
B. Steeping				
①lowering caustic soda		○		
②suppression of O_2 gas		○		
③shortening of steeping time		○		
④strong squeezing		○		
⑤low temperature		○		
C. Shredding				
①low temperature	○	○		
②short interval		○		
③N_2 atmosphere		○		
D. Ageing				
①No ageing		○		
E. Xanthation				
①large quantity of CS_2	(>45% cellulose)	○		
②replacement of O_2 with N_2		○		
③inert gas→ accelerate Xanthation				
④alkali/cell	<0.6			
F. Dissoluition				
①in mixture of water/CS_2		○		
②in water and CS_2 alternatively added		○		
G. Ripening				
①no ripening		○		
②short time	○			

Table 9b Specifications of three fundamental patents of Toramomen

Items	Early Toramomen JP 172,865 (1956)*1 [1943]	Toramomen (Polynosic)		Super Toramomen (Super Polynosic) Belg. 593,672 (1960) [1959]	
		USP 2,592,355 (1952) [1949]	USP 2,732,279 (1956) [1951]		
H. Viscose					
①extremely high DP					
cellulose xanthate		○			
②low alkali content					
alkali/cell. < 0.6	○	400～1000s			
		(DP=800～1000)			
③viscosity	750s	500～1500s			
		(DP=1000～1200)			
I. Spinning					
Spinning bath					
①low coagulation					
power	○				
②small regeneration					
power	○				
③alkaline		○			
④water		○			
⑤low acid			<3%H_2SO_4	<30g/ℓ	
		50g/ℓ			
⑥low in $NaSO_4$			○		
low salt	○				
⑦low temperature			<30℃	>30℃	
				35℃	45℃
Stretching					
stretching ratio	4		3	2.1	2.5
stepped godet			○		
conical godet		○			
Spinning	20m/min			40	45
J. Fiber					
①DP		>500		850	1650
wet-tenacity (g/d)		3.5g/d	2.51	3.2	4.2
			(1.56)*	0.74	0.76
D/W ratio			0.76	3.2/4.3	4.2/5.5
			(0.57)*		
			*by ordinary		
cycles de flexion			(spinning)process	650	1100

*a: application date *b: grant date

after the war they established Tachikawa Research Institute (TRI). TRI formed Japan Cellulose Kogyo (JCK) on May 1947, which continued production of Toramomen at Hofu plant during 1947～1950[93], under trade name of Polynosic. The new Toramomen technology, based on US Patent 2,592,355 (1952)[61], US Patent 2,732,279 (1956)[64] and Belgian Parent 593,672 (1960)[65], was licensed to domestic and oversea manufacturers.[94, 95]

(e) Evolution of Toramomen

Toramomen evolved as follows: Early Toramomem (Japanese Patent 172,865)→Toramomen (Polynosic) (US Patent 2,592,355+US Patent 2,732,279)→Super Toramomen (Belg. Patent 593,672).

Table 9 compiles comparison of specifications of the above three fundamental patents. It is evident that US Patent 593,672 is concerned with preparation of viscose dope and US Patent 2,732,279 with spinning method, both two forming a single technology for obtaining high-dry- and wet-tenacity viscose fiber. Belg. Patent 593,672 is an improvement of US Patent 2,732,279. In the patent, Tachikawa et al[65]. had shown that a very small amount of zinc sulfate (about 1 g/l) in polynosic type spinning baths permits an increase in bath temperature and spinning velocity and results in fibers with higher elongations. Tensile strength of Toramomen had increased from 3.5g/denier (1943) to 5.0 g/denier (1950～1960) and 7.5 g/denier (1950～1960).[96]

3. 8 How was Toramomen evaluated in Europe and USA?

For this purpose, the four major books on regenerated cellulose fibers[97～100] were investigated.

(1) Moncrieff[97] stated that 'Next came the important work of S. Tachikawa in Japan, described in US P 2,732,279: Elimination of the aging and ripening stages preserves the DP (degree of polymerization) and the more dilute spinning bath ensures slower regeneration of the cellulose and permits more of stretching and its accompanying orientation of the fibrous molecules to take place before regeneration is complete.' and 'Commercial manufacturing methods follow close the technique of Tachikawa.'

(2) Bucher[98] introduced 'Toramomen fiber' in his chapter that Tachikawa made fibers in Japan with DP twice as high as conventional fibers. Compared with regular rayon processes, viscose is spun into a coagulation bath of lower hydrogen ion activity; slower coagulation allows stretching of about 200% and a highly oriented fiber results, with low lateral order. The first Toramomen, based on US Patent 2,732,279, is strict sense, high tenacity fiber, but contemporary polynosic fiber is generally considered to originate from this (Toramomen's) technology.

(3) Schappel and Bockno[99] described in detail (29 papes) Toramomen (1943) and polynosic (1950

~1960)[101]. They stated that 'The present technology for the spinning of Polynosic rayon is based on the principles set forth by Tachikawa[61, 64] in 1952 and that 'Although Tachikawa's low-acid Toramomen process was patented in 1943[102], interest in high-wet-modulus rayon did not develop until the late 1950s, when commercialization of this process occurred.[102] However, extensive research on Toramomen process was carried out since 1956[102], as is shown by the abundant patent literature.

(4) Cook[100] stated that 'During World War II, further progress was made along these lines, notably in Japan. In 1951, this work culminated in the application for a patent by S. Tachikawa, covering the production of viscose rayon by a technique which yielded fibres of novel type. In particular, the Tachikawa rayons were stronger than regular viscose, with reduced elongation, and they had a greatly improved ratio of wet to dry strength (76 per cent, compared with the 56 per cent of regular viscose). This increased resistance to the effect of water was reflected also in a high wet modulus, with lower water imbibitions and reduced swelling. The new type of rayon differed structurally from regular viscose rayon. Development of the Tachikawa process in Japan led to the production of high strength, high wet modulus rayons which were marketed as 'Toramomen' and later 'Tufcel'.'

Hasegawa reviewed in 1977 that Asahi Otsu Plant was a world-famous pioneer of high DP viscose rayon industry, playing as a progenitor of its theoretical background.[103] Note that Oka[104, 105] did not describe in his book chapters on the viscose rayon in 1956 and 1958 (in Japanese) the name of inventor of Toramomen and even the name of manufacturer, although he cited numerous names of oversea' inventors and manufacturers for the viscose process.

4. STAGE V: POST—WAR RECONSTRUCTION

4.1 Reconstruction plan

When the war ended on 15 August, 1945, the total capacity of rayon filament out put in Japan was as small as 7 ton/day[106] at only three factories of two companies[107]: Asahi (at that time, Nitchitsu Kasei, Nobeoka); 3 ton/day for viscose rayon[108] and 4 ton/day for cuprammonium rayon[109], Kura—ray (at those days, Kurashiki Kouka, Sanjo); 4 (?) ton/day for viscose rayon.

Active capacity of rayon filament production was estimated on April 1946 to be 32.1 ton/day (five companies) for viscose rayon and 4 ton/day (one company; Asahi) for cuprammonium rayon, respectively.[109~111] Corresponding Asahi's capacity was 5.6 ton/day for viscose rayon and 4.0 ton/day for cuprammonium rayon.[100, 111]

After the war, Japan was occupied by the allied powers and its economy was under control of

GHQ (General Headquaters of the Supreme Commande for the Allied Powers) during September 1945～August 1952, whose measure beyond the law had been authorized by the Royal Edict No. 542 on 20 Sept. 1945. On 24 Nov. 1945 GHQ issued the order on restriction of company's dissolution and others. Then, on 8 June 1946 thirteen textile companies and their 246 subsidiary companies were specified as 'Restriction Company' by another order on supplementary addition of specified textile companies to the list of 'Restriction Company'[112].

An investigation of actual situation of production capacity by Chemical Fibers Technical Committee showed that the operation capacity at the time of 13 Dec. 1946 was 130.1 (for viscose rayon yarn)+20.3 (for cuprammonium rayon yarn)=150.4 ton/day[113, 114]. This is the revised registered capacity and should be compared with the fifth order reduction (181.58 ton/day) (Table 2). On 4 April 1947 GHQ approved in memorandum on 'Production capacity of chemical fiber' the reconstruction of rayon plants with capacity of 1.5 x 10^5 ton/year. The above magnitude is equivalent to that when all equipments of viscose rayon yarn with 151 ton/day (of capacity) and of staple yarn plants of 301 ton/day are operated for 360 days per year. This means that all the registered equipment can be restored.[115]

Three year plan of textile industry reconstruction was proposed by the government on September 1946 and the detailed enforcement plan for each rayon company (the first term reconstruction plan) was agreed at Ishiyama Conference by the five companies on the same month.[111] The first term plan was formally approved by GHQ on 22 April 1947.[116～118]

First term (April 1947～March 1948):

Restoration of plants with 64.5 ton/day[110, 111, 119] (including 7.8 ton/day of cuprammonium rayon and Asahi viscose rayon; 17.4 ton/day[111]): Total capacity attained to 100.7 ton/day (=36.2+64.5)[111] or (=36.1+64.6)[119] (including 11.8 ton/day of cuprammonium rayon).

Thereafter, the second term plan, indicated by GHQ draft on Oct. 1947[111], was decided by the five companies on the same month and approved by GHQ on 13 April 1948[118～121].

Second term (April 1948～March 1949):

Restoraton of plants with 39.92 ton/day[111, 112, 122, 123] (including 4.72 ton/day of cuprammonium rayon): Asahi viscose rayon, 5.8 ton/day.[111] Total capacity amounted to 140.62 ton/day (=36.2+64.5+39.92). The viscose rayon manufacturers including Asahi started to reconstruct their rayon plants on the basis of the above authorized plans. The record of out put was 90.994 ton/day on Oct. 1948, indicating that the achievement was below the plan.

Table 10 illustrates some typical plans drafted after the war.

Table 10 Reconstruction plans of viscose rayon yarn production in Japan during 1946～1953*

	Out put of viscose rayon yarn (1000ℓb/year)			
	Three-year plan	Five-year plan		
Year	Aug 1946[*a]	original May 1948[*a]	revised July 1949[*a]	Achievement
1946	30,000			10,591
1947	70,000			19,787
1948	120,000	50,000		43,240
1949		80,000	79,822	74,151
1950		140,000	90,000	114,937
1951		180,000	113,000	138,161
1952		210,000	148,000	148,532
1953			180,000	167,466

*a date of announcement
* Constructed from Textile Almanac 1947, 1948, 1949, and 1950 editions. See, for example ref. 124

4. 2 Reconstruction works at Asahi

Table 11 summarizes details of reconstruction works carried out three times as first works～third works at Asahi Nobeoka in 1947～1950.[125～127] In the table, the first and second works correspond to the first term reconstruction plan and the third works to the second term reconstruction plan, respectively. The associated infrastructure, such as carbon disulfide plant, sulfuric acid plant, thermal power generation plant, water supply for refrigerator and compressor, was also reconstructed.[128]

In the first works adjustment, repair, and service were main factors and only new, but pre-war type spinning machines were purchased from Kotobuki Heavy Engineering Co., with which Asahi had intimate relations since 1920s. In the second works the portion of new machines purchased increased: They were the most advanced machines at 1937～1940; for examples, Eirich crusher[129], and alkali cellulose pneumatic transportation equipment. In the third works more large scale machines, including large steeping machine and large alkali cellulose vessel, were purchased and installed.

Inspection of Table 11 leads us to the conclusion that these works completed in 1949～1950 are just restoration works to put back its technical level to the 1937's level (Stage III). Note that in this period any foreign technology-based machine was purchased by Japanese rayon manufacturers.

Table 11 Restoration works of manufacturing apparatus of viscose rayon filaments in Japan during 1947~1950 (Asahi Nobeoka Viscose Rayon Plant)

Process	Manufacturing apparatus		
	First works 1949 (11ton/day) Oct. '47~Apr. '49	Second works 1949 (5.8ton/day) Dec. '48~Apr. '49	Third works 1950 (5.8ton/day) May. '49~End '50
Steeping Ageing		Steeping machine: 9 (repair)	Large scale steeping machine: 4 (purchase)
Schredding	Shredder: 8 (repair • adjustment)	Eirich crusher: 3 Alkalicellulose pneumatic transportation (to ageing room)	Eirich crusher (purchase) Pneumatic apparatus
Xantation Dissolution	Kneader: 5 (repair)		Kneader→screw type
Spinning	Spinning machine: 46 (repair); 58 (purchase) (from Kotobuki), Potmotor, parts of spinning machines (purchase)	Adjustment of traverse system of each 5 spindle block	Spinning machine: 52 (restoration)
Scouring	Scouring machine:5 (repair) Dryer: 5 (repair)		
Rewinding	Rewinding machine: 30 (adjustment)	Rewinding machine: 15 (adjustment, reconstruction)	Rewinding machine: 15 (restoration)
Recovery	Sodiumsulfate crystallizer (repair) Spinning bath recovery apparatus: 5 (repair)	Water supply apparatus and plants of carbon disulfide, sulfuric acid (repair) adjustment	

5. STAGE VI: POST—WAR EXPANSION

5. 1 Import of USA technology

In 1950 the restoration works, which intended to put back the manufacturing technology to the level of 1937, was accomplished for the time being. Rayon industry in USA had been under complete control of European capitals up to mid 1930s.[130] At that times European subsidiary companies in USA had not their own function of research and development.[131] Exception was Du Pont Ltd., which had started in 1920 rayon business in form of joint venture with French capitals.[132] Confiscation in 1930s of German companies in USA as enemy-side capitals and half-compulsory sale of American Viscose Co., which was the largest American viscose manufacturer and a subsidiary of Courtaulds, to American-side[133] were very effective for upbringing of new powers of viscose companies with American capitals. Accordingly, it can not be said that before 1930s there was American-original technology in USA viscose manufacturers.

USA expanded, even after outbreak of the second world war, production of viscose rayon (until 1965). In this way, USA, being totally different from Europe and Japan, was not faced to reduce rayon business. Moreover, petrochemical industry emerged in USA in 1930s and the management technique of chemical process including chemical engineering made a significant progress. Americans were superior in building of effective technology of large scale production, based originally on the inventions made and commercialized by Europeans before. Viscose rayon was not an exception. When the foreign information of technology, developed during the war, was transferred to Japan in 1946～1949 the technical gap between Japan and USA (and Europe) was recognized to be serious. While expansion of demand due to Korea war (25 June 1950～July 1953 (Cease-fire agreement)) brought about booming of export and high profit was received by Japanese rayon producers.[134, 135] The profit was spent for purchase and installment of the most sophisticated machines, which were produced by Japanese companies, based on American technology, to increase production capacity. Mitsubishi Heavy Engineering made contract of technology transfer of viscose manufacturing equipments, including viscose flash deaerator and scouring machine, with Rayon Consultants Inc. (USA) in 1950,[136] and of spinning and scouring (finishing) machines with H. W. Butterworth & Sons Co. (USA) in 1951.[137] Kotobuki Kogyo (Heavy Engineering) contracted with Oscar Kohorn and Co., Ltd. (A subsidiary of Oskar Kohorn A.-G. Chemnitz, Germany) in 1950 on licensed production of screw press type continuous steeping machine and pressurized scouring machine.[137] During 1951 ～1957 Japanese viscose rayon factories underwent complete change by replacing main apparatus with USA type machines.

5. 2 Manufacturing apparatus at Asahi

Table 12 lists change of manufacturing apparatus of viscose rayon fibers at Asahi during 1950～1956. The table was constructed using the data in ref.138. In Table 11 Rayon Consultants type flash deaerator[138], Butterworth type spinning machine and Rayon Consultant type scouring machine were manufactured by Mitsubishi under license. Pressurized Oscar Kohorn type scouring machine[140] was also license—produced by Kotobuki. Eirich crusher was replaced by Werner type stumble crusher, in which ageing and shredding occurred concurrently.[141] For xanthation, out—dated kneader was replaced again by rotary hexagonal cylinder type dry churn.[141～143] It was noticed that churn requires less electric power, less repairing cost and less labor cost than kneader does.[144, 145] Cellulose xanthate synthesized in dry churn was scraped out and dissolved into aq. sodium hydroxide in dissolver to give viscose. Separation of xanthation and dissolution steps was effective to improve the yarn quality. Deaeration of viscose was carried out by Rayon Consultant flash deaerator, which enabled to shorten the treating time significantly.

Butterworth centrifugal spinning machine (112 spindle) had remarkable performance as follows 146: (1) The machine is equipped with compensator[147] to keep the winding tension constant, giving

Table 12 Change of manufacturing apparatus of viscose rayon filaments in Japan during 1952～1956 (Asahi Viscose Rayon Plant)

Process	Manufacturing apparatus			
	1st F works (1952: 5ton/day)	2nd F works (1953: 5ton/day)	3rd F works (1955: 5ton/day)	4th F works 1955: 5ton/day
	Mar. '52～July '52 ¥12.02×10^8	Nov.'52～Dec.'54 ¥9.52×10^8	Mar.'56～Feb.'56 ¥9.48×10^8	Dec.'55～Dec.'56 ¥6.53×10^8
Steeping • press	Sheet type large steeping machine: 2 (parchase)	2	2	
Shredding aging	Eirich crusher → Werner turn-over type shredder: 1	3	4	
Xanthation • dissolution	Kneader → Dry churn (Xanthation): 3 +Dissolver:3 (existing kneaders were converted)	3+5 3	4	
Viscose	Large tunk (dearation) → Ray-con type flash dearater: 1	1		
Spinning	Batterworth 112 spindle spinning machine (by Mitsubishi): 28	30	Batterworth spinning machine (128 sp): 20	(112 sp): 27
Spinning	Conveyer car → conveyer belt			
Scouring • finishing	Rotary pot scouring machine ↓ Ray-con type scouring machine: 1	pot type ↓ Ray-con dryer: 2 (2ton/day)	High pressure Oscar type-1	
Cone—winding	Universal cone winding machine: 30 (Kozu), (existing) + Saylor type cone winding machine: 16			
Recovery Spinning acid ricovery	Deacidiifier (20ton/day): 1 Continuous sodium sulphate crystallizer: 1	1 1		

the more uniform yarns throughout whole period of spinning a cake. (2) The machine is also equipped with high speed traverse system, which controls twill angle to give a coarse cake, through which scouring liquid in later process can flow smoothly.

In brief Butterworth spinning machine could supply the fine denier viscose yarns with superiority in homogeneous dyeability, which were eagerly demanded at that time by weavers for production of fine viscose cloth.

Cake scouring had been put into practice before the war by Kura-ray, Toyo-bo and others[148], but they failed to obtain satisfactory success.[148]

A rotary pot scouring machine arranged circularly 40 sets (in total, 160 cakes); each set was consisted of 4 cakes. Then, by pouring scouring liquid through hose from top downward all cakes were scoured and dehydrated at the same time.[149]

Rayon Consultant type scouring machine employed scouring cart, on which spindle bars stood up and separator plates, carrying as—spun untreated cakes, were piled on through the bars (In other words, cakes were mounted on perforated spindles). A single cart loaded 327 cakes. The scouring liquid was fed to the spindles and flew out through spindle holes and all cakes on the cart were scoured at once. Capacity of a machine was 7 ton (of yarn)/day[148]. The scoured cakes were dehydrated by pot-type dehydrator and dried on the cart.[140]

Although the national post—war out put of viscose rayon fibers had never exceeded the maximum value of pre—war out put (see Fig. 1 of ref. 1), Asahi made a new record of production (1,183 ton/-month) on Aug. 1954 (after completion of second F works (Table 7), which is compared with 1,107 ton/month on Aug. 1937[150]. Then, in mid 1957 (after completion of the fourth F works) Asahi produced 2,000 ton/month of viscose rayon fibers.[151] In addition, by the fifth F works (1956～1957), following machines were equipped[152]: Butterworth type spinning machines (112 spindles) 16 and (128spindle)34, slurry type steeping machines; 2, ageing tower; 1, churn: 3, instant deaerator; 2. Asahi further modernized the apparatus and up-graded the yarn quality and reinforced the production capacity, attaining total 72.2 ton/day.[152]

Table 13 summarizes the major manufacturing apparatus employed for viscose rayon yarns in 1950～1957. The table was constructed from data in ref.153. Note that new and powerful machines were domestic ones based on American technology (licensed products) and we could not find European machines any longer.

Slurry type steeping is a method in which pulp sheet is steeped after crushing it in agitator to give pulp porridge, then pressed with roller press and shredded concurrently and continuously. Usage of this method shortened remarkably the reaction time of alkali and pulp and steeping process became highly efficient, compared with the case where pulp sheet is directly steeped in aq. alkali[152] Machine by this method is said to be originally developed at Du Pont.[154] Rayon Consultant type is its compact and energy saving version of Du Pont's. Development of slurry steeping was attempted in Japan in 1942 by Asahi Otsu Plant using long screen type.[155] Then, Toyobo followed using press-roll.[155] This system was also developed and commercialized in Germany (for example, Fritz Müller).[156] After the war Rayon Consultant steeping machine was installed in 1952 at Teijin and Toho-rayon.[155] In 1956 about half of all steeping machines in Japanese chemical fiber industry was Rayon Consultant type.[155]

Steeping temperature of the slurry method is 55～60℃, which is higher than that (20～30℃) of the sheet method and in the former method[157] high press was impossible owing to the tenacity limit

Table 13 Modernization of manufacturing apparatus of viscose rayon filaments in Japan during 1950〜1957

Process	Manufacturing apparatus	Foreign (Japanese) maker	Effects
Steeping—press	Slurry type steeping machine (1957) (5th F works)	Rayon Consultant Inc. (USA).: (Mitsubishi Heavy Engineering)	Drastic shortening of treatment time (3〜6 days→1 day or more)
Ageing	Ageing⟹ageing tower (continuous ageing apparatus) (5th F works)		Remarkable speed up of ageing reaction (2 days→15hr)
Xanthation Dissolution	New type kneader Churn dissolver (1963) Large tank⟹ Instant deaerater (1952)	Saito Iron Works	
Spinning	Centrifugal type spinning machine with compensator and double godets	H.W.Butterworth & Sons Co. (USA) : (Mitsubishi) 112 spindle⟹128 spindle (1957)	Improvement of yarn quality (Fine denier yarn)
Scouring	Gear pump Cake scouring vehicle Ray-Con. type (1954) ⇓ Oscar—Kohorn (presserized scouring) (1957) ⇓ Asahi Baratte (1966)	Vinis (?) Ltd. Rayon-Consultant : (Mitsubishi) Oscar—Kohorn (USA) : Kotobuki	

of press role. Continuous shredder was employed in the slurry method. Quality of alkalicellulose by the sheet—steeping method is rather superior than that by the slurry method.[158] Rayon Consultant type steeping machine had advantages as follows:[158] (1) Homogeneity of quality of alkalicellulose, (2) high labor productivity (lower labor cost) (2.2 person/ton of the sheet method reduced to 0.6 person/ton), (3) small area for installment, and (4) shortening of the treatment time (steeping+pressing+shredding) (5 hr 15 min reduced to 15 min).

In Rayon Consultant scouring machine three layers of separation plates together with as-spun, untreated cakes had to be fixed on and taken off from the spindle bar. It was labored and troublesome for workers to repeat the above operation many times a day.[146] In addition, it was never easy task to put a heavy lead cup on the bar.[146] The worse working conditions and low efficiency mentioned above were relaxed by adopting the pressurized type Oscar Kohorn machine (Table 13), in which fixed base had the same function as the separator in Rayon Consultant machine and as result, excessive labor force was saved. Oscar Kohorn machine car could load larger number of cakes than Rayon Consultant car. Then, scouring capacity was remarkably improved.

The spinning and scouring processes made a significant progress with time. Forms of yarn product changed depending on such progress of these processes and on the market (weavers, knitters,

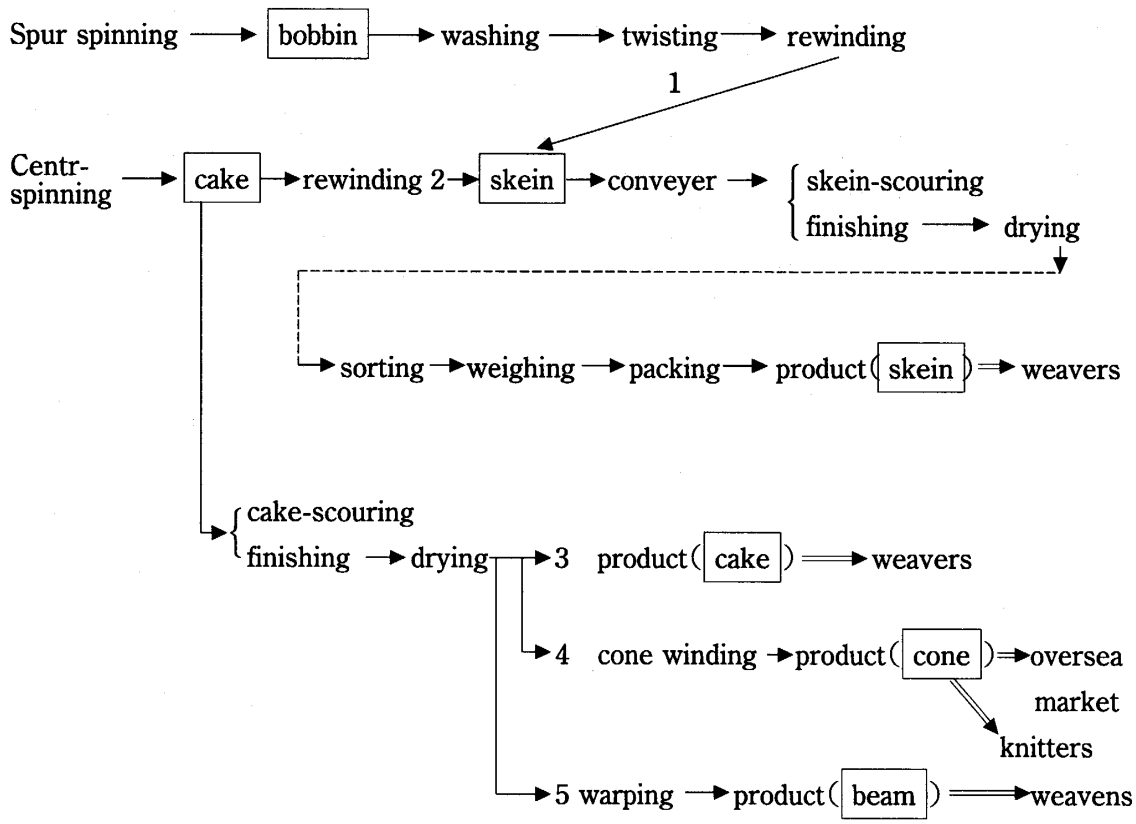
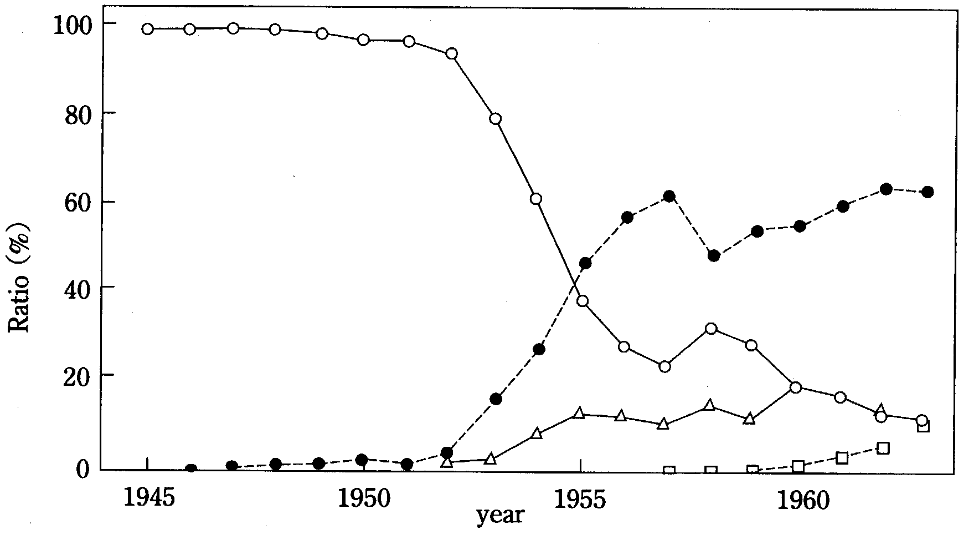


Figure 6 Methods of spinning and scouring in relation to forms of viscose rayon filament as products

and exporters) demand. Fig. 6 shows the forms of yarn in relation to the process as products. Rayon yarns were produced in the form of skein, cake, cone, and beam. Roughly speaking, the finishing and forming processes developed in the order: 1 → 2 → 3 → 4 → 5 (meanings of the number are indicated in the figure).

Skein was first produced by rewinding the bobbin in spool spinning method [1 in Fig. 6]. With introduction of centrifugal type spinning cake once made was wound onto skein, which was then scoured [2 in Fig. 6]. When cake scouring technique was established the scoured cake was directly supplied to weavers [3 in Fig. 6]. For benefit to tri-cot knitters and exporters the scoured cake was wound onto cone [4 in Fig. 6]. Note that on 26 May 1948 rayon yarn for export was decided to have form of cone.[159] For this cone winders were imported from USA. One time cake was warped directly to beam for weavers [5 in Fig. 6]. Generally, the beam was made from cone at weaver's side.

The process of skein production was longsome and complicated and in addition, it needed numerous human hands.[152] Weavers spent long time to use skein for preparation steps of weaving and skein could not be utilized for tri-cot knitting. Cake production became popular owing very much to technological advance in starching as well as weaving, which enabled usage of cake at weaver side. Of course, the production technology or know-how was developed in the course of evolution of yarn



○: skein (①, ②), ●: cake (③), △: cone (④), □: others (⑤)

Figure 7 Production ratio (%) of various forms, supplied by Asahi, of viscose rayon filaments

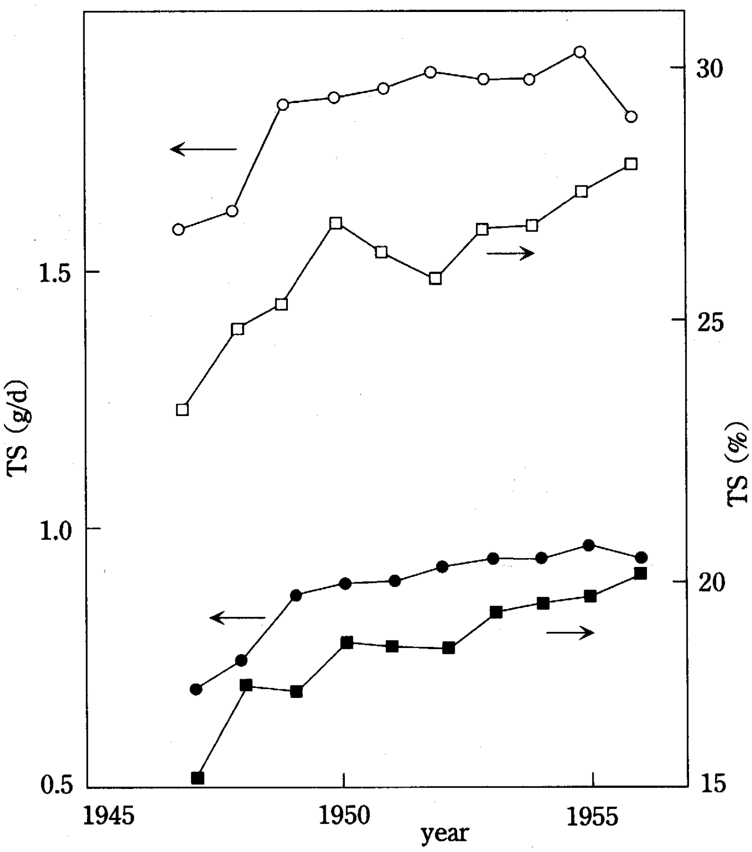
Table 14 Labor force needed for skein, cake and cone production[162]

Step	Labor force (person/ton—yarn/day)		
	Skein (2 in Fig. 6)	Cake (3 in Fig. 6)	Cone (4 in Fig. 6)
Rewinding	13.5	0	2.6
Scouring	2.91	3.5	3.5
Sorting	3.2	1.2	1.2
Total (three steps)	19.6	4.7	7.3

forms (Fig. 6). For illustrations, the following know-how was disclosed[160]: The water content of skein was relatively easily conditioned. Conditioning speed of water content of inner portions of the cake is said to be approximately 1/3 of that of skein. Strict control of temperature and humidity is necessary for the room, in which cakes are to be conditioned. Beautifully shaped cone could be produced by adding appropriate oil to yarn in the process. Hardness to collapse was improved by adjusting the tension of running yarn to pot in the spinning process.

Fig. 7 shows the plots of portion of various forms of viscose rayon yarns at Asahi Nobeoka Rayon Factory during 1945∼1963.[161] In the period 1951∼1957 the supply form of viscose rayon yarn changed skein to cake.

Table 14 compares the labor cost needed for production of skein, cake and cone.[162] Total labor force necessary for three steps (rewinding, scouring and sorting) decreased from 19.6 person/ton



○: TS (dry), ●: TS (wet), □: TE (dry), ■: TE (wet)

Figure 8 Improvement of tensile strength (TS) and tensile elongation (TE) of viscose rayon filaments (120 denier, bright)

-yarn/day to 4.7 person/ton-yarn/day [cake; 3 in Fig. 6] or 7.3 person/ton-yarn/day [cone; 4 in Fig. 6] by converting skein form to cake or cone form. Suppose a factory of 100 ton/day, total conversion of all yarn products from skein to cake saves (19.6—4.7)x100=1,490 persons.[162]

Improvement of quality of viscose rayon yarn during 1947~1956 is demonstrated in Fig. 8, where the tensile strength and the tensile elongation, at dry and wet states, of the bright yarn of 120 denier are plotted against year. The plot was constructed using Table 20 of ref.163 Note that in Fig. 8 the variance of denier is also plotted against the year of production. This represents the fluctuation of the yarn quality. Since the viscose rayon had been commercialized in 1900s, low breaking strength in wet state was the worst defect among yarn physical properties.[164] In 1950s, the tensile strength at wet state increased up to 0.9 gram/denier. These points are on the line extrapolated from the plots before the war. The denier fluctuation, which deteriorates seriously grade of fabrics, was improved soundly in about 10 years span after the war.

6. CONCLUSION

(1) In Stage III, out put increased monotonously. In this sense, the stage can be regarded as the stage of prosperity. But, in order to prevent catastrophic fall of yarn price due to overproduction operational curtailment — adjustment of production — was carried out twice voluntarily (Fig. 1 and 2, and Table 1).

(2) In Stage IV, under the world war system the rayon industry was categorized as non—military and not—important industry and as result the industry had been suppressed in all aspects, including capital, resource, and man power. Under the name of 'Preparation of Enterprise' the compulsory reduction of production was practiced by the authorized control body (Table 2). Small numerous technical attempts to keep up with shortages of resources and man- power were made.

(3) The difficulty caused by the external factors was examined by records of factory operation rate (Table 3) and yield of first grade yarn (Table 4).

(4) Even in Stage IV some technology research, as an extension of the most advanced research in Stage III, was performed (Table 6), but not developed well to the level of commercialization. Asahi men could keep their R&D activity throughout Stages IV and V (Table 5).

(5) Exception is development and commercialization of Toramomen (polynosic rayon) by Asahi and afterwards, Tachikawa Research Institute, spun out from Asahi. The research first started in Stage III as innovative study of each step and then, the results obtained for each step was step-wisely and slowly developed and commercialized to the viscose rayon filament process (Fig. 4). Asahi's new technology was outside of the VGF (German) instructions (Table 7). When the plant was converted from filament production to staple fiber plant in Stage IV the achievements accumulated for each step by rather individual study were totalized and developed further for application to production of high wet-tenacity and high wet-modulus staple fiber.

(6) The basic idea for production of high wet-modulus (HWM) rayon was gradually formed in Stage III～VI at Asahi and finally established in Stage V at Tachikawa Institute (Table 9 and Fig. 5).

(7) All the major books on man-made fibers had estimated highly HWM rayon (Toramomen) by Tachikawa's method, which created new category of rayon (polynosic rayon).

(8) According to the post-war restoration plans (Table 10), admitted by GHQ, the restoration works were carried out in Stage V. The works were limited to repair of broken machines and purchase of new, but old-fashioned machines (Table 11).

(9) In the reconstruction plan (1952～1956) (Stage VI), followed the restoration plan, new large-scale, continuous, and man-power saving apparatus, which was manufactured by Japanese machinery makers, to which USA's technology was licensed, was installed (Table 12 and 13).

(10) Finishing and forming process developed in Stage V; skein (via bobbin)→skein (via cake) →cake (from cake)→cone (via cake)→beam (from cake) (Fig. 6).

(11) In Stage V physical properties and uniformity of the viscose yarns were improved steadily (Fig. 7).

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