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Development of Manufacturing Technology of Viscose Rayon Fibers in Japan Since 1930s (Part 3) Rationalization and Reformation (1957～1990)

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SYNOPSIS:

Development of manufacturing technology of viscose rayon fiber at Stages Ⅶ (long-term recession and rationalization) and Ⅷ (reformation), defined in the previous paper (*This journal,* **20**, 1 (2005)) was studied. Stage Ⅶ was characterized by three sub-stages: Stage Ⅶa (1957～1962), curtailment; Ⅶb (1962～1970), new brand creation; and Ⅶc (1970～1979), oil crisis. At Ⅶa, in order to cut cost (in particular, labor cost) numerous devices on operation works were made (1957～1960) and then (1961～1962), two lines of spinning solutions at Asahi viscose rayon plant were integrated to single line and two finishing plants were also integrated at Asahi with equipment investments. At Ⅶb, the technology for creation of new brands such as ultra-fine yarns and bold yarns was developed to compensate significant reduction of out put of regular (120 denier) yarn due to erosion of synthetic fibers. Undaria™ was a typical example of new brand. Method of continuous spinning thick yarn (HVR) was developed at Ⅶb and commercialized at Ⅶc. At Ⅶc～Ⅷ, automatic 'cake changer' was developed (1976～1980) and then, commercialized at Ⅷ (1980). At Ⅶc, the continuous spinning of regular rayon was invented (1976～1980) and improved (1986～1989), and commercialized step-wisely (1980～1989) (Silmax™).

1. INTRODUCTION

In this article as the last part of the study on historical development of manufacturing technology of viscose rayon fibers in Japan since 1930s,[1,2] Stages Ⅶ and Ⅷ are targeted.

2. STAGE Ⅶ: LONG-TERM RECESSION AND RATIONALIZATION (1957～1979)

Throughout this stage of twenty years there existed the long-term recession and the numerous efforts of rationalization were paid to overcome the difficulty. However, the stage is never homogenous in nature and can be roughly divided into three sub-stages (see, also, Table 6):

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* This article is a drastically revised and enlarged English version of the paper originally in *J. Soc. Text. Machn., Japan,* **47**, p 410-419 (1994).

VIIa (1957～1962): Curtailment of output (excessive production capacity)

VIIb (1962～1970): Creation of new brand (endeavor to survive)

VIIc (1970～1979): Partial retreat or defeat in competition to synthetic fibers (serious 'oil crisis' damage)

In Japan three major manufacturing companies retreated from viscose rayon business (one at VIIb and two at VIIc).

2. 1 Stage VIIa (Curtailment)

Japanese viscose rayon manufactures invested the profit, gained from booming due to Korea War, to the manufacturing equipments of viscose rayon for expansion of production capacity. On the other hand, nylon fiber invaded the market of viscose rayon, especially, of 120 denier yarn and also world-wide depression occurred, both resulted shrinkage of market demand for (regular) viscose rayon yarns. Gap of supply and demand became serious since late 1956 and the curtailment of operation at factories started on August 1957: August～September 1957, 17% (Asahi, 20%) → October 1957, 29% (Asahi, 34%) → Jan. ～ March 1958, 50% (Asahi, 55%) → …… → 1962, 26%. The imbalance recovered in 1962 due to the retreat of Toray (See below for further details) and the curtailment ended on October 1962 (Stage VIIa). The curtailment was carried out by the control of output and full stop of operation of the spinning machines (by seal). For example, on January 1958 cut rate of output was 55% and 62 spinning machines were sealed at Asahi. Note that cuprammonium rayon was the outside of the curtailment, but Asahi cuprammonium rayon business was in cooperation with the curtailment agreement of viscose rayon.

The production of viscose rayon yarns decreased by 38% from 2,110 ton/month on July 1957 to 805 ton/month on January 1958. High rate curtailment of factory operation will bring about rise in production cost and excessive labor power unavoidably, if any effective measures are not put into force. At the stage VIIa (during 1957～1962 (Oct.)) cost reduction was attempted by rationalization of the process ; at the first half of the above period (1957～1960) numerous efforts for rationalization by small devices, which did not require financial investment, were accumulated. For this, management technology, originated in USA, for examples , ME (Method Engineering), PM (Preventive Maintenance), QC (Quality Control) and CC (Cost Control), were also adopted.

Tables 1～5 demonstrate small devices for rationalization made at Asahi rayon plant (Nobeoka)[2]. Main targets of the efforts were concentrated on reduction of pulp cost and labor cost.

Table 1 Rationalization in viscose rayon process: some examples at Asahi in 1959

Process	Examples
Steeping	Abolishment of continuous filtration of viscose; division of pulp－weighing and blending; simplification of feeding operation of alkalicellulose; improvement of deareation for saving of steam vapor; use of low α-cellulose content pulp; increase of waste alkali recovery rate
Xanthation	Saving of filtration materials
Dissolving	
Spinning	Installment of water－supply device at cake exchange operation for fine denier yarn spinning; rationalization of work at spinning room; lowering of high frequency wave; speed-up of AR; increase of number of spinneret, which one spinner should manage
Finishing	Improvement of operation of cake－scouring machine; increase of labor productivity of fine denier yarn brand; integration of two finishing & scouring sections; simplification of dehydration & humidification operations; speed-up of drying machine; change of package paper

Table 2 Rationalization in viscose rayon process: some examples at Asahi in 1960

Process	Examples
Steeping	Improvement of operation of steeping－shredding (1^{st} plant); improvement of operation of ageing tower; use of low α-cellulose content pulp; integration of day－time labor; improvement of pulp－feeding apparatus;
Xanthation	Improvement of xanthation (2^{nd} plant); improvement of discharge of viscose
Dissolving	
Spinning	Change of grouping of spinners; increase of number of spins at cake change per a spinner; re－use of pot; lowering of exclusion rate of yarn
Finishing	Improvement of reception work of cake; improvement of machine maintenance work; adoption of cone triple winding system; improvement of finishing operation of special yarn

Table 3 Rationalization in viscose rayon process: some examples at Asahi in 1961

Process	Examples
Steeping	Consecutive automatization of steeping － shredding － xanthation processes; automatic control of ageing tower
Xanthation	Improvement of scraping out hopper scale; improvement of alkali

Dissolving	filtration; change of filter and arrangement of filtration machine; use of low α - cellulose content pulp
Spinning	Improvements of water- - feeding method, spinning bath and of cake change work; integration and simplification of machine maintenance work
Finishing	Improvements of cone packaging work, works at humidification room, cake reception, distribution work, cake transportation work and scouring

Table 4 Rationalization in viscose rayon process: some examples at Asahi in 1962

Process	Examples
Steeping	Automatization of ageing room (2^{nd} and 3^{rd} plants); (Primary) integration of preparation process of spinning solution*a at 2^{nd} and 3^{rd} plants; use of low-price pulp
Spinning	Standardization of hank change work; (secondary) improvement of water − pouring method into pot; (primary) mechanization of netting work
Finishing	Centralization of spots of cake reception; roll−dehydration of skein; improvement of cake−conveyance

*a: total process of steeping + ageing + xanthation + dissolving

Table 5 Rationalization in viscose rayon process: some examples at Asahi in 1963

Process	Examples
Steeping	Secondary integration of preparation process of spinning solution*a at 2^{nd} and 3^{rd} plants; use of low−price pulp; improvement of waste alkali−recovery apparatus
Spinning	Improvement of hank − change device; utilization of cake−taking out tool; improvement of die − inspection method; improvement of pot−washing method; secondary mechanization of netting work; rationalization of die room; speed-up of spinning velocity

*a: total process of steeping + ageing + xanthation + dissolving

Fig. 1 shows change in the portions of costs of pulp, chemicals, resource (= pulp + chemical), and labor. In 1960 cost of pulp and that of labor, each were approximately quarter of the total production expenses. The expensive conifer pulp was replaced by cheap low α - cellulose content pulp

The technology, which enables usage of low α - cellulose content pulp to produce rayon fiber with the same or even better quality as or than those made from high α - pulp, was developed. In addition, the standardization and improvement of laborer's works were made over the whole viscose process so that elements of works were simplified and rationalized, resulting in reduction of the

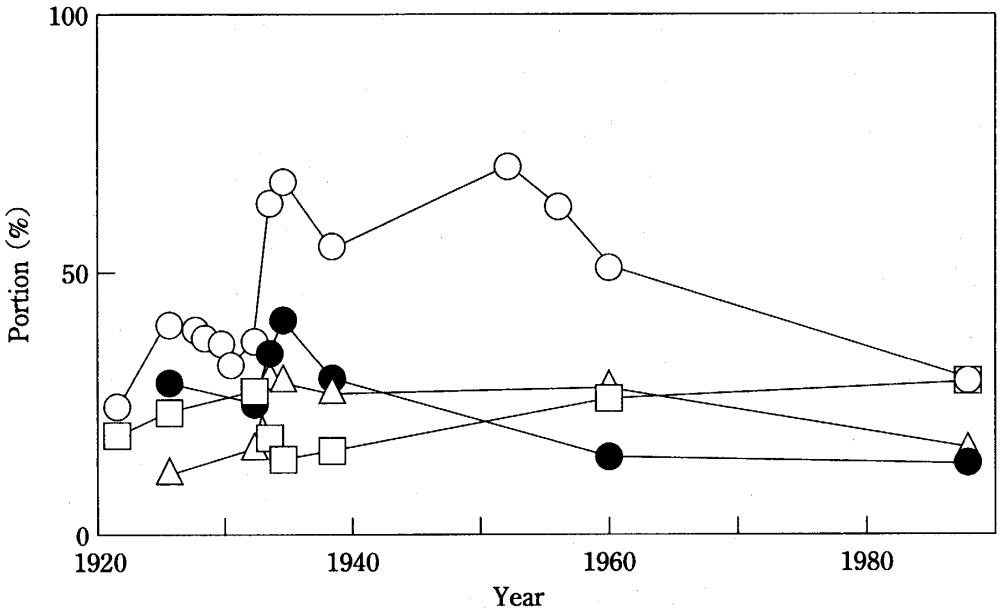

Figure 1 Portions of pulp, chemicals and labor costs in factory production cost: 1921[4], 1926[4], 1926~1930[5], 1932~1933[6], 1937[7], 1952[8,9], 1956[8,9], 1960[10], 1983[10] : ○; resource cost, □; labor cost, ●; chemicals cost, △; pulp cost.

labor cost. Young male laborers formed as surplus personnel (for example, 30 individuals in July 1957) were transferred to other plants, producing synthetic materials, of the company. In the latter term of 1962 integration of production lines of the factory was made energetically and with investment on instruments the manufacturing process was progressively rationalized and automatized as labor-saving measures (see, Table 1~5). The items underlined in Table 1~5 correspond to the above rationalization. At Stage VIIa, no laborer was dismissed or was not forced to resign for personal reasons from Asahi, although total numbers of dismissed persons in the same period are: 1,805 by Toray, 1,757 by Teijin, 2,992 by Kuraray, 714 by Mitsubishi, and 850 by Tohoray.[10,11]

In this stage the original instruments were devised and developed by themselves. As results, the per capita productivity of 13.5 kg-fiber/person/day in 1957 was significantly improved by about 50% up to 20.2 kg-fiber/person/day in 1963.[12] An attempt of integrating three independent spinning solution lines into single plant was made in 1962~1963.[13] For this slurry process and ageing process were improved: In order to increase the capacity of slurry steeping machine slurry temperature was raised. Note that as slurry temperature increased degree of swelling decreased, then leading to easy – squeezing as well as shortening of the reaction time, but hemicellulose eluted into the squeezed alkali solution. Addition of hemicellulose in advance to the solution prevented new elution of hemicellulose from alkalicellulose.[14] Slurry concentration was concurrently increased up to 30%.[8]

For shortening of ageing, oxygen gas of high concentration was blew into the ageing tower and temperature of alkali solution was increased. An increase in temperature brings about the broadening of molecular weight distribution of degenerated alkalicellulose due to non-uniform staying time of alkalicellulose molecules in the ageing tower, accordingly, lowering of the solubility of sodium cellulose xanthate, synthesized from the alkalicellulose. Note that in this case, the solubility does not mean average value, but difficulty of preparation of homogeneous viscose solution. This problem was ultimately dissolved with installment of new scraping equipment inside of the ageing tower.

Integration of the plants of preparation of spinning solution afforded the reduction of 78 individuals during 1961～1963.[15]

Next, the two finishing lined were integrated.[16] In the past, cakes were transferred from conveyer to scouring car one by one in Oskar Kohorn type system, which was replaced with Parette (?) type scouring car, on which a shelf lifting about 30 cakes could be loaded.[17] In the past, after scouring cakes were once unloaded from scouring car to be centrifuged. Now, cakes on the car, exactly as it was, was dehydrated by air without transshipment.[18] In addition, by changing the operating conditions such as the concentration of scouring liquor and the temperature of scouring, the treatment time was shortened from 25 min to 18 min and finally to 12.5 min and 300 persons were saved.[19]

Table 6 collects the amount of investment in plant and equipment for the rationalization at Asahi rayon plant during 1959～1963 and the number of persons, which could be saved by the investment and the estimated economic effect achieved by the rationalization.[12]

Table 6 Achievements of rationalization at Stage Ⅶa[12]

Fiscal year	Estimated profit (10^4 yen)	Investment (10^4 yen)	Reduced persons
1959	15,247.0	822.3	355
1960	17,628.1	1,345.4	300
1961	20,076.0	5,519.4	469
1962	17,518.2	4,377.4	316
1963	19,677.3	7,869.7	347

Since 1961 the amount of investment increased significantly, but the saved number of laborers and the effect of rationalization seems almost leveled off. Effect of the investment can be expressed in terms of a kind of rate of profit (RP). In this case the ratio of the estimated profit to the corresponding investment (RPI) or that of the reduced number of laborers to the investment (RRI) were

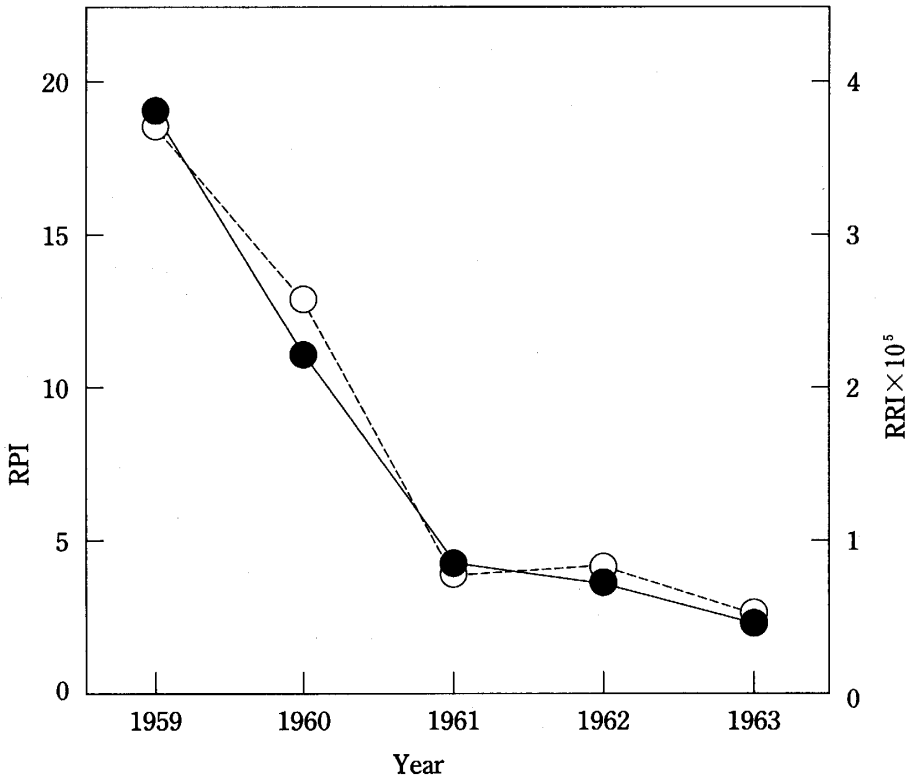

Figure 2 Ratio of the profit to the investment (RPI) and that of the reduced number of laborers to the investment (RRI), ○; RPI, ●; RRI

plotted against the fiscal year in Fig. 2. Both indexes decreases rapidly with year, indicating that the most profitable items were adopted to dissolve at earlier stage and the less profitable and less promissing items remained. The cost − effectiveness was declined slowly with time.

Conclusively, the efforts of rationalization changed from small trivial device to process modification (more saving of energy, workforce and raw resource) via integration of the factory lines (slimming down of the factory).

2. 2 Stage Ⅶb

2. 2. 1 Competition against synthetic fiber

Curtailment of rayon output might be due to the imbalance of demand and supply (recession cycle), but the shrinkage of rayon production (and then, market) since 1960 (see Fig. 1 of ref. 1) is closely related with the reduction in size of rayon market encroached by synthetic fibers, resulting in decisive slippage of rayon from the position of general−purpose fiber (commodity product) to special fiber for smaller market. Note that since 1960 rayon yarns were confronted severe competition against synthetic fiber (first, nylon, and next, polyester) in Japan. Output of rayon yarns

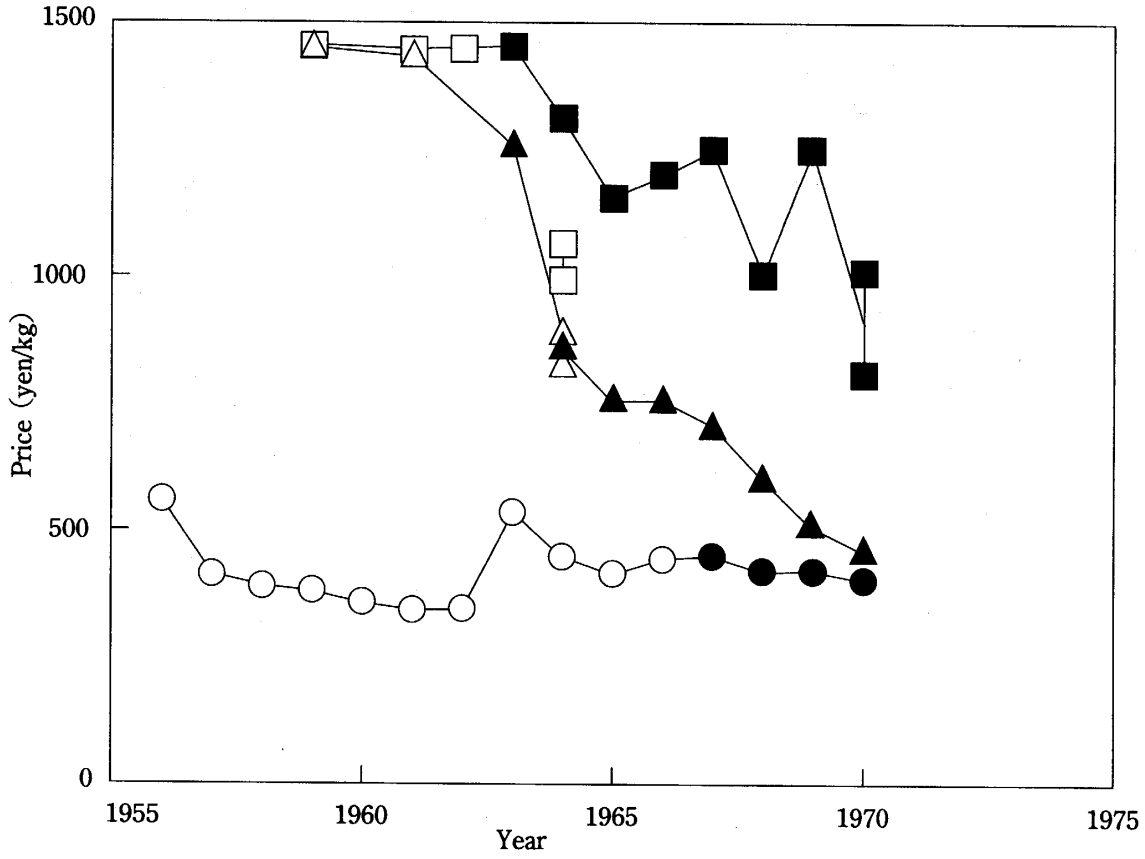

Figure 3 Price of viscose rayon, nylon and polyester : ○ ; viscose rayon, 120d[20], ●; viscose rayon, 120d[21], △; nylon, 110d[22], ▲; nylon, 75d[23], □; polyester, 110d[24], ■; polyester, 75d[25]

was outstripped by that of nylon in 1963 and then, by polyester in 1965. Thereafter, within a few years the difference in output between rayon yarn and synthetic fibers expanded rapidly. Until 1960s the price of synthetic fiber (nylon and polyester) was 1,400～1,500 yen/kg, being 3～4 times of that of rayon. In 1960s yarn price of nylon and then that of polyester lowered quickly, both owing to mass－production effect, approaching to the same level as that of viscose rayon in early 1970s, immediately before 'oil crisis' (Fig. 3).

In this manner, synthetic fiber grew to a ferocious rival for viscose rayon in 1960s. With spread of synthetic fibers viscose rayon left main stream of fiber business. In comparison with viscose rayon fiber synthetic fiber was said to be superior in its tenacity, water content (low), heat resistance, and weather－proof.[26] At present, viscose rayon yarns are highly estimated in the following characteristics; high absorbency (of humid), good feeling, and bright color. Then, we should recognize that value of commodity varies depending on the social circumstances.

Toray , which had the production capacity of 69 ton/day, was discouraged about the future of

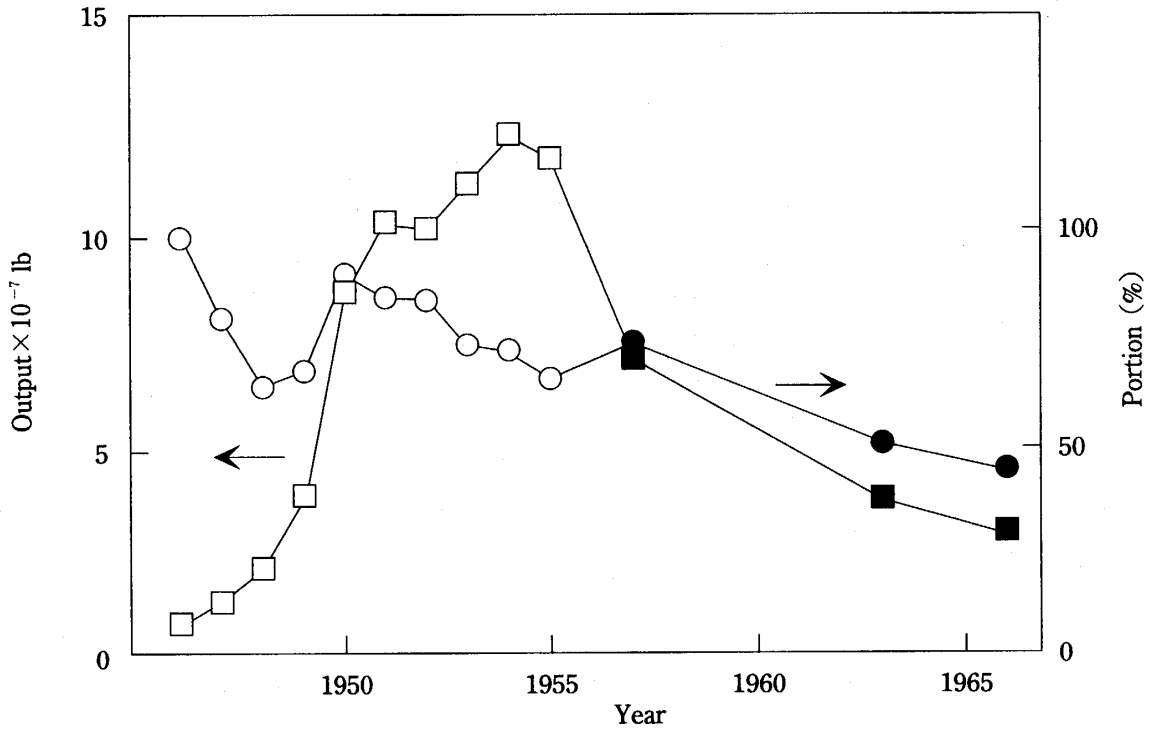

Figure 4 Output of viscose rayon yarn (120d) and its portion among total yarn production: ○[32], ●[32]; △[33], ▲[33]

viscose rayon industry and retreated completely from the business in 1963.[27,28] It seems reasonable for Toray to consider at that time that improvement of productivity of viscose rayon can not be expected in future and profit of synthetic fiber business will have a tendency to increase. Then, they decided to centralize resources to synthetic fibers taking out regenerated cellulose fiber: Toray scrapped Otsu plant of regular viscose rayon, expanding capacity of nylon plant on Aug. 1961.[29] And on January 1962 Toray suspended the production of viscose rayon[30] and on May 1963 they made a final decision of retreat from the viscose rayon business.[31] Competition of viscose rayon with synthetic fiber brought about shrinkage of the market of (then) main rayon brand (120 denier yarn), in other words, reduction of its output (Fig. 4). For example, output of viscose rayon (120d) reduced dramatically from 1,324 ton in 1957 to 365 ton in 1963 (only 28% of the record of 1957) in Japan.[34]

In order to supplement the dramatic decrease in market demand for 120d fiber there was a real need, therefore, to develop new brands. Examples are fine denier yarns (50~75 d) and thick yarns (larger than 250d; 250, 300, and 500d) and special yarns with own particular specialty such as ultra-fine denier yarns (AR yarn; 20~40d) and yarns with non-circular cross sections. Fig. 5 shows new

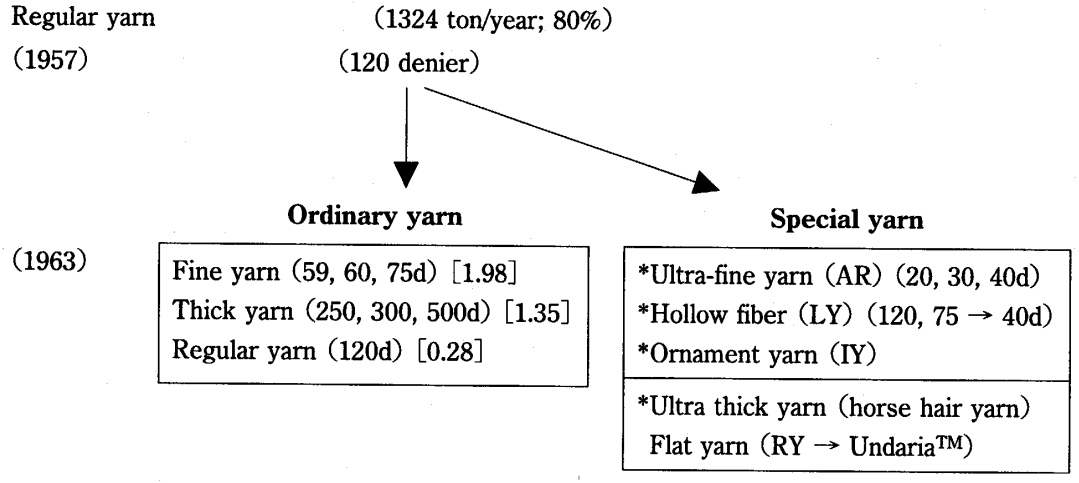

Figure 5 Development of new brand in StageⅦb[34,35] : [ ]; ratio of production in 1963 to that in 1957 *; new brands

brands merchandized at Asahi with some economical success during 1957～1960s.[35,36]

Until that time the tensile strength of fine yarns, manufactured by conventional method, showed about 1.8 gram/denier (g/d) , which was too low for further treatment (to arrange the warp in parallel each other under tension) in preparation process for weaving. Method for spinning fine viscose yarn with higher tensile strength was invented: Viscose, riped to greater extent (i. e., lower molecular weight of cellulose xanthate), was wet－spun by the two－stage bath stretching spinning method, in which 1/3 of the lower part of the second godet was immersed in the second spinning bath.[37,38] By using this technology the high－tenacity ultra-fine denier viscose rayon yarn of 20 and 30d could be produced commercially. The tenacity of these yarns was 30% larger than that of normal yarns.[39]

In general, development of fine denier yarns was performed in 1956～1958, aiming to up-grade the quality of rayon cloth. Production of the ultra-fine yarns (20, 30, and 40d) (AR yarns) started on January 1958 on a considerably smaller scale; 1 ton/month. AR yarns, which had feels similar to genuine silk yarns, were utilized for handkerchief and scarf[40] and thin habutae silk, satin weaves, silk-rayon mixed fabric and tricot fabric.[39] AR yarn's production expanded to 22 ton/month in 1959, reaching to 55 ton/month in 1963.[40]

Thick 'Bold yarns' (250, 300, and 500d), which could be produced with productivity, were utilized for cotton-mixed Damask for export, toy seals, strings, cords and ribbons.[39]

Hollow fibers (air-bubble containing fiber with lotus root-like section) (Lufter yarn; LY yarn) was developed in around 1957. Initially, denier of the fiber was 120d and then, decreased via 75d down to 40d.[40] Production, started on October 1958 on 4 ton/month scale, increased to 34 ton/month

in 1962. Macaroni-type had been invented before the war, but it was week in tenacity. Hollow fiber had light and bulky feels and silky gloss.[40] The production of LY yarn was suspended in 1976.[41]

Ornament yarns (Illumination yarn, IY yarn), consisting of rigid single filaments, were gloss, cool and sturdy, and were used for sweater and cloth by blending with wool and cotton.[40] The production started on January 1959 on 6 ton/month scale, and grew into 120 ton/month in 1962.

Ribbon-like broad flat monofilament yarn (RY yarn) (1,100 and 2,000d, after that, 4,000 and 6,000d) was merchandized in around 1959 (June 1958 at 9 ton/month → 170 ton/month in end of 1962). The yarn was bulky and sturdy. The yarn was named on August 1963 as Undaria™, because it had shape similar to undaria pinnatifida (sea weed). Since then, Undaria became the Asahi's trade mark of all viscose rayon special yarns.[42]

Table 7 summarizes a brief history of development of Undaria.™.

Table 7 Development of broad flat monofilament yarn, Undaria™ manufacturing technology

Phase	Year	Method	Remarks
1st[43, 44]	1961～1962	new nozzle	nozzle shape & material
2nd[45, 46]	1964～1965	hank-type spinning	skein: 400～500 ton/M ('65～)
3rd[47, 48]	1968～1970	continuous spinning	HVR: Jan. 1971; 1st line; Nov. 1972; 2nd line: 240 ton/M

Undaria™ was used first for seal and mogal (braid, lace)[40] and then widely for hat and handicraft work.[40] Since then, the fiber found application as industrial materials, such as carpet, wall paper (wall cloth) and curtain,[49] and finally the fiber was used for clothing. Silber yarn (horse hair yarn) was thick and sturdy, used for mosquito net, hat and broad sash (tied over a kimono).[50] Horse hair yarn had already been merchandized in the first half of 1920s by Vereinigte Glantzstoff Fabriken A. G. (VGF), Germany.[51]

Special yarns were produced in Japan on scale of about 1,000 ton/month until 1956. Its production increased abruptly in 1957～1962, amounted to 7,000～8,000 ton/month, of which 80～90% was manufactured by Asahi.[52] Asahi got annual profit of $10～20 \times 10^6$ yen/year from thick flat yarns.[53] Rayon handicraft yarns became booming (until 1965) by efforts including nation-wide seminar of handicraft works.[54]

Thick yarns larger than 600 denier could not be produced by centrifugal-type spinning machine,

because due to large thickness the spinning pot was soon filled in short time with yarn. Hank type, in which yarn was wounded on skein frame, was a little better in this respect. Even if hank type spinning was employed, (1) it took 7～9 min for change of the frame by hand, (2) working environment was extremely bad: laborer contacted directly with sulfuric acid (coagulant), (3) if the fiber was wounded by hank, rotating at constant rate of rotation, the denier of fiber varied significantly owing to variation of surface velocity of hank between beginning and ending of the winding operation, (in the case of 4,000 denier yarn the difference was estimated to be 200 denier), (4) loss of yarns during exchange step occurred due to large thickness.[55] To overcome the above short points new hank-type spinning machine, which enabled to wind yarns larger than 4,000 denier, was invented in 1969.[56] The Agency of Science and Technology awarded the prize to Asahi for this invention in 1972.[57]

As will be shown below, the process was batch process, which needed large man power for transportation of half-products between steps.

(New hank method):

spinning solution → new hank-type spinning machine → skein → scouring → dyeing → humidification → sorting → rapping → shipment skein

In 1970 production of about 70 brands, which were supplied in form of skein, was abolished. The hank process was improved in 1971 to continuous process, which was named as HVR (Hank Victory Rayon).[58] HVR rayons were shipped in the form of cheese (and not in the form of skein).[58] At stage Ⅶa the flat yarn was outside the subject of curtailment. Then, it was expected that commercialization of the flat yarn will contribute to increase in operation rate of the plant and employment of surplus man power formed with the curtailment. In addition, marginal profit was larger for the flat yarn than ordinary rayons: The price difference of Undaria™ and ordinary rayon yarn was 40～50 yen/kg during 1963～1969 (i.e., 43 yen/kg (1963), 52 (1964), 59 (1965), 43 (1966), 40 (1967), 37 (1968), 40 (1969))[59], but the difference decreased to less than 20 yen/kg in 1970～1972. Sugimoto reviewed that the price of special yarns was 550 yen/kg～800 yen/kg at the time when that of regular yarn (120d) was in the range 350 yen/kg～380 yen/kg.[42] The production of Undaria™ attained maximum in 1970～1972.[60]

Thus, business constitution of viscose rayon industry converted in Stage Ⅶb from low-value added commodity to high-value added items. Indication of shortage of regular rayons was observed in market in 1971. The surplus of production capacity was used for regular rayon except some Undaria™ with good profit.[61]

2. 3 Stage Ⅶc Defeat to synthetic fiber (oil crisis)

Special yarns met difficulty doe to dullness of export caused by dollar shock (August 1971) (drastic change of exchange regime from the fixed exchange rate system to the floating exchange rate system). Toyo-bo and Teijin retreated their viscose rayon business on April 1971[62] and on October 1971[63], respectively. The supply-demand balance of regular yarn (120d) recovered again. Since then, Asahi, Kura-ray and Unichika continued viscose rayon production in Japan until 2003.

Petroleum crisis occurred twice in 1970s. Crude oil price increased four times in the first crisis (October 1973 and January 1974) and the price increased again approximately three times during 1978～1981. Totally, crude oil price jumped about ten times. As result, energy cost had taken a jump. Viscose rayon industry is a typical energy consuming industry[64] and its production cost became more expensive than that of synthetic fiber.[64]

Fig. 6 shows output and price of Asahi viscose rayon yarns during 1962 and 1990.

The ratio of the various factory expenses in 1976 to those in 1971 is summarized in Table 8. In the table the corresponding values (portions) in 1960 are included.

Table 8 Various factory expenses of Asahi viscose rayon plant[65]

Item	Portion (1960)	Ratio (1976/1971)
Proportional cost	0.56	2.09
Fixed cost	0.44	1.87
Pulp cost	0.27	1.96
Energy cost	0.11	2.50
Laborer cost	0.25	1.71
Fiber price		1.42

It is evident from Table 8 that after oil crisis the factory cost increased round twice, but the fiber prices increased only 1.4 times.

Fig. 7 shows difference of the yarn price and the factory cost during 1963～1989. The difference serves as a measure of profitability of the business. Before oil crisis, the difference was roughly constant around 150 yen/kg. The difference exhibited maximum (216.5 yen/kg) in 1971, followed by minimum (36.5 yen/kg) in 1976, owing to the time-lag of price rising (speculative buying) and cost rising caused by the first oil crisis. Similar phenomena were observed at second oil crisis: second maximum (201 yen/kg) in 1980 and minimum (85.0 yen/kg) in 1984. Since then (1985～), the

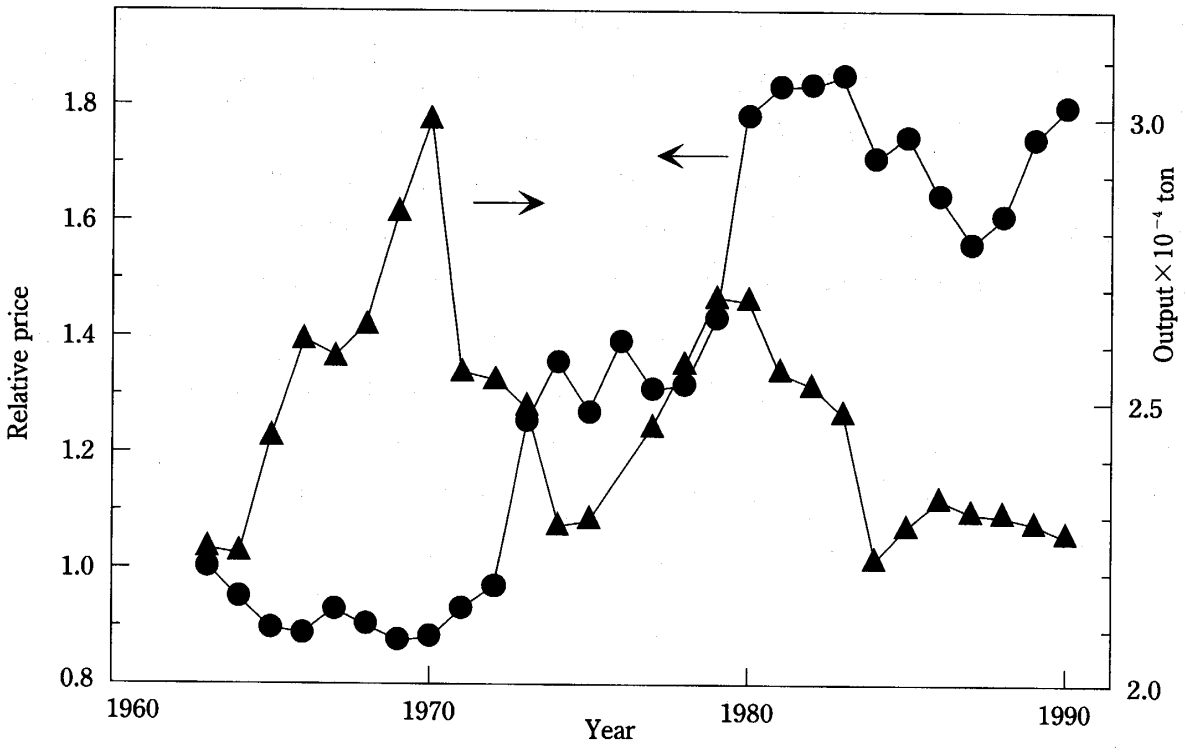

Figure 6 Output, price and cost of Asahi viscose rayon yarns

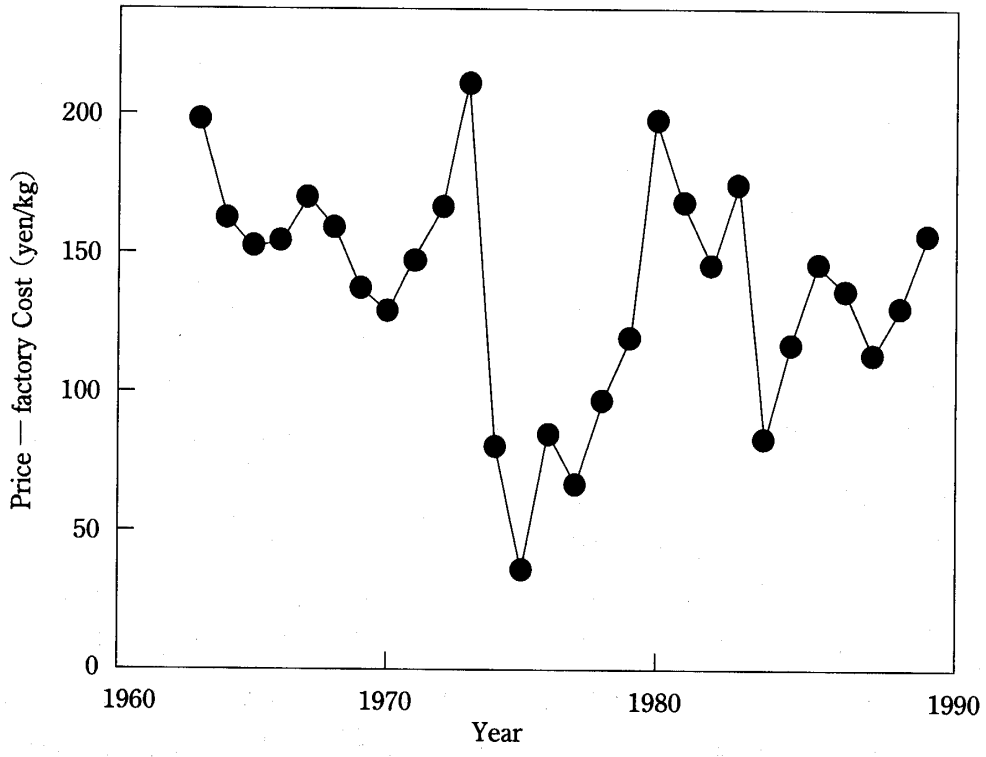

Figure 7 Difference between the yarn price and the factory cost of viscose rayon yarn

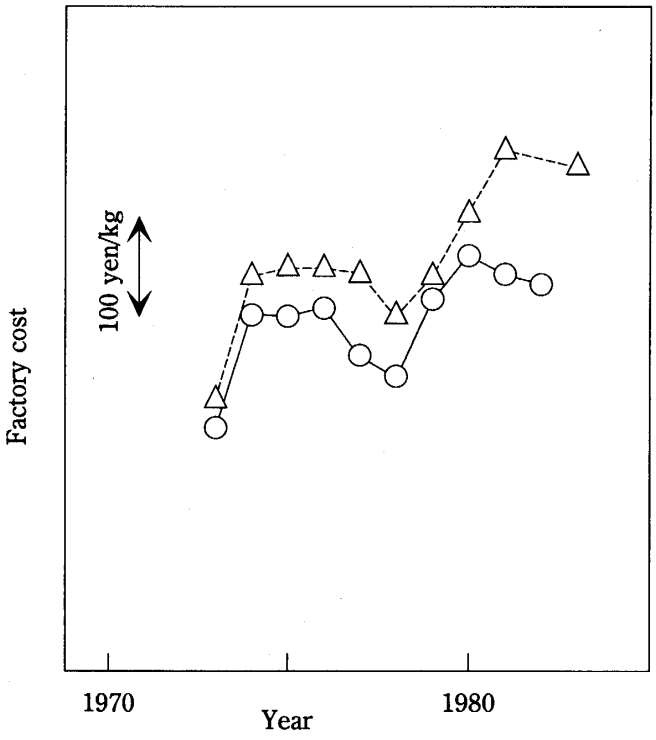

Figure 8 Factory production cost of viscose rayon and polyester[66]
△; viscose rayon, ○; polyester

difference ranged over 100～150 yen/kg,

Fig 8 shows relative change in production cost of viscose rayon yarn and polyester yarn in Japan during 1973～1983.

After the occurrence of the oil crisis the difference in factory production cost increased between regenerated cellulose fibers and synthetic fibers (Fig. 8). That is, immediately before the first oil crisis the difference was round 30 yen/kg and the difference expanded to 50～60 yen/kg in the first oil crisis and to 150～200 yen/kg after the second crisis. As results viscose rayon industry loosed gradually price competitiveness against synthetic fibers in the same commodity area. Output of viscose rayon at Asahi decreased from 27,266 ton/year in 1973 to 22,129 ton/year in 1975.[67] Numerous efforts were made to recover output, in other words, to rise the price, which can offset the expenditure.[67] For this purpose, following high-value added yarns were put on market:

(1) New hollow fiber (N－LY) (February 1976).
(2) Threads (AS150MB) for exclusive use of embroidery lace (1976).
(3) Yarns spun from viscose mixed with dye (i.e., dyed yarn can be obtained in viscose process without inserting dyeing process) (Asahi Black; January 1977).
(4) Yarns (KY) for warp of lining (1979).

In addition, owing to export market expansion formed by retreat of European viscose manufacturers, the export ratio of viscose rayon increased from 30% (before oil shock) to 50% (after oil shock). The output recovered in 1978, reaching to 27,053 ton/year.

Due to serious recession after oil crisis and encroachment of Undaria™ market by paper and plastic imitations, the demand for Undaria™ curtailed year by year, resulting in reduction of its output in 1977 by 50% of 3,000 ton/year in 1973.[68] To make bad things worse, the rise of production cost, caused by low degree of operation, made continuity of Undaria™ (monofilament thick flat yarn) 's production difficult.[68] Then, since around 1980 multi-filament thick yarns (600~30,000 d) were developed by using new scouring method, by which separation of each filament was possible, (BS continuous spinning as a modification of HVR (see Table 8). The products were supplied in forms of cheese (Raffit™ ?) for padding, buff and brush or tow (Silm ™ ?) for high class fabric. In this way. Undaria™ evolved to these new two brands.

During 1976~1980, Asahi reopened the development project on continuous spinning technology of regular viscose rayon (see Table 11). The project was successfully practiced in Stage Ⅲ.

Table 9 summarizes the economical circumstances, manufacturing technology and market in Stage Ⅶ.

3. STAGE Ⅷ: REFORMATION (1980~1993)

Since the occurrence of petroleum crisis, attempts had been made to reduce production expenses by throughgoing factory automatization, labor-saving and saving of other expense items.

3. 1 Research and development activity

Research and development activity, as measured by number of published Japanese Patents, of three viscose rayon manufacturers, which continued the production of viscose rayon at least until 1990s, is listed in Table 10. Total number of Japanese Patent Publication on regenerated cellulose fiber published during 1975 and 1990 was 59 by Asahi, 2 by Kura-ray, and 2 by Unichika, respectively.

R & D activity toward viscose rayon differed greatly among the three companies and Asahi was Japan's premier viscose rayon company at that time. Note that the number for Asahi in Table 10 includes Japanese Patent Publication of cuprammonium rayon[69] and new cellulose fibers.[70]

3. 2 Preparation process of viscose dope

Fig. 9 illustrates comparison of the preparation process of viscose spinning dope in 1955 with that in 1990. In 1955 there were three similar processes in the three plants, and three processes were

Table 9 Long-term recession (1957～1979)

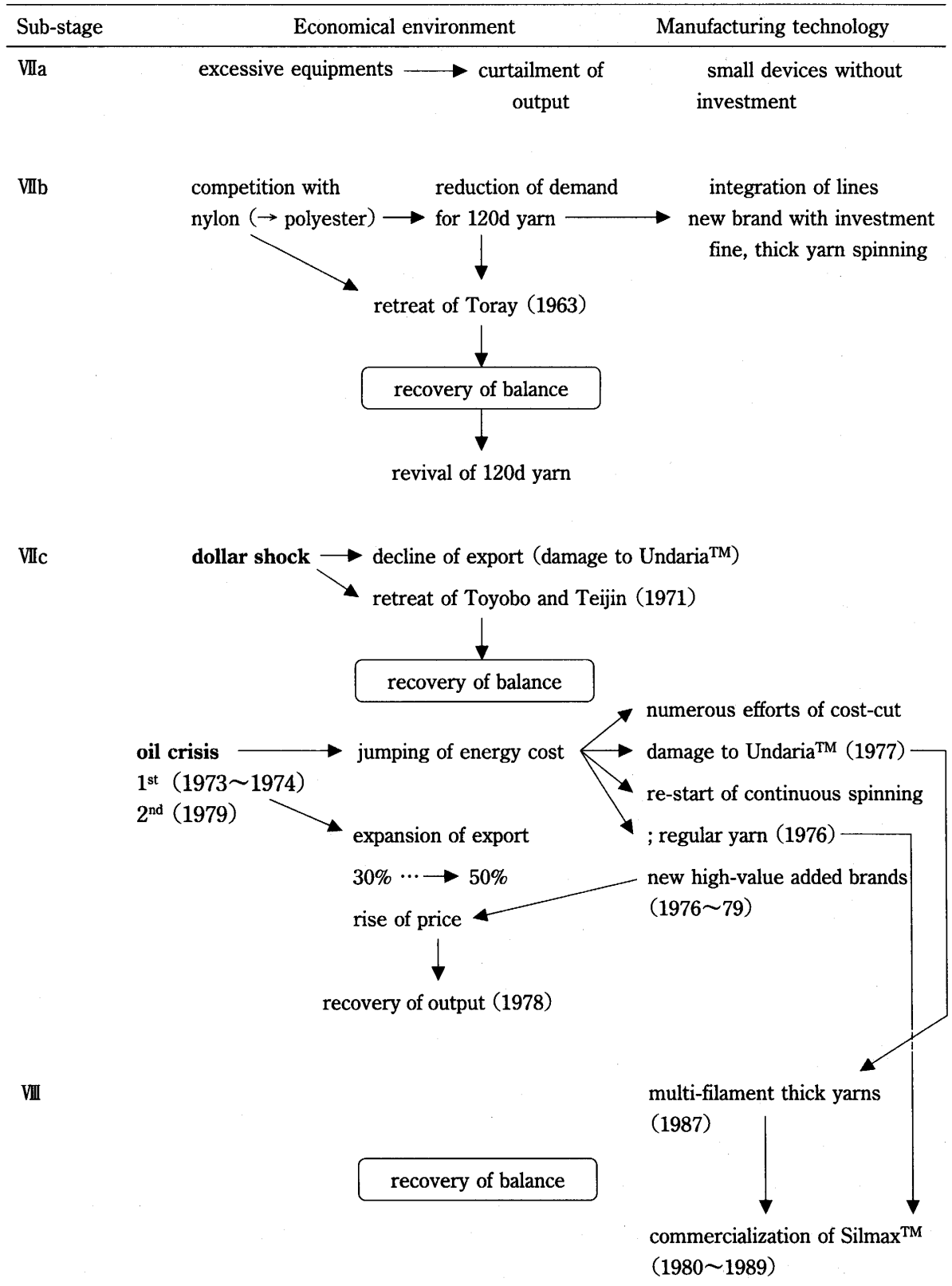

Table 10 Number of Japanese Patents published during 1955～1990

Year	Asahi	Kua-ray	Unichika	Year	Asahi	Kura-ray	Unichika
1955	4	3	1	1976	3	0	1
1956	4	0	0	1977	5	0	0
1957	1	4	1	1978	5	0	0
1958	1	1	0	1979	5	0	0
1959	3	3	0	1980	2	0	0
1960	8	1	2	1981	1	0	0
1961	8	2	0	1982	1	0	0
1962	10	3	1	1983	4	0	0
1963	11	2	2	1984	1	0	0
1964	1	0	1	1985	8	0	0
1965	5	2	2	1986	3	0	0
1966	3	8	2	1987	4	0	0
1967	0	3	0	1988	3	0	0
1968	10	5	2	1989	7	0	1
1969	7	3	4	1990	2	1	0
1970	7	0	0				
1971	7	5	0	Total	168	53	21
1972	2	4	1	Subtotal	59	2	2
1973	6	1	0	(1975～1990)			
1974	9	1	0				
1975	9	1	0				

integrated until 1990 into single line.

During 1955～1990 output of viscose rayon yarn was kept almost constant, but man power of the above process (i.e., pulp～spinning dope) in 1990 reduced drastically to 1/16 of that in 1955.[71] During the above period (1955～1990), the following technological advances were performed: In 1966 slurry process was integrated to the second plant and in 1969 Fendar (?) filter was installed. Computer control system (Rayon Automatic Control System (RACS) – I) was introduced to preparation process of spinning dope in 1986, and in 1987 counter- current filter was installed.[72]

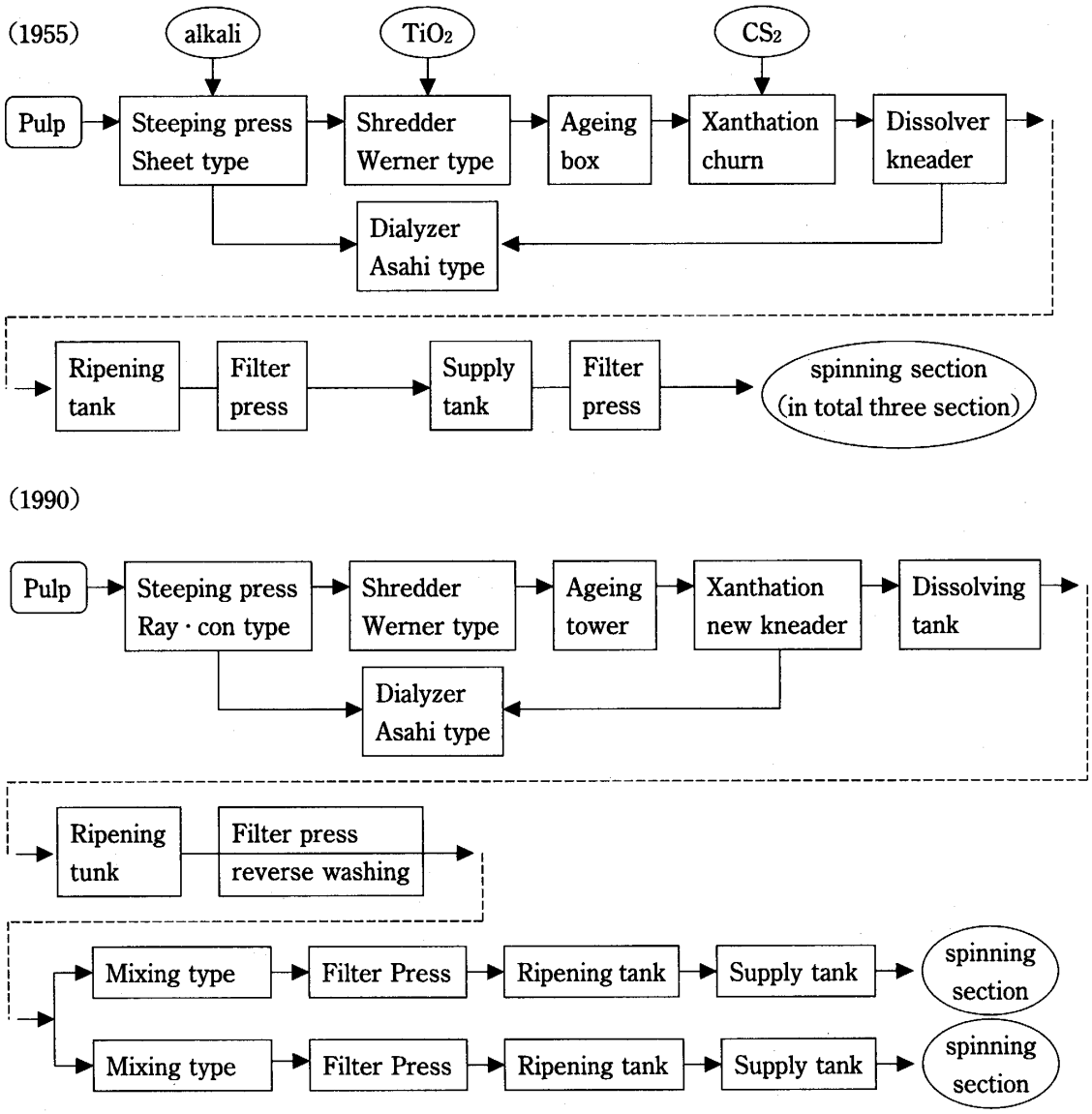

Fig 9 Rationalization of preparation step of viscose spinning dope step

3. 3 Wet－sinning process

In the wet－spinning process man power was reduced from about 3,000 individuals in 1955 to about 200 in 1990, which is 1/15 of that in 1955.[73] Most laborious and time-consuming works in the spinning process, such as (1) taking out of cake, (2) putting of net on the cake, and (3) re-start of spinning (setting of flowing yarn line, came out from spinneret, by pouring a cup of coagulating liquid through glass funnel (located above the pot) with yarn into the rotating centrifugal pot), were first automatized at Stage Ⅶ.

In particular, in 1965 automatic 'pouring water with filament into pot' (simply, 'pouring into'

equipment, which covers the works (1) and (3), was practiced by Asahi first in the world and man powers for this work (change or conversion work) was reduced down to 270. As result, the spinning work could be carried out without any temporary cut off of the running fiber during (1) and (3). The fiber formed during (1) and (3) was wounded on a special drum. The automatic 'pouring into' equipments was incorporated into the spinning machine during 1963～1966. To the invention[74] of the apparatus, the Prime Minister's Prize was awarded in 1967.[75] The technology was exported worldwide.

Advantages of automatic 'pouring water into pot' apparatus are[76]:

(1) Increase in labor productivity.

(2) Increase in yarn yield.

(3) Increase in net-working rate.

(4) Increase in fiber quality (constancy of length of yarn constituting a cake).

(5) Easy operation for even unskilled or advanced age laborer.

In 1963 the hand-rotation type rapping machine was developed. Next year automatic cake rapping machine was practiced. The rapping velocity (efficiency) of the latter, which could be operated by 1/3 of labor force of the former, was 10 times of the former. In other words, the labor productivity in the rapping section improved 30 times. In 1976 an automatic net supply equipment was devised and in 1982 automatic net squeezing equipment, which enabled to use directly rolled net in automatic rapping machine, was completed.[77] In this way, development of rapping machine continued over almost twenty years. The above inventions were made not by engineers in R & D division, but by highly-skilled factory workers.[78] Rayon manufacturers purchased the Asahi automatic rapping machines: For examples, Unichika, 2; Courtaulds (UK), 1; Beaunit (USA), 1.[78]

In 1968 electronic computer (FACOM 230－10) was introduced to the plant for production management.[79]

On the basis of the above mentioned individual inventions the automatic 'filled pot changer' was completed in 1980. In this case, assistant hand-work (at hopper cover and holder) was in part needed. In 1990 the complete automatic pot changer was put into practical use and thus the big target was achieved last.

3. 4 Scouring, finishing and sorting

Rationalization and automatization of the scouring, finishing, and sorting processess allowed to reduce man power in 1990 to 1/7 of about 1100 in 1965.[80] In 1990s completely automated scouring process was in short of reaching completion. It should be noted again that rationalization of the

process could be realized with development of the equipments by the factory one self, not depending on machine manufactures.[81]

3. 5 Continuous spinning

In this period innovative processes were also developed. An example is the continuous spinning machine (MR). Here, continuous spinning process means that the process in which spinning − scouring − drying − winding are continuously carried out. Although some foreign companies (AKZO and SNIA) employed the continuous method in their plants in the past the process had not yet been completed and had numerous unsolved typical problems and it had been considered that the continuous method was economically inferior to the centrifugal method.

In general, the continuous process had the problems in following points[82];

(1) running of a large number of fibers in narrow space,

(2) effective isolation of chemicals utilized in the process.

Fortunately, on the basis of accumulated know-how of thick flat yarns (HVR) Asahi started development of continuous spinning of regular yarns and on May 1980 constructed the equipment with capacity of 1 ton/day. The process evolved further (SL− I → ……→ SL − V) and the production recorded successfully up to 7.7 ton/day.

Table 11 summarizes a brief history of development of the continuous wet-spinning method.

The rayon yarns spun by the continuous spinning method in Asahi (Silmax™) had the special features such as[84]

(1) remarkably high uniform dyeability with keeping the as-usual characters of rayons,

(2) drastic decrease in fuzz (→ increase in productivity in preparation process, weaving and knitting process → less defect (stripe), high quality product),

(3) large pirn of 2 kg fiber, (later, cheese of 4 kg fiber) as supply form of yarn (→ easy handling at weaving or knitting stage and low frequency of their change of pirn at the stages (→ labor-saving and innovation at weavers or knitters).

Silmax™ was the first rayon yarn which could be applied to the market of velvet and outer. SL− Ⅲ type yarn was produced since 1986 at the velocity of 200 m/min, about twice of the velocity in the conventional centrifugal method. Supply form was improved from 2 kg yarn−pirn to 4 kg yarn− cheese. Pirn was superior in rewinding yarn to cake, but it could not keep up with rapid progress of weaving technology. On the other hand, cheese could adapt to high velocity air−jet loom, which was developed on September 1979 by Textile Research Laboratory at Asahi.[85] SL−Ⅳ, commercialized in 1989, was produced at the spinning velocity of 600～1,000 m/min. Then, SL−Ⅳ process differs fundamentally from the preceding types. In addition, SL−Ⅳ had more superior uniformity in

Table 11 Development of continuous spinning method[83]

Year/Month	Scale	Capacity (ton/day)	Remarks
1972	Start of development		with co-operation of SNIA
1973	Asahi type bench-scale spinning machine (primary)		market research with test samples
----------	oil crisis	----------	----------
1976	Asahi type bench−scale spinning machine (secondary)		MR prototype machine
1980/May	SL−I (MR)*a	1.0	2 kg yarn/pirn Silmax™*b
1983/Nov.	SL− II	1.6	
1986/Nov.	SL− III	2.4	spinning velocity 200 m/min
	SL−IV*c	——	
1987/Dec.	SL− V	2.5	
		(Total; 7.5 ton/day: 2,700 ton/year)	
1989/Apr.	SL−VI (FMR)*d		600～1,000 m/min

*a Modern Rayon (MR) process
*b Commercial name of fibers spun by MR process
*c not commercialized
*d Future Modern Rayon Process (FMR)

dyeability and super fitness to weft for air−jet room, in which the weft was inserted with the help of air flow. Air−jet loom was becoming a main stream of weaving in 1990s.[86]

Quality as well as the productivity of viscose rayon yarn were markedly improved in 1980s. Note that remarkable technological advance was achieved after the rayon industry fell in decay period. In 1980s new cellulose fibers, based on new principle, was under development.[87, 88] An example is the production of the fiber by coagulation of cellulose dissolved in dilute alkali solution without carbon disulfide (toxic material) using acid coagulant (SK−14). The physical property of the fiber was equivalent with that of viscose rayon fiber[88] and various characteristics of woven fabric were very satisfactory.[88]

As is evident from the above, Stage VIII (1980～1990s) is the period of regeneration.

3. 6 Labor productivity

Fig. 10 shows an improvement of per capita productivity in viscose rayon plants during

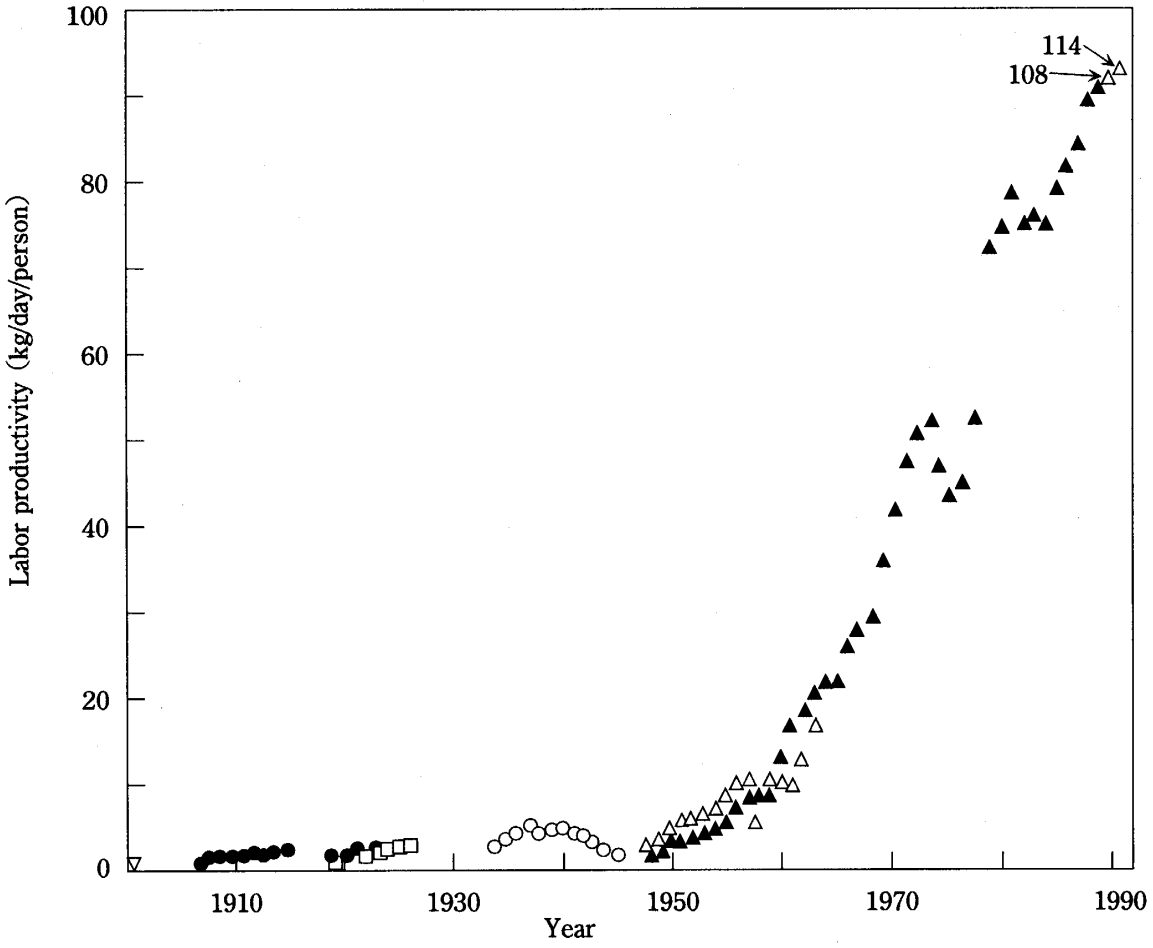

Figure 10 Labor productivity of viscose rayon: ▽; VGF (Germany)[89], ●; Coutaulds) UK)[89], □; Teijin[89,90], ○; Asahi (rayon)[91], △; Asahi (rayon)[92], ▲; Asahi (Bemberg)[93]

1901～1990. The figure includes the corresponding data points of cuprammonium rayon for comparison. Until about 1950 the labor productivity remained at level lower than 2 kg/person/day. The productivity at Asahi increased rapidly from around 1950, when many other enterprises began to consider the closure of viscose rayon yarn plants. This means that viscose company could not survive, at least, without innovating the existing process, although there remained numerous other issues yet to be resolved. In 1990s both viscose rayon method and cuprammonium method attained the level of about 100 kg/person/day. The work force needed for a plant with capacity of 50 ton/day is estimated to be 500 individuals. Fig. 8 suggests strongly that there seems no upper limit in per capita productivity at least in 1990s～2000s, provided that investment against R & D will be made continuously in the future.

The portions of resource and labor cost in the total production cost were demonstrated (Fig. 13

of ref 1 and Fig. 1). Inspection of these figure shows that in spite of enormous efforts to save man power by automatization the portion of labor cost continued to increase, then further full factory automatization is required.

3. 7 Mass of resource materials needed to produce unit mass product

In order to reduce the production cost, it is useful to decrease the mass (weight) of each resource material, which is necessary to produce unit mass of the product. Table 12 collects the such mass units of pulp, sodium hydroxide, sulfuric acid and carbon disulfide during 1937～1988.

Table 12 Change in unit mass of resources, which are consumed for production of unit mass fiber

Resource	Year			
	1937[94]	1945～1950[95]	1956～1957[96]	1988[97]
pulp	1.15	1.25	1.08	1.10
sodium hydroxide	1.05	0.90	0.75	0.69
sulfuric acid	1.45			
carbon disulfide	0.35			

The manufacturing technology had advanced remarkably over fifty years. Nevertheless, improvement of unit mass of resources is not notable, except sodium hydroxide. Therefore, cost－down of the viscose yarn product through reduction of unit mass, which can be effectively realized only by scale-up of the production unit, can not be expected even in the future. Unit mass of pulp is closely correlated with quality, in particular, the content of α- cellulose (because only α- cellulose can constitute the fiber). In around 1937 pulp imported form northern Europe was exclusively consumed, but during immediately before and after the war crude, low quality nation-made pulp had to be used. After the war high class pulp imported from USA was used together with nation-made pulp, whose quality was gradually improved. In Stage Ⅶ, inexpensive pulp replaced them. Unit mass of sodium hydroxide reduced consistently due to improvement of recovery rate of waste soda. Consumption of carbon disulfide depends on the average degree of substitution (DS) of the reaction product (cellulose xanthate). With an increase in DS the solubility of cellulose xanthate into aq. alkali solution increases. Lowering of unit mass from 0.35 to 0.30 owes to progress of technology of homogeneous reaction and dissolution of xanthate.

4. TECHNOLOGICAL PROGRESS IN STAGES Ⅶ AND Ⅷ

Attempts were made in Stages Ⅶ and Ⅷ, mainly by factory operators and technicians, to modify or to improve all the small parts, machines, operating works, flow of resource or half-products in the process. Table 13 and 14 summarize main development of the viscose rayon process at Stages Ⅶ and Ⅷ at Asahi.

Note that main development of preparation process of spinning solutions (i.e., from steeping to viscose) had already been finished at Stage Ⅶa and that this process had a common nature of chemical industry. The key process in viscose rayon production is wet-spinning. Fiber formation phenomena of viscose rayon are very different from those of cuprammonium rayon: In the viscose method rapid solidification makes the stretch − spinning impossible. Development of the wet-spinning continued throughout Stages Ⅶ and Ⅷ. Technology progressed steadily, finally to the continuous spinning system at 600～1,000 m/min. In this case, the technology of continuous wet-spinning (net process)[98] was transferred to viscose rayon.

Table 15 summarizes labor saving effect at Asahi viscose rayon plant during 1955～1990. Output increased by 147%. Nevertheless, laborers reduced in number to 6.3% (preparation), 6.7% (wet spinning), and 14.3% (finishing), respectively. The last ratio corresponds to the spun of 1965～1990.

Fig. 11 demonstrates change in technical level of manufacturing technology of viscose rayon yarns in Japan over 70 years. Evidently, Japanese viscose rayon industry had depended greatly on foreign technology. In particular, introduction of European technology (1920～1930) and purchase of new machines based on USA technology (1951～1957) played decisive role in improving the level of Japan. Thus, Japanese viscose rayon technology had long been not hardy enough, being dependent of Europe and USA. Since 2nd half of 1950s, the manufacturing technology was rationalized unaided. Labor productivity was improved significantly since 1950s. Since 1980s the Japanese manufacturing technology became sophisticated and automatized on the basis of its own R & D efforts. As results, an increase in labor productivity was shown to be accelerated dramatically, reaching to 113 kg-fiber/person/day. Now, old-fashioned energy−and labor−intensive industry, born in the late 19th century, transformed beautifully itself into knowledge−intensive industry, although facing uncertain future.

5. CONCLUSION

(1) Throughout Stage Ⅶ there existed a long−term recession. At Ⅶa, curtailment of factory operation was performed. Numerous small efforts for cost−cut were made without additional

Table 13 Main development of preparation process of spinning solution at Stage Ⅶ

Stage	Preparation of spinning solution			
	steeping	ageing	xanthation	dissolving
Ⅶa	O'60	O'60		
	◀——— consecutive automation (1960) ———▶			
	◀——— integration of two lines (1961, 1963) ———▶			
Ⅶc	O'74		O'74	
	automation of pulp blending		new kneader	
				O'77
				central control system of ripening

Table 14 Main development of wet-spinning and after-treatment at Stages Ⅶ and Ⅷ

Stage	Wet-spinning	After-treatment	
		scouring	finishing
Ⅶa	ultra-fine yarn ['56～'58]		
	broad flat yarn ['61～'62]	◀——— integration of lines ———▶	('59)
Ⅶb	ultra-fine yarn ('58; '59)		
	hank－type spinning of thick yarn ('64～'65)		
	'pouring water into pot' equipment ('65)		
	electronic computer system ('68)		
	continuous spinning of thick yarn (HVR) ['68～'70] ('71～'72)		
Ⅶc	automatic 'spinning change' equipment ['76～'80] ('80)		
Ⅷ	continuous spinning ('80～'89)	automatic scouring machine	
	complete automatic 'spinning change' equipment ('90)	('90)	

( ); development, [ ]; commercialization

Table 15 Labor saving and output at Asahi viscose rayon plant

Items	Preparation of spinning solution	Wet－spinning	After－treatment
laborers ratio	1/16 (1990/1955)	1/15 (1990/1955)	1/7 (1990/1965)
output ratio	22,000 (ton/year) (1990)/15,000 (ton/year) (1955)＝1.47		

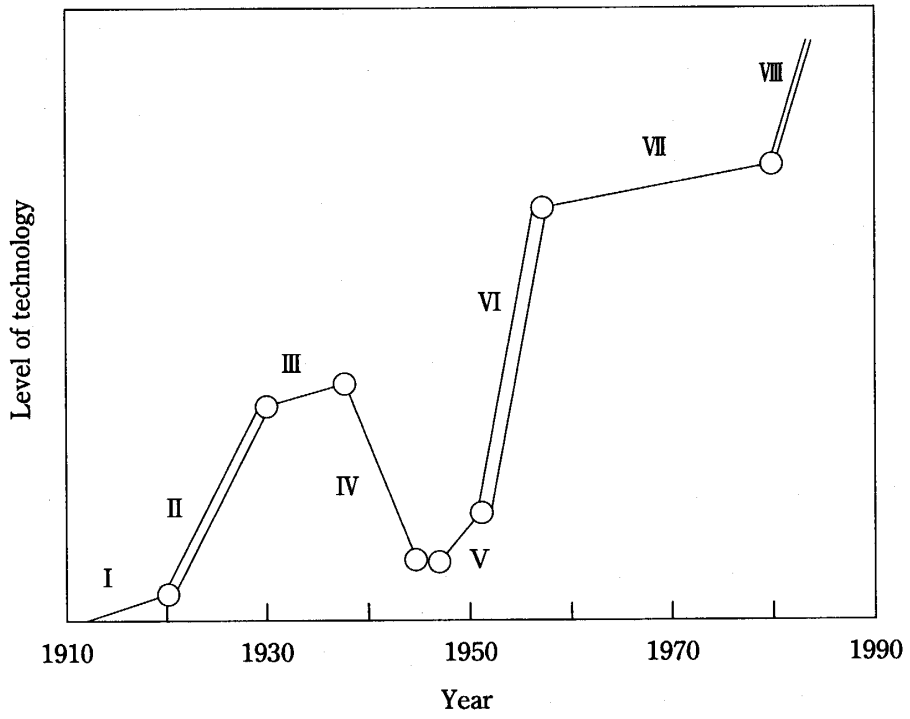

Figure 11 Change in level of production technology of Japanese viscose rayon industry

investment at first half of VIIa (Tables 1~5). At the second half the rationalization of the process was made with investment, in particular, for the preparation of spinning solutions. Ratio of profit to investment (RPI) decreased with year (Table 6, Fig. 2).

(2) At VIIb synthetic fiber, nylon 6, became a ferocious rival, resulting in occurrence of diversification of viscose rayon brands: Ultra-fine and thick fibers. Undaria™ is a typical example. Manufacturing technology of new brands was developed (Table 7). Toray's retreat (1961~1963) made temporary recovery of balance of supply and demand.

(3) Dollar shock (1971) gave a serious damage to the export of Undaria™ and induced retreat of Toyobo and Teijin from viscose rayon business.

(4) At VIIc (oil crisis) the energy cost of viscose rayon rose 2.5 times, but the price rose only 1.42 times of those at 1971 (Table 8, Fig. 6 and 7). The cost difference between viscose rayon and synthetic fibers expanded (Fig. 8). Development of manufacturing technology of regular rayon revived, mainly at wet-spinning process, and some important innovative projects started at this sub-stage.

(5) Market of viscose rayon yarns continued to shrink in size through Stage VII. The recession was owing to overproduction at VIIa, but at VIIb it was due to erosion of synthetic fibers (Table 9).

(6) In Stage Ⅶ, automatic cake rapping machine (1964) and automatic 'pouring water with yarn into pot' equipment (1966) were commercialized (Table 14).

(7) Stage Ⅷ was a reformation stage. Only three companies could survive to continue viscose rayon production. R & D activity was concentrated to Asahi (Table 10).

(8) Following technology was developed and commercialized in Stage Ⅷ: (a) filled pot changer (1980), (b) automatic net supplier (1980), (c) continuous spinning process (regular yarn) (1980～1989) (Silmax™) (Table 14, Table 11).

REFERENCE

1. K. Kamide and H. Suzuki, *J. Ind. Econ., Nara Sangyo Univ.*, **20**, 1 (2005).
2. K. Kamide, *J. Ind. Econ., Nara Sangyo Univ.*, **20**, 205 (2005).
3. Asahi Chemical Ind., Co., 30 Years History of Asahi Rayon Factory, p 96, 98, 1964.
4. Soc. Chemical Fiber of Japan (ed.), *History of Japanese Chemical Fiber Industry,* p 46 (data of Y. Kami), 1974.
5. Ed. Committee, *History of Japanese Silk and Rayon Fabric,* p 281, Fujin Gahosha, 1959.
6. *History of Japanese Chemical Fiber Industry,* p 131, Table 22.
7. *History of Japanese Chemical Fiber Industry,* p 183, Table 1.
8. *History of Japanese Chemical Fiber Industry,* p 447, Table 2.
9. Asahi Chemical Industry Co., *60 Years History of Asahi Viscose Rayon Factory,* p 91 and others, 1994.
10. Asahi Chemical Industry Co., *30 Years History of Asahi Rayon Factory,* p 88, 1964.
11. *60 Years History of Asahi Rayon Factory,* p 86, 1994.
12. *30 Years History of Asahi Rayon Factory,* p 96, 1964.
13. *60 Years History of Asahi Rayon Factory,* p 91.
14. Sakio Ikeda, *'Study on Patterns of Process Reaching to Invention',* p 58～59, Nikkan Kogyou Shinbun, 1993.
15. unpublished results.
16. *60 Years History of Asahi Rayon Factory,* p120.
17. Y. Nishi et al., Japanese Patent Publication, No. Sho 46-423.
18. S. Tsukuma et al., Japanese Patent Publication, No. Sho 42-8726.
19. S. Ikeda, *Study on Patterns of Process Reaching to Invention',* p 57～58.
20. *History of Japanese Chemical Fiber Industry,* p 666.
21. *History of Japanese Chemical Fiber Industry,* p 949.
22. *History of Japanese Chemical Fiber Industry,* p 743, Table 3.
23. *History of Japanese Chemical Fiber Industry,* p 949, Table 2.
24. *History of Japanese Chemical Fiber Industry,* p 744, Table 3 (continued).
25. *History of Japanese Chemical Fiber Industry,* p 949, Table 2.
26. *History of Japanese Chemical Fiber Industry,* p 941.
27. See, for example, K. Kamide, *History of Textile Industry,* p 336～337, Soc. Text. Machn., Japan, 1993.
28. *History of Japanese Chemical Fiber Industry,* p 667.
29. *History of Japanese Chemical Fiber Industry,* p 1143.
30. *History of Japanese Chemical Fiber Industry,* p 1144.
31. *History of Japanese Chemical Fiber Industry,* p 1145.

32. Ed. Committee, *History of Japan Textile Industry,* p 601, Table 19, 1958.
33. *History of Japanese Chemical Fiber Industry,* p 667.
34. *30 Years History of Asahi Rayon Factory,* p 122.
35. *30 Years History of Asahi Rayon Factory,* p 95.
36. *60 Years History of Asahi Rayon Factory,* p 95.
37. S. Ikeda, *Study on Patterns of Process Reaching to Invention,* p 50~51.
38. T. Doi and K. Yasuzawa, Japanese Utility Model Right, Sho 37 − 18,305, Sho 39 − 6,519, Sho 39 − 13,512, Sho 39 − 13,513.
39. Fumio Sugimoto, *Memoirs,* p 48.
40. *30 Years History of Asahi Rayon Factory,* p 122~123.
41. *60 Years History of Asahi Rayon Factory,* p 194.
42. Fumio Sugimoto, *Memoirs,* p 50.
43. S. Ikeda, *Study on Patterns of Process Reaching to Invention',* p 52.
44. H. Doi and H. Chayamichi, Japanese Patent Publication Sho 37 − 14,413.
45. S. Ikeda, *Study on Patterns of Process Reaching to Invention',* p 62.
46. A. Nakajima, A. Asami, and K. Takada, Japanese Patent Publication Sho 44 − 18,364: Swiss Patent 436,559: Italy Patent 808,647.
47. *Study on Patterns of Process Reaching to Invention',* p 73.
48. *60 Years History of Asahi Rayon Factory,* p 130.
49. *60 Years History of Asahi Rayon Factory,* p 140.
50. *30 Years History of Asahi Rayon Factory,* p 125.
51. K. Kamide, *History of Textile Industry,* p 286.
52. See, *60 Years History of Asahi Rayon Factory,* p 144, Fig.
53. S. IKeda, *Study on Patterns of Process Reaching to Invention',* p 52.
54. *60 Years History of Asahi Rayon Factory,* p 141.
55. S. Ikeda, *Study on Patterns of Process Reaching to Invention',* p 62.
56. A. Nakajima, A. Asami, and K. Takada, Japanese Patent Publication Sho 44 − 18,364.
57. *Study on Patterns of Process Reaching to Invention',* p 52~53 and p 62~63.
58. *60 Years History of Asahi Rayon Factory,* p 130.
59. Evaluated form Figure in *60 Years History of Asahi Rayon Factory,* p 113.
60. *60 Years History of Asahi Rayon Factory,* p 143.
61. *60 Years History of Asahi Rayon Factory,* p 144.
62. *History of Japanese Chemical Fiber Industry,* p 1156.
63. *History of Japanese Chemical Fiber Industry,* p 1157.
64. K. Kamide, *History of Textile Industry,* p 437, Table 10.7.
65. Constructed from *60 Years History of Asahi Rayon Factory,* p 91 and p 195, Table.
66. Data of 'A' company.
67. *60 Years History of Asahi Rayon Factory,* p 194.
68. *60 Years History of Asahi Rayon Factory,* p 144, 204, 236~237.
69. See, for example, K. Kamide, *J. Ind. Econ., Nara Sangyo Univ.,* **15**, No. 4, p 81~104 (2001).
70. See, for example, K. Kamide, *Cellulose and Cellulose Derivatives, Molecular Characterization and its Applications,* 4.7 and 5.1, Elsevier, 2005.
71. See, for example, *60 Years History of Asahi Rayon Factory,* p 273, Table.
72. *60 Years History of Asahi Rayon Factory,* p 273.
73. See, for example, K. Kamide, *J. Soc. Text. Machn., Japan,* **47**, P 440 (1994).

74. S. Matsuda, A. Asami, K. Fujusawa and S. Masai, Japanese Patent Publication, Sho－23,206, US Patent 703,317, British Patent 1,003,800, Indian Patent 90,304/63, Pakistan Patent 114,551, Italia Patent 716,112, Canadian Patent 708,397, France Patent 1,403,640, Yugoslavia Patent 30,564, Mexican Patent 79,580, Brazil Patent 86,051, Argentine Patent 150,449, Chili Patent 20,994, Peru Patent 8,051, Colombia Patent 14,444, Holland Patent 124,272.
75. S. IKeda, *Study on Patterns of Process Reaching to Invention'*, p 55～56.
76. *60 Years History of Asahi Rayon Factory,* p 121～123.
77. *60 Years History of Asahi Rayon Factory,* p 122.
78. *60 Years History of Asahi Rayon Factory,* p 123.
79. *60 Years History of Asahi Rayon Factory,* p 126.
80. *60 Years History of Asahi Rayon Factory,* p 275, Figure.
81. *60 Years History of Asahi Rayon Factory,* p 119.
82. *60 Years History of Asahi Rayon Factory,* p 234.
83. *60 Years History of Asahi Rayon Factory,* p 234～239, p 286～289.
84. *60 Years History of Asahi Rayon Factory,* p 239, p 286.
85. *60 Years History of Asahi Rayon Factory,* p 341.
86. *60 Years History of Asahi Rayon Factory,* p 286～289.
87. K. Kamide, *History of Textile Industry,* p 338.
88. K. Kamide, *Cellulose and Cellulose Derivatives, Molecular Characterization and its Applications,* p 445～548.
89. *History of Japanese Chemical Fiber Industry,* p 47, Table 4.
90. *History of Japanese Chemical Fiber Industry,* p 46, Table 3.
91. Asahi Chemical Industry Co., Rayon Division, *History of Nobeoka Rayon Plant,* p 82, Table, p 101～102, Table, 1951.
92. *History of Nobeoka Rayon Plant,* p 96.
93. Asahi Chemical Industry Co., *60 Years of Asahi Bemberg Plant,* p 436～437, 1991.
94. *History of Japanese Chemical Fiber Industry,* p 183, Table 1.
95. *History of Japanese Chemical Fiber Industry,* p 397, Table 3. (Note that explanation of Table 3 given in ref 80 does not coincide with main statement of the reference.).
96. *History of Japanese Chemical Fiber Industry,* p 438, Table 1.
97. Unpublished data
98. See, for example, K. Kamide, *J. Ind. Econ., Nara Sangyo Univ.* **15**, No. 4, p 81 (2001).