History and future prospects of plastics machinery

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—Synopsis—

The history of plastic machinery in JSW goes back to 1951, when we started domestic production of single-screw extruders. We expanded into the market of film & sheet processing equipment in 1959 and blow molding equipment in 1962. The single-screw extruder was developed into the large-sized twin-screw mixer in 1970, leading to the development of twin screw extruder TEX for plastic compounding in 1979. We describe here the history of our technologies from the beginning of each product and future prospects as well.

1. Introduction

Japanese chemical industry is said to have originated from the production of agricultural fertilizers around 1880[1]. Then, the origin of fine chemical industry was created when the domestic production of dyes and medicines was promoted due to unavailability during the World War I from 1914. In the 1920's, organic chemistry using coal and natural gas started to progress, and synthetic ammonia, synthetic acetic acid and methanol were put into commercial production in succession. Japanese chemical industry was damaged in the production facilities by the World War II from 1939 to 1945, however, the chemical fertilizer industry rapidly recovered after the war thanks to the preferential treatment given by the government. In the 1950's, introduction of foreign technology was boosted by the start of the law concerning foreign investment, leading to full-scale development of petrochemistry based on the technologies introduced from the United States and Europe. At the dawn of petrochemical industry, JSW took the first step as an extruder manufacturer. Over fifty years since then, we have been aiming to be a world's leading diversified manufacturer of plastics molding/processing machines even in boom-and-bust cycles of petrochemical industry. And we have established ourselves as a market leader in manufacturing pelletizing equipment for plastic materials, extruders for compounding, film/sheet production equipment and blow molding machines while achieving steady development. We will describe here the history of over fifty years and future prospects in plastics machinery.

2. History and future prospects

2.1 Pelletizing extruders

2.1.1 Single-screw extruder

In the early 1950's, when Japan had been struggling to recover from the devastation of the World War II, the domestic petrochemical industry was in a time of change brought by technologies introduced from process owners in the United States and Europe. JSW started the plastics machinery business with a sensitive awareness of such industry trends. After much trial and error, we developed the first extruder, a single-screw extruder of 65 mm screw diameter for flexible PVC (**Photo. 1**). Around 1958, the naphtha centers started running to produce ethylene in Mitsui Chemicals, Inc., Sumitomo Chemical Company, Ltd., Mitsubishi Chemical Corporation, Nippon Oil Corporation and so on.[2] Backed by this large supply capacity of ethylene, Japanese petrochemical industry made a great leap forward especially in ethylene-based derivatives like polyethylene. JSW launched full-fledged development of extruders and it was the

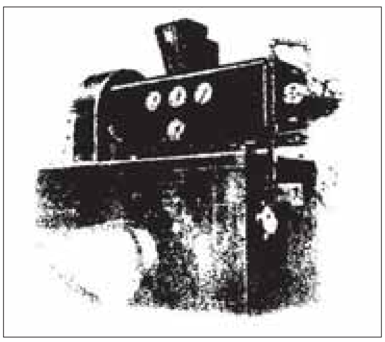

Photo. 1 The 1st extruder made by JSW (1950)
2-1/2 inches dia. Hot oil heating type
For flexible PVC

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dawn of pelletizing extruders and the beginning of "the era of single-screw extruder"[3]. Polyethylene (PE) and polypropylene (PP) were highlighted for molding products, films and wire-coating applications in the 1960's. Single-screw extruder was the mainstream of extruders at that time and JSW manufactured single-screw extruders P200 (screw diameter: 200 mm) for LDPE in 1960 (**Photo. 2**), P200 for HDPE and P200 for PP in 1962 respectively. In 1965, the Ministry of International Trade and Industry announced the approval criterion of 100,000 tons per year for production capacity of ethylene and increased it up to 300,000 tons per year in 1967. Along with such industry trends, plastics production in Japan had rapidly increased about 10-fold in a decade from 1960 to 1970 and demands for high-capacity pelletizing extruders became strongly apparent.

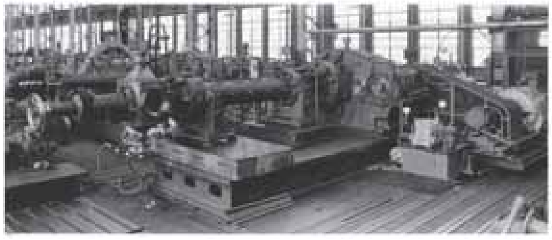
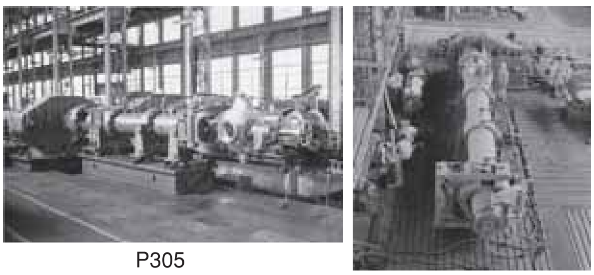


Photo. 2 Single screw extruder - P200 (1960)

There were three types of single-screw extruders for LDPE in those days, (1) melt feed type, (2) homogenizing type and (3) melt-homo type. The melt feed type applies two types of polymerization systems, autoclave type and tube type, and the tube type has remained in the mainstream until now because it meets the market demands for large-scale production. Single-screw extruder is suitable for LDPE because the polymer does not require plasticization. The extruder size has been getting larger and larger to meet the demand for high throughput rate and we manufactured larger extruders successively, P200 in 1960, P305 in 1961, P380 in 1969 and P460 in 1974. (**Photo. 3**) Now, in response to the increasing plant capacity, we are continuously developing large-sized single-screw extruders. For example, P600 for 50 tons per hour was delivered in 2000 and P700 is in production as of 2007. (**Photo. 4**) The extruders of homogenizing type had been used to knead LDPE into pellets to improve optical properties since 1961, but it was discontinued in 1991 due to the limitation of its kneading performance. The melt-homo type was the rationalized extruder having both features of the melt feed and the homogenized types. JSW manufactured KE450 in 1976 based on the technology introduced from Berstorff GmbH in Germany, however, this type went out of fashion as a result of advancement in polymerization technology.



P305

P460

Photo. 3 Single screw extruder P305 (1961)
P460 (1974)

For HDPE and PP, we came to the end of "the era of single-screw extruder" when we manufactured P305 in the late 1980's because these polymers requires plasticization and it is difficult to meet increasing demands for high throughput rate with a single-screw extruder.

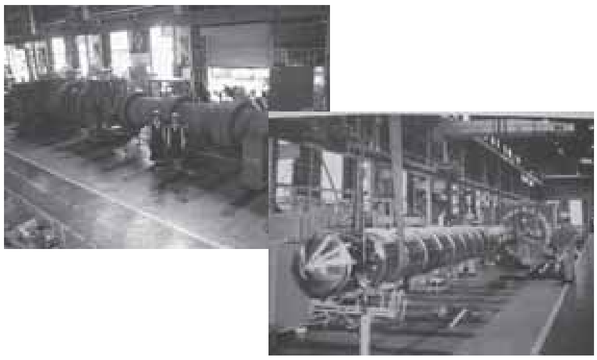


Photo. 4 Large- sized single screw extruder P600 (2000)

2.1.2 CIM + single-screw extruder

In the early 1970's, in order to achieve high throughput rate over 10 tons per hour in response to the market demands, we developed the system of counter-rotating twin-screw mixer CIM (Continuous Intensive Mixer, **Photo. 5**) combined with a single-screw extruder. The system was called a tandem type which consisted of CIM with dramatically improved plasticization ability by "slot" that is a unique device to control the degree of mixing and a

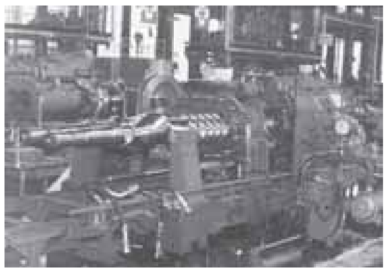


Photo. 5 Tandem type twin- screw mixer CIM320 (1970)

single-screw extruder for pumping. With this system, the throughput rate for PP and HDPE could be dramatically increased from 4 tons per hour to 10 tons per hour. In the 1970's and early 1980's, foreign leading companies actively employed the systems and approx. 110 sets of CIM+single-screw extruder were shipped. The capacity was further improved by development of CIM400 in 1974. However, this tandem system required large space to install two extruders on different floors respectively. In the 1980's, large-scale plants by gas phase method were developed and it required an extruder to produce pellets at 30 tons per hour. We needed to develop a further advanced system.

2.1.3 Large-sized gear pump

Our basic concept was to develop one-stage system of high capacity to save space, but we faced a challenge to deal with high polymer pressure at screen and die plate along with high throughput rate. Gear pump solved this issue. It allowed the same throughput rate while consuming approx. one third less energy compared to the conventional system and it did not cause a significant decrease of conveying ability even under high polymer pressure around 20 MPa. We developed the new model, CMP (Continuous Mixer Pump System) by combining the technologies gained from counter-rotating twin-screw mixer CIM with our own gear pump. Throughput rate was greatly increased when the conventional system with twin-screw mixer + single-screw extruder shifted to the new system with twin-screw mixer + gear pump. The large-sized pelletizer CMP400 (**Photo. 6**) achieved a high throughput rate at 32 tons per hour in the plants of U.S. and Canada. However, CMP series was discontinued after shipping approx. 20 sets because more stable operation was required.

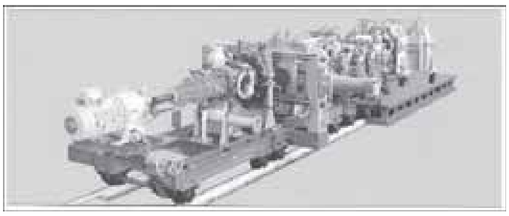


Photo. 6 Twin screw extruder with gear pump - counter rotating type CMP400 (1986)

In the middle of 1980's, we developed the new CMP-X series having co-rotating twin-screw with excellent stability to solve the problems in CMP. In 1987, CMP305X was delivered to Himont, a major company of polypropylene, for pelletizing at 20 ton/hour (**Photo. 7**). The large-sized gear pump GP450T was developed by ourselves in 1986 (**Photo. 8**) and we became able to provide the pelletizing system for high throughput rate without using other company's gear pump. CMP-X has achieved excellent cost effectiveness. Approx. 120 sets of CMP-X have been used by major international oil companies worldwide.

Photo. 7 Twin screw extruder - co- rotating type CMP305X (1987)

Photo. 8 Casing of large sized gear pump The first GP450T (1986)

The petrochemical industry was remarkably reorganized in the 1990's and the era of ultra-large plants started. The giant major oil companies increasingly made large-scale capital investments in Middle East and China, and then the trend accelerated growth in pellet production rate from 30 tons per hour to 60 tons per hour. In response to it, we developed the new CMP-XⅡ series with longer screw length 24～32 L/D to improve plasticization performance. We have achieved higher throughput rate with CMP335XⅡ delivered in 2000, CMP362XⅡ delivered in 2006 and CMP387XⅡ in production as of 2007. We can now ensure 70 tons per hour for PP. And, we have successfully developed the gear-pump-less extruder by improving the screw design to allow more energy-saving and higher system stability (**Photo. 9**). Concerning the pelletizing systems for PP, we have gained strength as one of world-leading manufacturers while we improved on CMP-X to develop CMP-XⅡ. For the systems for PE, we have launched the CIM-P series in the late 1990's to deal with high viscosity grades and bimodal mixing. The CIM-P is characterized by screws supported on both ends having high performance rotors and a gear pump to achieve high throughput rate. It has a long list of delivery for pelletizing of HDPE used for pipes and films, including CIM280P in 1997 and CIM460P in 1999. (**Photo. 10**)

Photo. 9 Twin screw extruder without gear pump CMP362X Ⅱ (2006)

Photo. 10 Large-sized extruder for polyethylene CIM460 (1999)

2.1.4 Future prospects of pelletizing extruders

Fig. 1 shows history of pelletizing extruders. They have been improved to meet the market demands for higher capacity. Through the era of single-screw extruders in the 1960's, CIM+single-screw extruder in the 1970's and gear pumps in the 1980's, we have entered "the era of optimum selection" to provide the most suitable equipment for each user's process by utilizing our accumulated technologies and experiences. We describe here the two points in future outlook of pelletizing equipment.

1) Higher capacity

There have been significant changes in the environment for global petrochemical industry since around 2001. Along with escalating prices of the materials such as crude oil and natural gas, it is necessary to drastically improve cost effectiveness by achieving higher throughput rate of the equipments. Pelletizing equipments are now required to have capacity around 70 tons per hour and the demand is possibly going to reach a level around 80 - 100 tons per hour in the future. (**Fig. 2**) In order to certainly achieve such high capacity, it is necessary to (1) select most suitable equipment for each polymer and (2) develop larger machines. The polyolefin industry is divided into major three categories, (1) PP, (2)

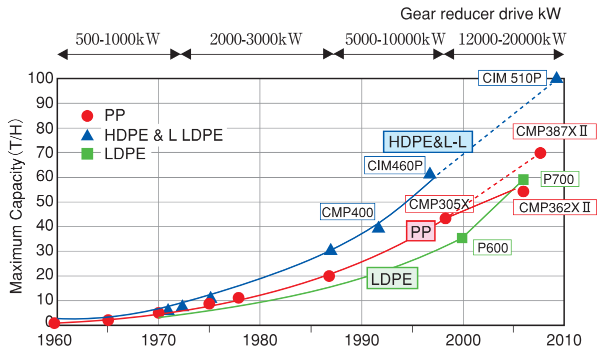


Fig. 2 Growth of Extruder capacity

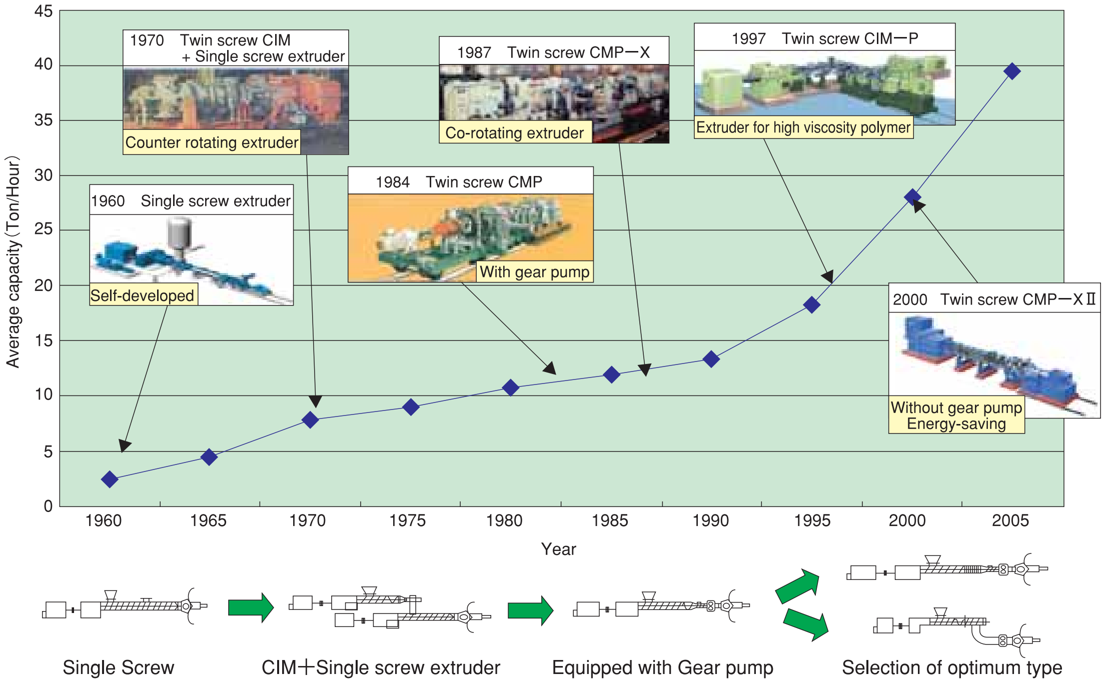


Fig. 1 Transition of Pelletizer

HDPE & L-LDPE and (3) LDPE. PP has relatively low viscosity and good chemistry with additives. The co-rotating twin-screw extruder CMP-XⅡ is suitable for PP because it provides lower shear mixing and longer residence time. HDPE & L-LDPE have very high viscosity and require more mechanical endurance for the processing machines. The counter-rotating twin-screw extruder CIM-P is suitable for HDPE & L-LDPE because it provides high shear mixing and shorter residence time, and two screws are supported on both ends. The single-screw extruder P series is suitable for LDPE that requires cheaper system by melt feeding. (**Fig. 3**) Referring back to the history, we have developed all these types of extruders through approx. 50 years, the single-screw extruder first, and then the counter-rotating twin-screw extruder and the co-rotating twin-screw extruder. Utilizing the know-how accumulated over the years, we believe we can achieve excellent performances at higher throughput rate by selecting optimum equipments depending on the properties of each polymer and by developing larger extruders. We are going to meet the customers' demands with large-sized extruders, such as CMP387XⅡ for PP (in production as of 2007), CIM510P for HDPE & L-LDPE (in market in 2007) and P700 for LDPE (in production as of 2007). We will also develop larger sizes of other components like gear reducer, gear pump, auto screen changer and cutter unit. It is necessary to increase the capacity of gear reducer up to a level over 20 MW because drive power is greatly increased for high throughput rate. (Fig. 2) The gear pump GP560T-M will be put on the market in 2007 following GP450T in 1986 and GP500T-M in 2002. Auto screen changer of dual-bar cartridge type is now under development based on experiences from the slide plate type (1970), the cartridge type (1987), the dual-bar type (1990) and the three-dimensional screen type (1999). And we have developed the new auto cutter unit of ADC-S type following the manual SMC type (1960), the manual LMC type (1972), the manual DDC type (1983) and the auto ADC type (1987).

2) Energy saving and labor saving
Recently, the lower life-cycle cost and the energy-saving/automation system are getting more important in customer's evaluation. We are promoting development to reduce electric power consumption with gear-pump-less extruders, to improve mechanical reliability of major parts like screws and gear reducers, to elongate service life of consumable parts like cutter blades and die plates and to realize the auto start system to reduce polymer purging works in view of safety. Especially, the automated system operation to ensure operators' safety is more important in recent projects because many operators in local plants are not well-trained as a way of reducing production costs.

2.2 Twin-screw extruders (TEX series) for compounding

2.2.1 Counter-rotating twin-screw extruder

The history of twin-screw extruder for compounding in JSW dates to the technology introduction of the non-intermeshed counter-rotating twin-screw extruder from Welding and the intermeshed co-rotating twin-screw extruder called DSM from Krauss Maffei. DSM was mainly used for extrusion

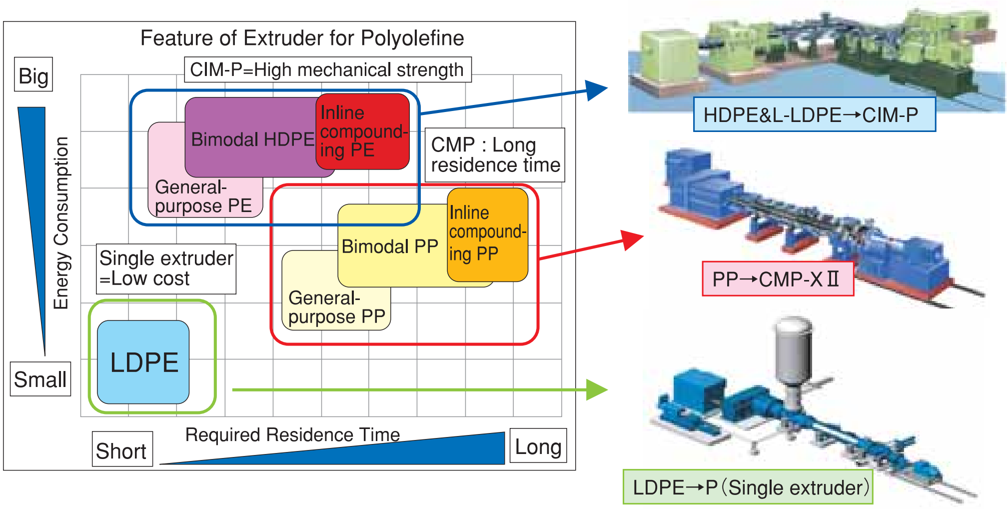


Fig. 3 Selection of optimum extruder

of PVC and ABS, and approx. 80 sets were delivered for 15 years from 1965 to 1980. We actually started the development of our original twin-screw extruders, so-called "TEX" series in 1978. The first TEX extruder was the intermeshed counter-rotating twin-screw extruder of 65 mm screw diameter. It was introduced to the laboratory in our Hiroshima Plant to collect data from fundamental experiments and verify the specifications of customers. **Fig. 4** shows the appearance of an initial TEX65 that was delivered for commercial production.

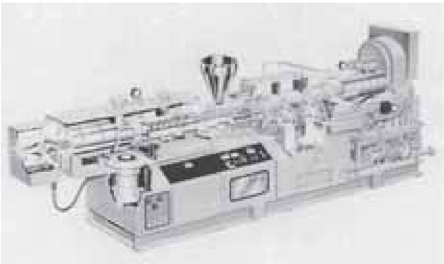


Fig. 4 TEX 65 initial model counter- rotating type

TEX series was characterized by its simplified, space-saving and energy-saving system compared to the conventional two-stage system with a CIM mixer and a single-screw extruder. And they showed many other advantages because they could additionally offer degassing, devolatilizing or dewatering performances. They contributed to rationalize the processes. TEX series had longer L/D over 30 compared to 5〜7 L/D of CIM of those days and they could have two or more vent ports at any location. Taking advantage of them, we achieved the production rate at approximate 10 tons per hour with TEX305S-32(O)-3V that was delivered in 1984 for a devolatilization process of LLDPE by solution method. (**Photo. 11**)

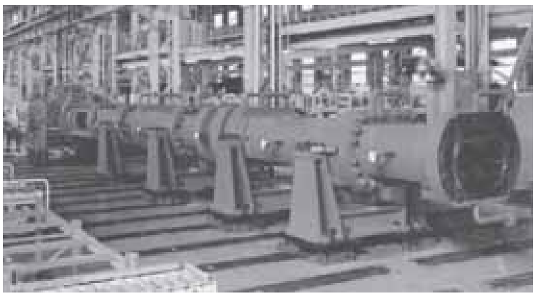


Photo. 11 TEX305S-32(O)-3V

2.2.2 From counter-rotation to co-rotation

Around 1985, the compound industry increasingly demanded homogenous dispersive mixing of two or more ingredients and higher throughput rate. TEX series employed the system to flexibly switch the screw rotation direction depending on applications between counter-rotation that provides high shear and co-rotation that provides good extrusion stability and self-cleaning effect, which allowed us to take maximum advantage of polymer properties and obtain products of higher quality. And we divided the screws and barrel of TEX into segments and blocks respectively for more flexible design. This segmented system had advantages that we could partially replace a damaged part due to corrosion or other problem and that we could design various types of screws by selecting from multi-flight full flight segments, rotors, kneading blocks, and seal rings. (**Photo. 12**)

Photo. 12 Screw elements for hexagonal shaft (used until 5th generation TEX)

Around 1988, the compounding technology utilizing twin-screw extruders with excellent mixing and kneading performances has entered the mainstream of plastics industry for polymer alloys and engineering plastics, and a number of users employed TEX series. TEX series was in the forth generation at that time and the throughput rate was significantly increased. The screw flights of deeper channel depth were developed to increase the screw channel volume in response to the growing market demands for higher throughput rate. And research and development were revitalized especially in the twin-screw extrusion technology called "reactive processing" for polymer alloys or reactive extrusion. The co-rotation type twin-screw extruders taking advantage of self-wiping ability well fitted the market needs of the time and the mainstream of twin-screw extruders has shifted from the counter-rotation type to the co-rotation type. In TEX series, since around 1990, sales of the co-rotation type have been increasing instead of the exchangeable type. **Fig. 5** shows the numbers of sales per year in TEX series, which clearly shows the shift from the counter-rotation type to the co-rotation type.

2.2.3 Co-rotating twin-screw extruder

In 1993, we experienced a temporary decrease in sales of TEX series due to the stagnant economy

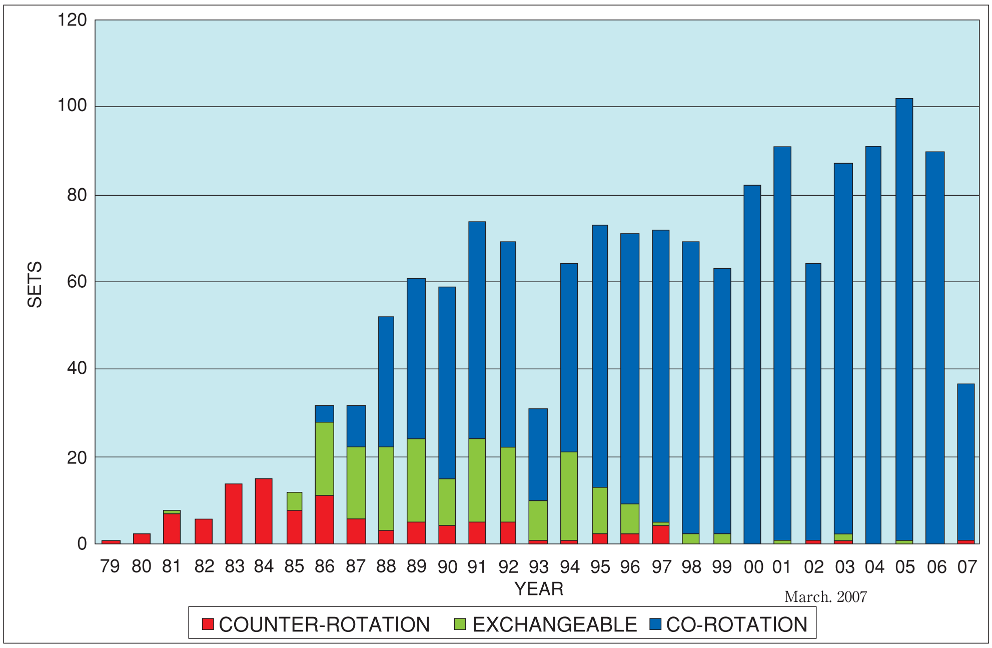


Fig. 5 Delivery experience of TEX series

following the collapse of the bubble. In the meantime, we developed various technologies to differentiate our products. One of them was the special kneading cylinder that significantly improves mixed dispersiveness. As shown in **Fig. 6**, this is a self-developed cylinder called "NIC" with a unique channel structure on cylinder inside to make various flows in the polymer like a elongational flow for the purpose of better dispersion. This technology has given satisfactory results in the fields of polymer alloys and polymer blending that require good dispersive kneading of two or more ingredients at larger viscosity ratio, and master batch compounding that requires good dispersive mixing of particulate fillers in the polymer.

From 1994 to 1997, TEX series further advanced from the sixth generation to the seventh generation. We developed the screw shaft of involute shape to achieve higher throughput rate and deeper screw channel depth. The torque of TEX has more than doubled compared to the first generation and the output capacity increased twofold or threefold

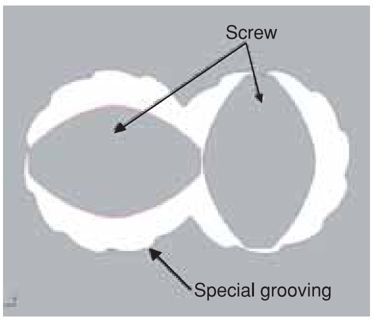


Fig. 6 Special Kneading Cylinder "NIC", cross-section

accordingly. **Table. 1** shows the features of successive TEX series.

TEX series, developed by our own unique technologies, was first commercialized in 1979 and have evolved into the eighth generation at present. The annual number of orders crossed the 100 units mark in 2005 for the first time. The total number of shipments exceeded 1000 units in 2000 and reached 1500 units in 2006. Now, more than twenty models are available ranging from TEX20 for laboratory use to TEX400 for large-scale production, which can meet a wide range of requirements. You can see the position of TEX series within our plastic machinery products in **Fig. 7**. We have carried out research and development regarding the other auxiliary equipments besides TEX as well. We developed and commercialized the material feeding equipment such as weighing feeders and the downstream equipments such as gear pumps and pellet cutting units. We especially focused on development of the material feeding equipment because of its importance in the compounding system. **Fig. 8** shows the advancement of weighing feeders. We have recently developed the cluster feeder that significantly contributes space-saving[(4)].

2.2.4 Compounding in high capacity

Fig. 9 shows the increase in throughput rate of TEX65 for polyolefin compounding through generations. From 1997 to 2000, the throughput rate of small-sized TEX was dramatically increased. In response to the growing market demands for

Table. 1 Features of each TEX series

GENERATION MODEL	1st S	2nd SS	3rd C	4th HCT	5th XCT	6th α	7〜8th α II (i-TEX)	New series V
YEAR	1979—1984	1985	1986	1987—1989	1990—1993	1994—1995	1996—NOW	2005—
GEAR BOX	COUNTER-ROTATION	COUNTER & CO-ROTATION	CO-ROTATION	CO-ROTATION HIGH TORQUE	CO-ROTATION SUPER TORQUE	CO-ROTATION SUPER HIGH TORQUE	CO-ROTATION ULTRA HIGH TORQUE HIGH SPEED	CO-ROTATION ULTRA HIGH TORQUE HIGH SPEED
SCREW	SOLID THREAD CONNECTION 回転方向 回転方向	SEGMENTED HEXAGONAL SHAFT	SEGMENTED HEXAGONAL SHAFT	SEGMENTED & DEEP CHANNEL HEXAGONAL SHAFT	SEGMENTED & DEEPER CHANNEL HEXAGONAL SHAFT	SEGMENTED & DEEPER CHANNEL INVOLUTE SHAFT	SEGMENTED & DEEPER CHANNEL INVOLUTE SHAFT	SEGMENTED & ULTRA DEEP CHANNEL INVOLUTE SHAFT
SYLINDER	LONG SLOT RING	BLOCKED	BLOCKED	BLOCKED	BLOCKED	BLOCKED NIC (OPTION)	BLOCKED NIC (OPTION)	BLOCKED NIC (OPTION)
CONTROL	—	—	—	—	—	EXANET WEIGHING FEEDER	EXANET WEIGHING FEEDER NET100	EXANET WEIGHING FEEDER NET100
TORQUE RATE (%)	100	130	130	167	183	210	251	—

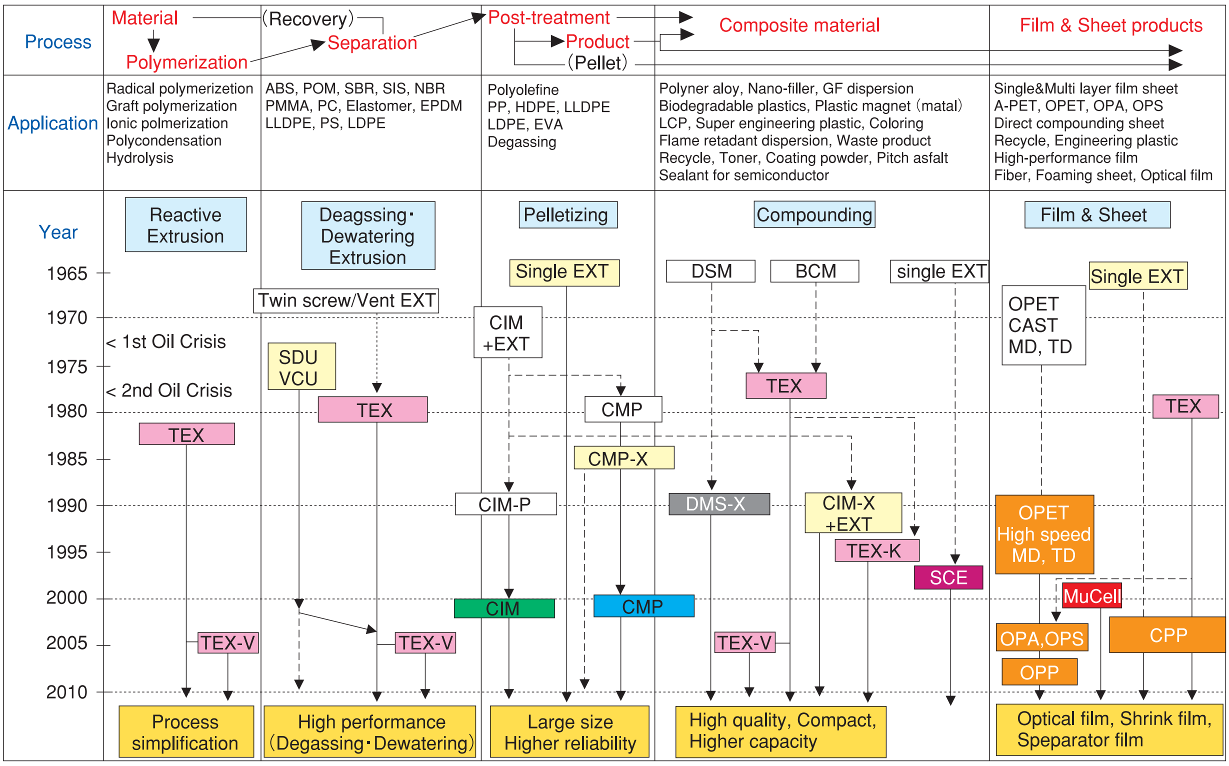


Fig. 7 Development road-map of Plastics Machineries

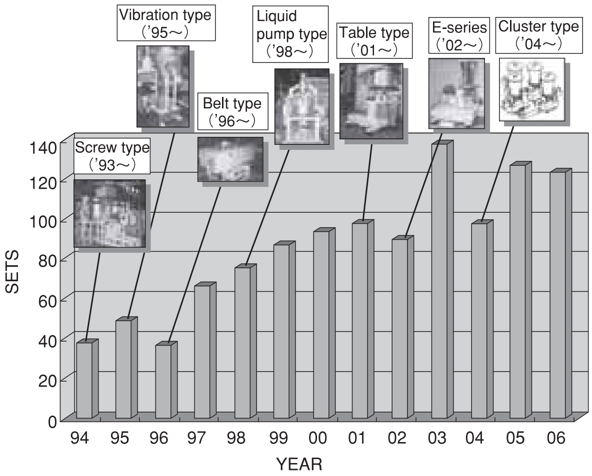


Fig. 8 Advancement of Material Feeder

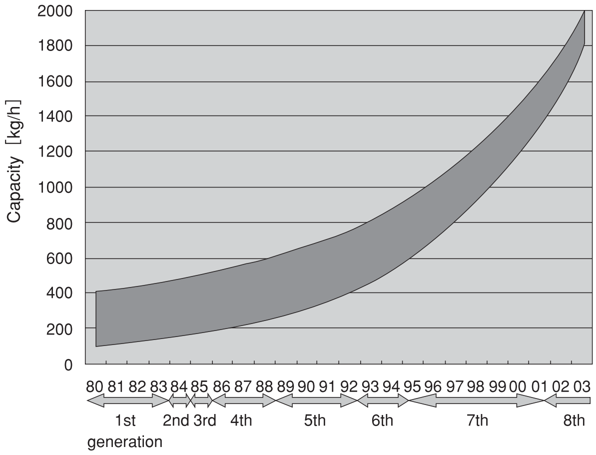


Fig. 9 Capacity transition of polyolefin compounding－TEX65

downsizing and higher capacity, the throughput rate has been increased by almost ten times as compared to the equivalent size of the first generation. Cylinder arrangement and screw geometry are the core technologies and we have accumulated various know-how such as a full understanding of material properties like fillers. We also developed devolatilization and dewatering technologies in plastics compounding processes aiming at further simplification and environment-friendliness. The twin-screw extrusion technology for in-line devolatilization that is directly connected to the polymerization process is one of the key areas that we have started developing in early period and it has been employed in many processes for engineering plastics for optical application such as polycarbonate (PC) and polymethyl methacrylate (PMMA). In 2000, we delivered TEX400 for devolatilization (**Photo. 13**). This is a twin-screw extruder of the world largest size, whose screws are 443 mm diameter and 17 meters long. We expect that our large-sized twin-screw extruders for devolatilization will be continuously employed in a great number of processes for high-function plastics in the future.


Photo. 13 TEX400－One of the world biggest extruder

2.2.5 Development of TEX-V series [5]

Around 2005, twin-screw extruders were expected to have easier handling and be downsized to produce a wide variety of products in small quantities. The plastics compounding market had a trend to further pursue high capacity and energy-saving, and especially expected large growth in throughput rate. To meet such market demands, we have developed SUPER TEX-V, a new series of co-rotating twin-screw extruders. TEX-V series has an improved kneading performance compared to the conventional TEX-α series in the eighth generation. It has a deeper screw channel that increases throughput rate by 20 % or more and ensures excellent extrusion performance at lower temperature. **Fig. 10** shows the difference in screw channel depth between TEX-α series and TEX-V series. TEX-V series is suitable for a process requiring larger free volume and longer residence time, targeting the fields of high-capacity compounding, devolatilization and dewatering. **Photo. 14** shows an appearance of TEX59V. The TEX-V series is available in six sizes ranging from TEX28V to TEX101V. We are developing the "modular skid system" with TEX-V which aims to improve efficiency of on-site installation and offer a system engineering from upstream to downstream. It is getting popular especially in compounding plants overseas. **Fig. 11** shows a conceptual drawing of modular skid system.

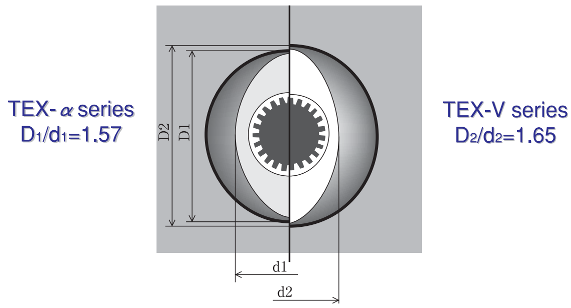


Fig. 10 Comparison of screw channel depth

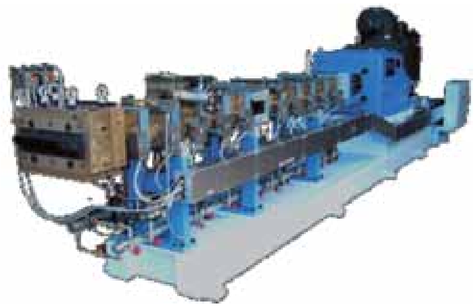


Photo. 14 TEX－V series（TEX59V）

Fig. 11 Conceptural diagram of Module Sikd

2.2.6 Development of simulation technology

Development of CAE technology is one of the recent trends of twin-screw extrusion. World's leading universities and research institutes have developed analysis methods for polymer flow behavior or other factors in twin-screw extruders since around 1990. Around 2000, computer processors were dramatically improved and now we can process complex analyses much faster by using personal computers compared to time consuming work using large computers in the past. Simulation technologies in JSW have significantly advanced as well. In 2003, we commercialized our original flow analysis software for twin-screw extruders, called TEX-FAN. It has been utilized in researches and experiments, and as a guide to determine the screw geometry for production machines. In 2006, we built a simulation model for devolatilization process(6) and developed it into the upgrade version of TEX-FAN (**Fig. 12**). This is a pioneering approach worldwide and quite useful for research, development and scale-up examination as a rapid analysis method of devolatilization simulation. CAE technology will be indispensable for development of twin-screw

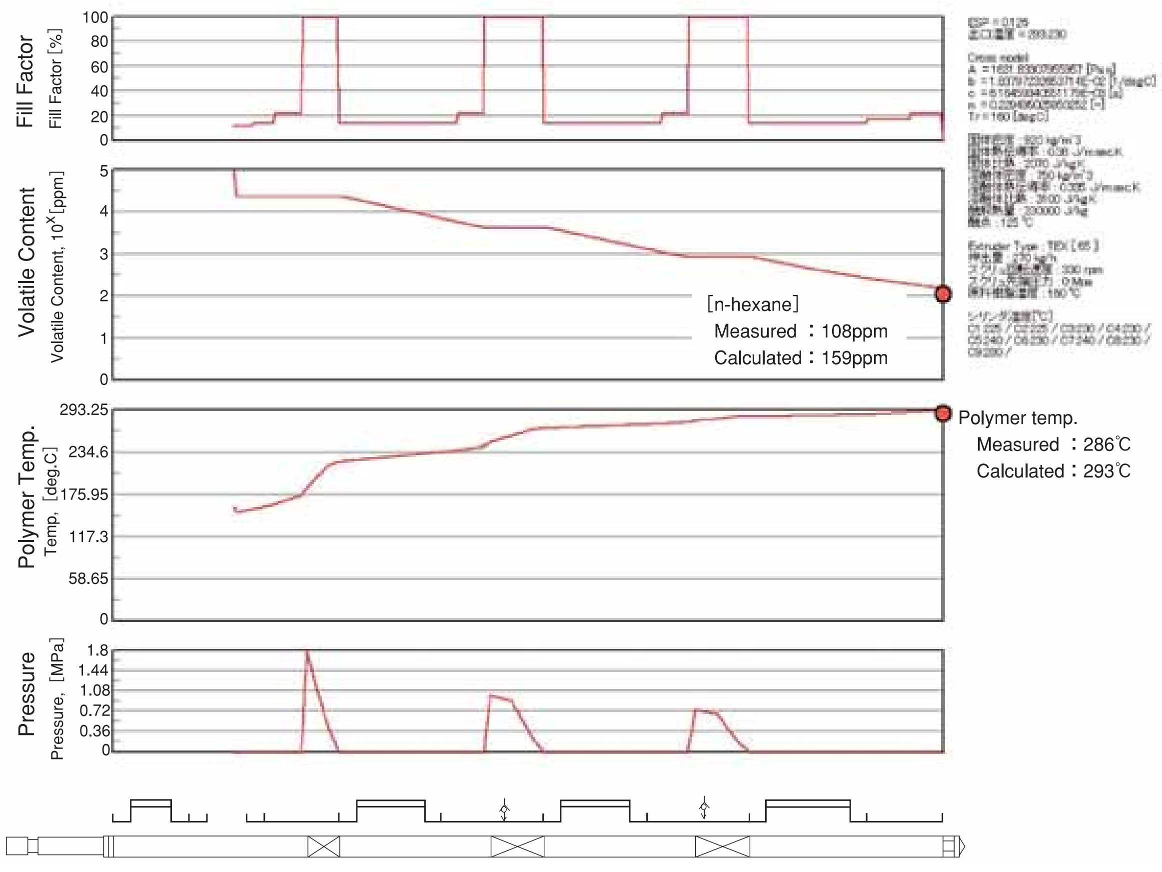


Fig. 12 Simulation model for devolatilization process "TEX-FAN"

extruders in the future. Based on the data obtained from experiments, we will develop an analysis method of higher accuracy and apply it to various processes.

2.3 Film and sheet production equipment

2.3.1 Summary

The history of cast film production equipment in JSW dates back to 1959. According to our records, a PVC film production equipment with T-die was operated for load test from February 20 to 25 in 1959, which was the first one manufactured by JSW. Meanwhile, we started the development of biaxially oriented film production equipment around 1962 and we shipped the first commercial machine for PET film in 1964. However, we had purchased the transverse direction stretcher at that time even though it was a key component of the film production line. Anticipating the promising future of this field, we entered into the license agreement regarding the technologies of casting, machine direction stretching and transverse direction stretching machines with Dornier in Germany in 1970. The technological introduction was started for BOPP films at first, but it was specialized in BOPET films eventually. The agreement with Dornier had continued until 1990. In 2001, we integrated the division of film and sheet production equipment in Yokohama plant into the one in Hiroshima plant. And in 2006, the business relating to film and sheet production equipments by Mitsubishi Heavy Industries, Ltd. was assigned and transferred to JSW. We have conducted business activities in this field for half a century.

2.3.2 Biaxially oriented PET film production equipment

Fig. 13 shows an overall view of a typical biaxially oriented PET film production line. In the 1970's, we started manufacturing the production equipments for films of 5 meters width at 150 m/min which were mainly used for packaging materials. In the 1980's, magnetic tapes became a major application of films and the production equipments were getting wider and faster, from 6 meters width at 250 m/min in the 1980's to 7 meters width at 350 - 400 m/min in the 1990's. And in the 2000's, we experienced a sharp downturn in demand for magnetic tapes and increasing demand for heavy gauge PET films used for LCD base materials. The produced films became thicker around 250 μm and wider around 8 meters.

A revolutionary technology in these developments was Twin Screw Extruder TEX applied to the film and sheet production systems. Because TEX has a good material conveying ability and high devolatilization performance, it was employed as an extruder for recycling of PET films in 1983, and then TEX120 was employed in a biaxially oriented film production line in 1987. It was the first extruder that realized extrusion of undried PET material without a drying process. Approx. 80 sets of TEX ranging from TEX30 to TEX180 (throughput rate: approx. 4000 kg/h) have been delivered for PET recycling and PET film production systems (**Photo. 15**). We have shipped approx. 180 sets of TEX for PET application in total including for sheet production and spinning systems.

Photo. 15 Twin Screw Extruder TEX for BOPET

The transverse direction stretcher, which is the heart of biaxially oriented film production systems, originally had ovens of stationary type (**Photo. 16**). For this type of ovens, it was necessary to bring all oven elements like frames and panels to the local plant site and assemble them into ovens on site from

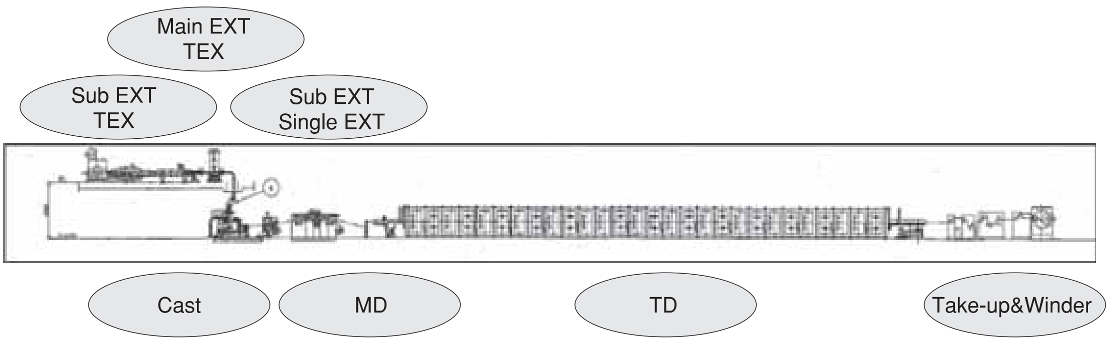


Fig. 13 General Layout for BOPET

scratch. It took quite a long time for field installation and there were many problems which were difficult to locally deal with. Then, we have developed module type ovens of approx. 1.5 meters width. They were first employed in the transverse direction stretcher for a Taiwanese customer in 1986. We prefabricate ovens with nozzles, frames and insulation panels in our factory prior to field installation. We only need to joint completed ovens on site and field installation period is dramatically reduced (**Photo. 17**).

Photo. 16 Stationary Type Oven

Photo. 17 Module Type Oven

As the production speed has been increased, clips for the transverse direction stretcher have been improved by increasing the number of roller bearings in optimized arrangement. At present the transverse direction stretcher mounts JHS-9 type clips for films thinner than 100 μm and JHD type for films thicker than 100 μm respectively as standard equipment. Recently, JMS-4 type is increasingly employed in the stretchers used for retardation films (**Photo. 18**).

Applications of PET films have changed from packaging to magnetic tapes and now base materials for LCD, and accordingly, advanced quality has been required for film products. The quality of film products depends on nozzle air speed, air temperature accuracy and air flow inside ovens of

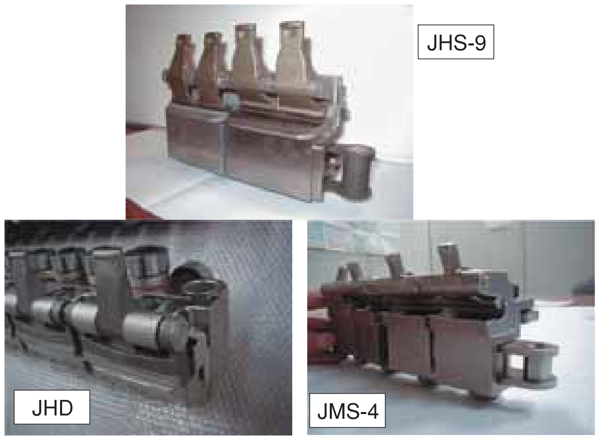


Photo. 18 Clips

the transverse direction stretcher. Nozzles have been improved in various points from the first generation based on the technology introduction from Dornier, and they have evolved into the fourth generation at present. In 2000, we developed the computer simulation method to analyze air flows from nozzles and inside ovens. Combining it with conventional experimental methods, we can now complete the development and engineering in a shorter period with higher accuracy. **Fig. 14** shows a typical analysis result of the simulation to show air flow and temperature distribution in an oven when punching plates are installed between nozzles so as to efficiently transfer the heat of hot air from nozzles to film surfaces.

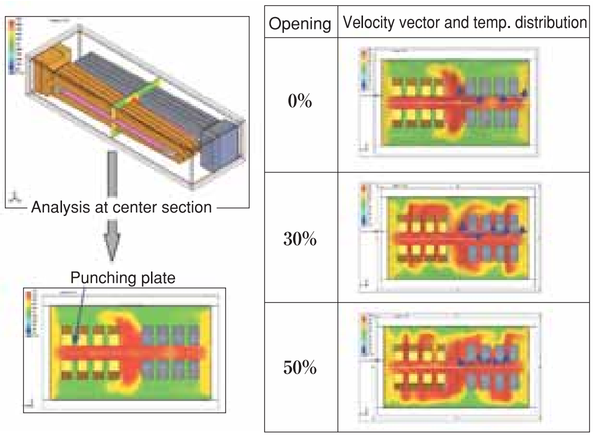


Fig.14 A typical analysis result of the simulation to show air flow and temperature distribution in an oven

2.3.3 Heat-shrinkable film production equipment

We have manufactured the heat-shrinkable PVC film production equipment since the 1970's. In the late 1980's, while the material rapidly shifted from PVC to PS from an environmental point of view, the demand for production lines of heat-shrinkable films used for PET bottle labels increased as production volumes of PET bottles increased. In response to such demands, we developed the new type of single-screw extruder for PS and sold it to domestic customers with a transverse direction stretcher of 4 meters width. And in 2003, we delivered a heat-shrinkable film production equipment to a Chinese customer (**Photo. 19**). The new screw has three stages consisting of two-stage maddock + one-stage cross saw to prevent fish-eyes. Recently, the single-screw extruders for PS heat-shrinkable films became larger up to 175 mm screw diameter although they initially had 90 mm screw diameter.

Photo. 19 Heat-shrinkable Film Production Equipment

2.3.4 Stretched film production equipment for LCD

In the early 2000's, various displays were rapidly converted from CRT to LCD. Then, the demand for production equipments of optical films made from COP, PC and TAC increased. The stretchers for this field requires more sophisticated technologies than before especially in temperature distribution and clip running accuracy. We continue to answer customer's requests with new technologies such as the simulation analysis around oven nozzles to improve temperature accuracy and the high-accuracy width adjustment control with independently-driven clips and AC servo motors.

2.3.5 Cast film/sheet production equipment

Until the 1970's, we had mainly sold PVC film production equipments. PVC is difficult to process because it is thermally degraded faster and easy to have discoloration or spots in films. We developed the screws, adapters and T-dies that were most suitable for PVC and delivered a lot of equipments to our customers since 1959. At the beginning of 1980's, while PVC products gradually fell into disuse, PP and PS were getting popular instead. For PS sheets, which were used for trays or blister packs, we developed and marketed the single-screw vent type extruder, and we can offer this type of single-extruders up to P130 at 800 kg per hour at present. We put the roll stands on the market not only for production of ordinary sheets but for simultaneous laminating with printed films and they enjoyed a good reputation. In 2000, the market began to demand conductive PS sheets including carbon in the application of trays for electronic parts. They requires further advanced devolatili-zation and higher kneading at lower temperature as compared to the conventional PS products. We met the quality requirements by employing twin-screw extruder TEX in the production systems. And ceramic coating on the T-die lips allowed to prevent die lines on the product sheets. For PP sheets, which were increasingly used for stationery and tray, we developed and marketed the extruder with a grooved barrel below the hopper to achieve higher throughput rate in 1983. The grooves on the circumference increase the friction coefficient between material pellets and barrel bores to improve the feed rate, and consequently the throughput rate increases 1.5～2 times as compared to the conventional extruders. In 1990, plastics recycling and dioxin problems began to draw increasing attention, leading to increasing demands for PET sheets that are recyclable and environment-friendly. Based on the achievements in the field of stretched film production, we delivered the first PET sheet production line employing a twin-screw extruder TEX which allows for extrusion of undried PET material in 1990. The line had the throughput rate at 400 kg/hr with TEX90 at that time. We delivered approx. 50 lines of PET sheet production equipment by 2005 and the throughput rate was increased up to 1200 kg/hr with TEX120. **Fig. 15** shows a typical outline of PET sheet production line. In 2006, we developed and delivered a sheet pro-

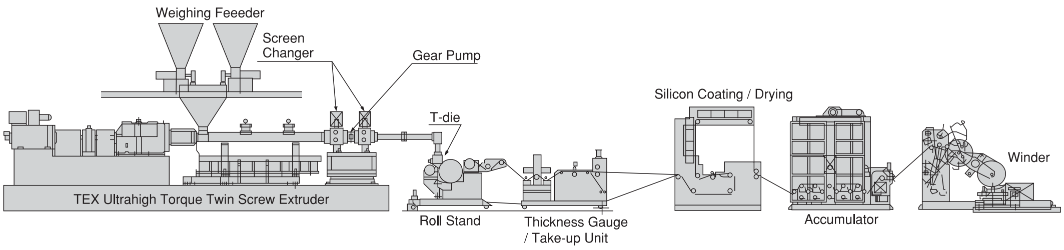


Fig. 15 Typical Outline of PET Sheet Production Line

duction equipment for biodegradable plastic (PLA) that is more environment-friendly based on the un-dried PET extrusion technology. Since the beginning of 2000, the demand for production equipment of cast film/sheet used for LCD has increased. To meet technological requirements for higher accuracy, various elemental technologies have been revolutionized, for example, the ceramic coating on T-die lips to prevent die lines, the polymer filter technology to eliminate contamination, the direct motor (gearless) to reduce errors in roll rotation, the ceramic coating for roll surfaces and the flexible mirror finished rolls. In 2005, we developed and marketed the precise sheet production equipment integrating these new technologies (**Photo. 20**).

Photo. 20 Precise Sheet Production Equipment

2.3.6 Future prospects of film/sheet production equipment

At the beginning of the 21st century, the film and sheet production equipments began to require higher-accuracy for optical applications due to the rise of LCD. We are going to continue further development to achieve "higher accuracy" on the assumption that this trend will continue in the near future based on the growing global demand for LCD. Meanwhile, in November 2006, JSW entered into the transfer contract of the business relating to film and sheet production equipments with Mitsubishi Heavy Industries, Ltd. Mitsubishi excelled at the business field of BOPP, CPP and large-sized single-screw extruders, which had not been covered by JSW. We have to develop the business by generat-ing a great synergistic effect between Mitsubishi's and JSW's technologies and experiences so that we can serve customers' needs as a diversified manu-facturer of plastics film and sheet production equipments. The film and blow technology develop-ment center was established in our Hiroshima plant in September 2007 and it will function as a develop-ment center for CPP and other cast films (**Photo. 21**). And we will further improve the existing test facilities for biaxially oriented films to meet a wide variety of customers' demands.

Photo. 21 Film and Blow Technology Development Center

2.4 Blow molding machines

2.4.1 Advancing from a technical tie-up with an overseas maker to domestic manufacturing

In 1962, the Yokohama Plant introduced V8 blow molding machine technology (**Photo. 22**) from Kautex, a German company, and began full-fledged machine production. We faced many difficulties and had to learn from our failures in our effort to move to domestic production of components received as part of the technical tie-up. We made attempts to select alternatives for the motor, reduction gears, hydraulic unit, and electric parts. As a result of improvements achieved through trial and error, we succeeded in manufacturing highly evaluated machines. In those days, plastic containers were considered as cheap products because of their lightness and lack of high-quality appearance. However, eye droppers made from polycarbonate (PC) used by an eye drop maker offered the appearance of quality and were accepted by consumers, making them a big success. This in turn led to growth in sales of V8 model blow molding machines that proved to be well suited for production of these types of eye droppers. To date sales of this product,

Photo. 22 V8 Blow Molding Machine

as a single model, have reached the 170-unit mark.

2.4.2 Responding to the increased size of molded products

Approval for the use of high-density polyethylene kerosene tanks was first obtained in 1965 – for use of the tanks in the transport of dangerous goods. The use of conventional continuous extrusion molding for this type of large container presented difficulties because of drawdown, that is, because parison extends under gravity. As a countermeasure, an accumulator-type machine that extrudes the stored resin at a stroke was necessary, and the technology used in B-series blow molding machines with a mold clamping force of 30 tons or more was introduced from Kautex. With kerosene tank sales booming, and with the advent of the accumulator head, development of much larger blow-molded products became more widespread. The introduction of ultra high molecular weight polyethylene spurred this trend further. This kind of resin has less drawdown and is high in rigidity because its melt index (MI) is one-tenth or less than that of the conventional polyethylene, making it ideal as a material for large containers. The introduction of this new resin led to increased demand for tanks for agricultural chemicals, floats for rafts used in fish cultivation, and industrial chemical cans. By 1980, demand for parts in solar energy systems had risen due to rising concern about energy conservation, which was spurred by the energy crisis (called the "oil shock" in Japan). These systems utilize large blow molded products for solar water heaters. This contributed to increased sales of extra-large blow molding machine with a mold clamping force exceeding 100 tons. For medium- to large-size machines with a mold clamping force of 20 tons or more, the B Series was replaced, first by the newly-developed NB-S Series, and later by the current NB-SII Series, which is an improvement in terms of energy saving, repeatability, and setup change performance. (**Photo. 23**)

Photo. 23 NB-SII Series

2.4.3 Advent of the electrically driven blow molding machine

Blow molding machines employed a hydraulic drive that was compact and powerful, but had disadvantages such as oil leakage after long-time use, which adversely affects the environment, and variation in molding conditions due to temperature differences occurring in the hydraulic oil in summer and winter. To overcome these disadvantages, the JEB Series of fully electrically driven compact blow molding machines was brought to market in 1992. These machines are advantageous and have won a high reputation among customers for clean molding performance, energy saving, high cycle and low noise, satisfactory repeatability of molding conditions, and ease of maintenance. By 2002 more than 200 units of JEB Series products had been sold. Strong market demand arose for substantial improvements in container quality. This spurred development of the JEB-R Series of new models, which were presented in "IPF 2002" held in 2002. This new series has also gained a good reputation, and to date, cumulative deliveries are at 55 units (**Photo. 24**). This new series of products meets strict user requirements for the conventional features available in electric drive, plus the realization of precision molding through high rigidity and accuracy, shorter setup change time, and further improvements in reproducibility of molding conditions.

The trend toward using electric drive has not been limited to small machines. It has spread to medium- and large-size machines. Brought to market in 1995, the hydraulic/electric hybrid NEB Series has gained a high share as a blow molding machine compatible with clean rooms for manufacturing IT cleaning tanks. Demand for these products has grown dramatically.

Photo. 24 JEB-R Series Blow Molding Machine

2.4.4 Entry into the automotive fuel tank market

Overseas, single-layer plastics tanks or those with inside surface treatment had been used since around 1980, but they were not put to practical use yet in Japan. We started development of the blow molding machine for plastic fuel tanks (PFT) in 1987, and marketed 5 layers of 3 materials automotive plastics fuel tanks using polyamide as a barrier layer for the first time in the world. By 1992, nine units had been delivered to auto companies and five had been delivered as testing machines for tank materials to resin manufacturers. This product won the "Materials Process Technology Center/Sokeizai Industry Technology Award" in 1992 and "the Japan Society of Polymer Processing Best Technology Award" in 1993. Today multi-layer type plastics tanks are required to be of higher quality and to provide superior performance because of subsequent needs for tanks for special fuels in which alcohol is mixed, and strict environmental measures such as regulation of fuel permeation.

Outside Japan, Kautex in Germany has marketed continuous multi-layer plastic fuel tanks in a manufacturing system that consists of barrier layers of ethylene, vinyl, alcohol (EVOH). We have also developed machines with practical applications that can rival the above system and marketed it in 1998. To date, since the delivery of the No.1 PFT machine as the world fastest machine, 23 production machines have been delivered, 10 double-station and 13 single-station types (**Photo. 25**).

Car production by Japanese manufacturers tends to grow inside and outside Japan. This is expected to lead to growing demand for the PFT machines. In 2008, the fuel permeation regulation applied conventionally only to automotive fuel tanks will be extended to motorcycles, buggies, leisure-related and even to universal tanks. In 2003, in advance of this regulation, we developed and marketed an automotive PFT manufacturing system and a medium-size version PFT molding machine. This field is expected to expand further in the future in view of the active introduction of automotive and motorcycle PFT systems to cope with more regulations and greater concern about environmental issues, including the goal of reducing CO_2 worldwide.


Photo. 25 PFT blow Molding Machine

2.4.5 Business integration with Tahara Machinery Ltd.

November 2006, we acquired all of the shares of Tahara Machinery Ltd. to make it a wholly owned subsidiary. Our objective was to strengthen and expand our blow molding machine business. Tahara Machinery, which was founded in 1969, is a specialized manufacturer of blow molding machines. In particular, Tahara Machinery is a top manufacturer with a solid reputation in the field of small machines inside and outside Japan. In the future, manufacturing of small electrically driven blow molding machines with a mold clamp force of 40 tons or less will be concentrated at Tahara Machinery, and we will focus on manufacturing medium- and large-size machines with a mold clamp force of over 40 tons, as well as PFT blow molding machines. We will fully exploit our respective areas of expertise to provide customers with top-ranked performance, quality, and services, while striving for further business expansion.

3. Conclusions

We described the history of over fifty years and future prospects concerning plastics pellletizing equipments, extruders for compounding, film/sheet production equipments and blow molding machines as above. It is more than probable that the era of plastics will continue in the 21st century backed by worldwide prosperity especially in the BRICs countries. However, the circumstances surrounding us have been significantly changing such as inflating oil prices, further spread of globalization, rapid evolution of IT, tightening of RoHS regulations and growing concern over global warming. Plastics machinery industry will probably have a tough road ahead. At this difficult time, we will do our best to increase the value of JSW brand by further improvement of technologies and establish a firm position among the world's leading diversified manufacturers of plastics molding/processing machines while respecting the good tradition established by our seniors in the plastics machinery division.

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