History and Future Prospects of Plastics Machinery

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―Synopsis―

The history of plastics machinery at JSW dates back to 1951, when we started domestic production of single-screw extruders. We expanded into the film and sheet production equipment market in 1959, and blow molding machine in 1962. The single-screw extruder was developed into the large-sized twin-screw mixer in 1970, leading to the development of TEX, a twin-screw extruder for plastic compounding, in 1979. In this paper, we describe the history of our technology from the beginning of each product as well as their future prospects.

1. Introduction

With the advent of petrochemicals following the Second World War, we took our first steps at JSW as an extruder manufacturer. For over 60 years since then, JSW has striven to become the number one comprehensive manufacturer of plastic molding/processing machine in the world even in boom-and-bust cycles of the petrochemicals industry. During this time, JSW steadily expanded into the business fields of polyolefin extruders for resin material production, extruders for compound production, film and sheet production equipment, and blow molding machine, and firmly established our position in these markets. In this paper, we describe and analyze the 60-year history and future prospects of JSW's technology of plastics machinery.

2. History and Future Prospects of Various Plastics Machinery

2.1 Polyolefin extruders

2.1.1 Single-Screw Extruders

The domestic petrochemicals industry underwent a period of great change at the beginning of the 1950's with the introduction of technology from the process owners in United States and Europe. Sensing the trend of this industry, JSW entered the plastics machinery industry. After much trial and error, we developed our first machine with a single-screw extruder with 65-mm screw diameter for soft PVC (Photo 1).

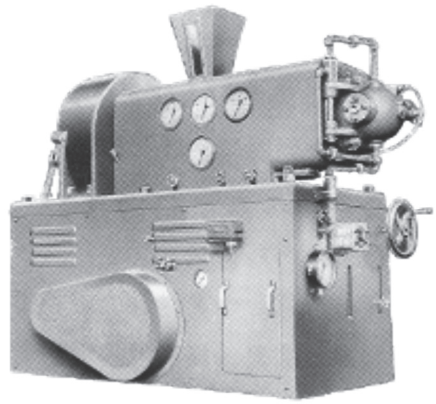

Photo 1 JSW first single-screw extruder (2·1/2”) in 1950 for soft PVC

Around 1958, petrochemical companies started operation of naphtha centers and initiated production of ethylene.(1) The creation of this strong ethylene supply system provided dramatic leap forward by the Japanese petrochemicals industry focused mainly on ethylene derivatives such as polyethylene, which resulted the start of full-scale extruder development by JSW.(2) During the 1960's, polyethylene (PE) and polypropylene (PP) were highlighted for molding products, films, electrical wires, and many other applications. With single-screw extruders as the main type in the industry at the time, JSW started manufacturing the P200 single-screw extruder (200-mm screw dia.) for low-density polyethylene (LDPE) in 1960 (Photo 2), followed by the P200 for high-density polyethylene (HDPE) and for PP in 1962.

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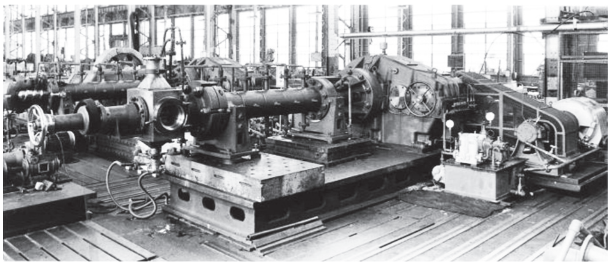


Photo 2 Single-screw extruder P200 in 1960

At the time, there were three types of LDPE process:

1 Melt-feed type
2 Homogenizing type
3 Melt homogenizing type

Polymerization process for melt-feed LDPE are divided into autoclave and tube types, with the tube type still used as the main market technology because it respond to the market demands for high capacity. The melt-feed type has been used for single-screw extruders where there is no need for melting of polymers, allowing JSW to develop large-scale equipment able to provide increased capacity of the P305 (1961), P380 (1969), and P460 (1974). Furthermore, we have been developing large-scale single-screw extruders in response to the continuing need for higher capacity due to increasing plant size, such as the P600 (2000), with a 600-mm screw diameter capable of 50 tons/hour and the P700 (2007) for 70 tons/hour (Photo 3). Conversely, the need for homogenizing and melt homogenization types of single-screw extruders has gradually disappeared due to some reasons of upstream polymerization technology.

In regards to mixers for HDPE and PP use, single-screw extruders are limited in their ability for high capacity resulting in the last production of the P305 in the latter half of the 1980's and a shift to twin-screw extruders.

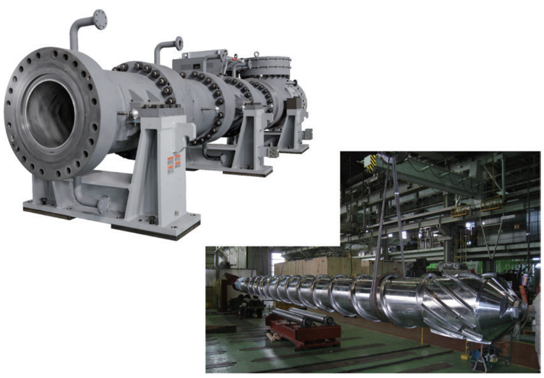


Photo 3 Large scale Single-screw extruder P700 in 2007

2.1.2 Counter-Rotating Twin-Screw Mixer + Single-Screw Extruder

In order to achieve the market demands in the beginning of the 1970's for high capacity performance of over 10 tons/hour, development shifted from single-screw extruders towards tandem equipment consisting of a counter-rotating twin-screw, continuous intensive mixer (CIM) (Photo 4) and a single-screw extruder.[(3)] The CIM dramatically improved melting capability with a unique "slot" mixing control function to create a system in combination with a single-screw extruder serving as the pressure boosting device. This system enabled a massive increase in PP and HDPE processing capacity to 10 tons/hour.

CIM/single-screw extruder tandem equipment was actively adopted to prominent overseas customers from the 1970's through the early 1980's with some 110 units delivered by JSW. Development of the CIM400 in 1974, the largest machine at the time, greatly improved processing capacity. However, as this tandem equipment required a large space inside the building to install two extruders on the first and second floors respectively, it also resulted in new issues such as increasing plant costs. Furthermore, the advent of the gas phase method in the 1980's resulted the demand for large capacity of 30 tons/hour with single unit.

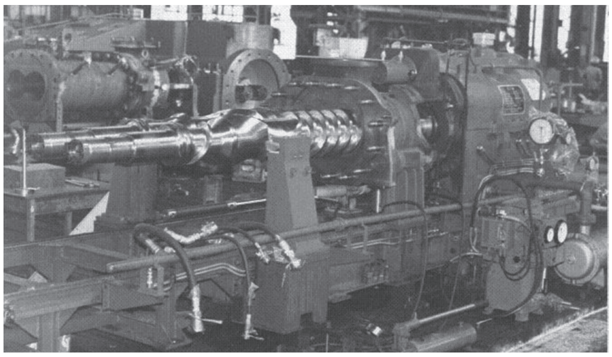


Photo 4 Tandem type Twin-screw mixer CIM320 in 1970

2.1.3 High-Efficiency and Energy-Saving Operation with Gear Pump Adoption

Use of gear pump enables extrusion using one-third of the energy consumption in comparison with the use of conventional single screw extruders, as well as providing continuous operation with stability even under excessive discharge polymer pressure of 20 MPa. JSW developed a new type of a continuous mixer pump system (CMP) that combines JSW's gear pump with the counter-rotating twin-screw mixer technology achieved with the CIM. Use of gear pump resolves the issue of extremely high discharge polymer pressure that generates screens and die plate in accordance with the higher capacity. The CMP400 (Photo 5) achieved the largest capacity at the time, which was 32 tons/hour (modifications enabled it to achieve 60 tons/hour later on) when used in North American plants, as the result, total of some 20 units of this counter-rotating CMP Series were sold.

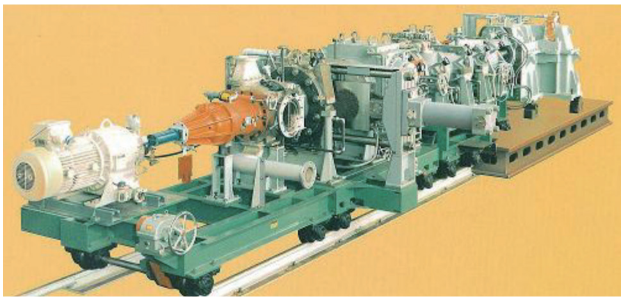


Photo 5 Counter rotating Twin-screw extruder with Gear pump CMP400 in 1986

The new CMP-X Series, which adopts co-rotating twin-screw for excellent operational stability, was developed in the mid-1980's instead of counter-rotating twin-screw mixers to solve the technical issues of the CMP Series. In 1987, the CMP305X was first sold for 20 tons/hour polypropylene production to a major petrochemical company. The excellent cost efficiency of the CMP-X resulted in some 120 units being widely adopted by major companies in the petrochemicals industry.

JSW also developed the GP450T in-house large-scale gear pump in 1986 (Photo 6) and became a manufacturer being able to provide large-scale pelletizers. JSW developed the GP560T-M capable of producing 70 tons/hour for PP in 2013 (Photo 7).

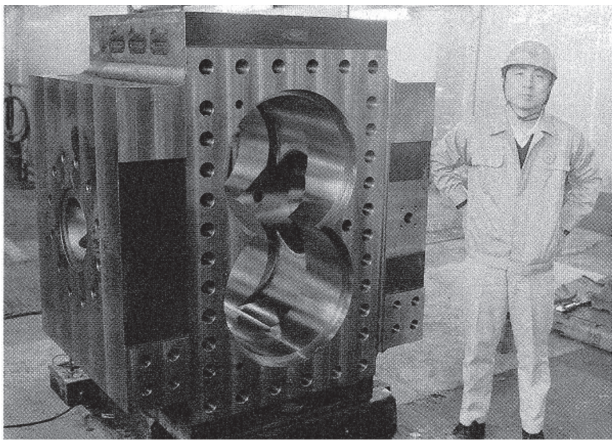


Photo 6 Casing of first large scale Gear pump GP450T in 1986

The production plant capacity was increased drastically during the period of 1990's when the considerable reorganization of the overseas petrochemical industry was advanced. Major

Photo 7 Gear pump GP560T-M in 2013

global petrochemical companies made large-scale capital investments for polymer plants in the Middle East and China. As a result, pelletizing processing capacity was rapidly increased jumping from 30 to 60 tons/hour. In order to achieve this higher capacity, JSW developed the new CMP (-XII) Series with more than doubled screw length compared with conventional type to improve resin conveying and melting capability. Additionally, screw design was further improved to successfully create the gear pump-less CMP (-XII) in order to save energy consumption and provide system stability (Photo 8). (Note: The "XII" at the end of the name is currently omitted due to name consolidation.) The development of large-scale models such as the CMP335 (XII) in 2000, CMP 362 (XII) in 2006, and CMP387 (XII) in 2007 enabled an increased capacity of 70 tons/hour for PP to clearly establish JSW as a global leading mixer manufacturer.

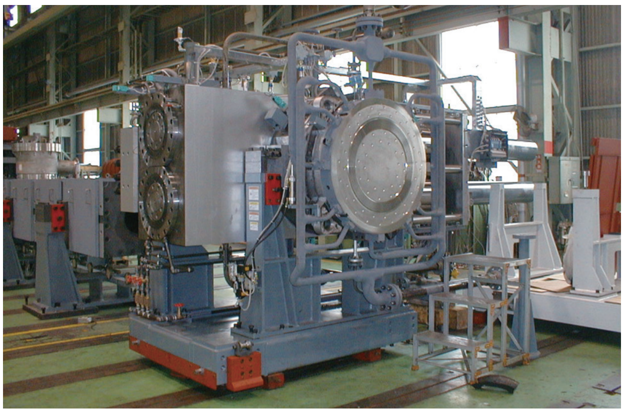


Photo 8 Gear pump-less pelletizer CMP362 in 2006

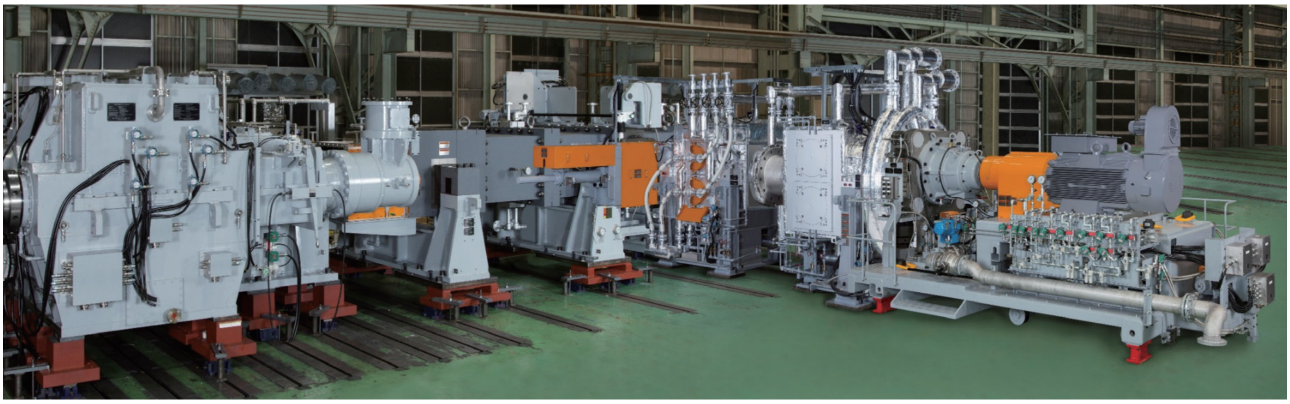


Photo 9 Outline view of CIM510

The CIM (-P) Series was placed on the market for polyethylene use in the late 1990's to deal with high-viscosity and bimodal grades. Features of this CIM (-P) include a high-performance rotor with non-intermeshing, counter-rotation and a structure that supports both ends of the screw to provide both high-mixing performance and high capacity. The CIM (-P) resulted the development of large scale models such as CIM280 (P) in 1997, CIM460 (P) in 1999, and CIM510 (P) in 2015 that are used for HDPE production for pipe and film applications (Photo 9). (Note: The "P" at the end of the name is currently omitted due to name consolidation.)

2.1.4 Future Prospects of polyolefin extruders

The history of polyolefin extruders as describes above is shown in Fig. 1. JSW polyolefin extruders passed through the period of single-screw extruders in the 1960's, through CIM + single-screw extruders in the 1970's, and through the use of gear pump in the 1980's, finally has entered the "period of model selection" to provide the most suitable equipment for each user's process by utilizing our accumulated technologies and experiences.

We will discuss the following two points in relation to the future prospects of polyolefin extruders.

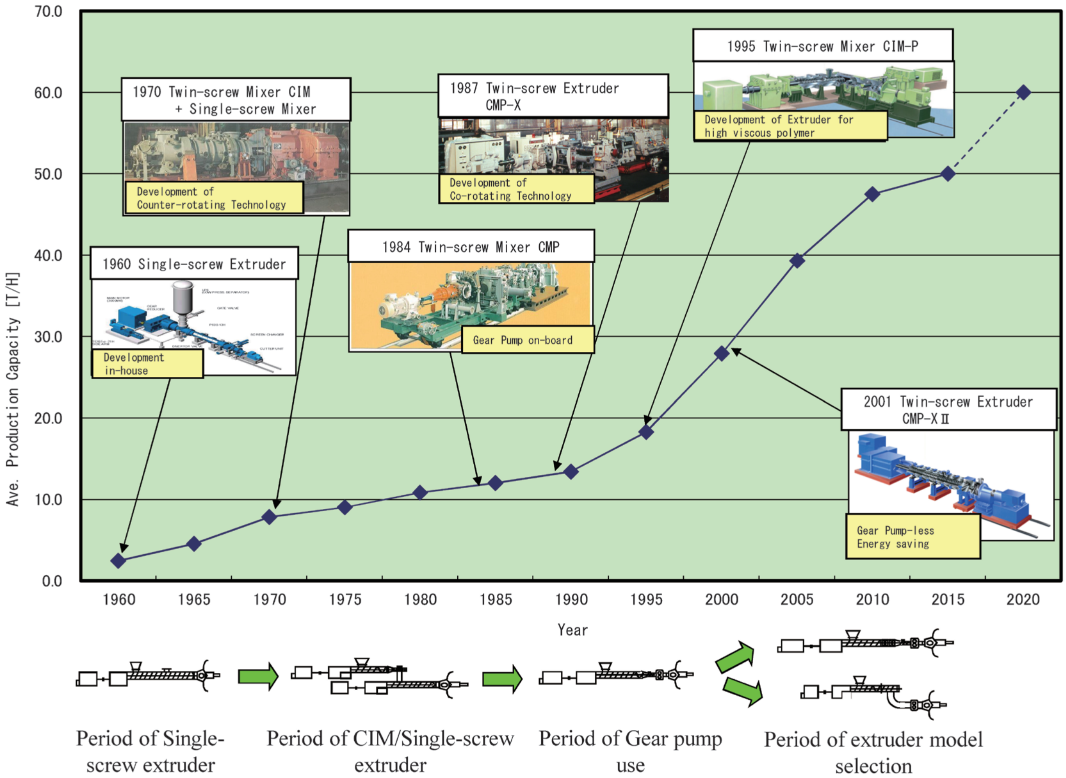


Fig. 1 History of Polyolefin Extruder

1) Increased Capacity

With the start of full-scale shale gas production in the late 2000's, petrochemical companies have been implementing numerous expansion plans on the back of an abundant supply of raw materials. A feature of shale gas plants is a high rate of ethylene production, resulting in numerous projects to construct polyethylene plants and the subsequent need for production capacity of 100 tons/hour for each series. (Fig. 2)

In order to securely obtain such high capacity, it is necessary to select a model that is appropriate for the resin/plastic being used and to increase the size of such equipment. The polyolefin industry is roughly divided into four types: PP, HDPE, linear low-density polyethylene (L-LDPE), and LDPE. The co-rotating twin-screw extruder CMP (-XII), with a long residence time and low-shear mixing, is suitable for PP which has a relatively low viscosity and good chemistry with additives. The counter-rotating twin-screw extruder CIM (-P), with a short residence time, high-shear mixing and both sides of the screws being supported, is suitable for HDPE and L-LDPE, which has a relatively high viscosity requiring high mechanical durability. The single-screw extruder P Series is suitable for LDPE, which requires an extruder for melt feeding without melting (Fig. 3).

JSW is planning to provide for our customers' needs in the future with the following models that are already a part of our product line-up. PP: CMP443 (XII) (released in 2008) HDPE and L-LDPE: CIM560 (released in 2010) and LDPE: P800 (released 2008). We are also further increasing the size of auxiliary equipment such as gear box, gear pump, auto-screen changer, and underwater pelletizer.

At the same time, JSW is currently developing technology to obtain even higher capacity with the same machine size, while also studying measures for remodeling existing plants or new plants for processes that have completed verification on the laboratory scale.

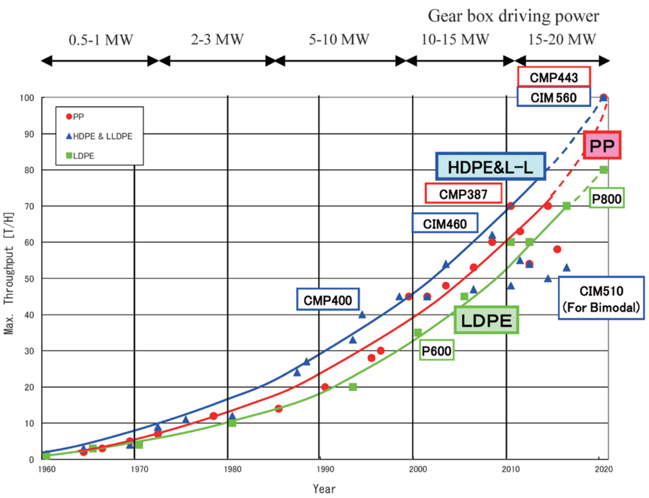


Fig. 2 Prospective increment of production capacity

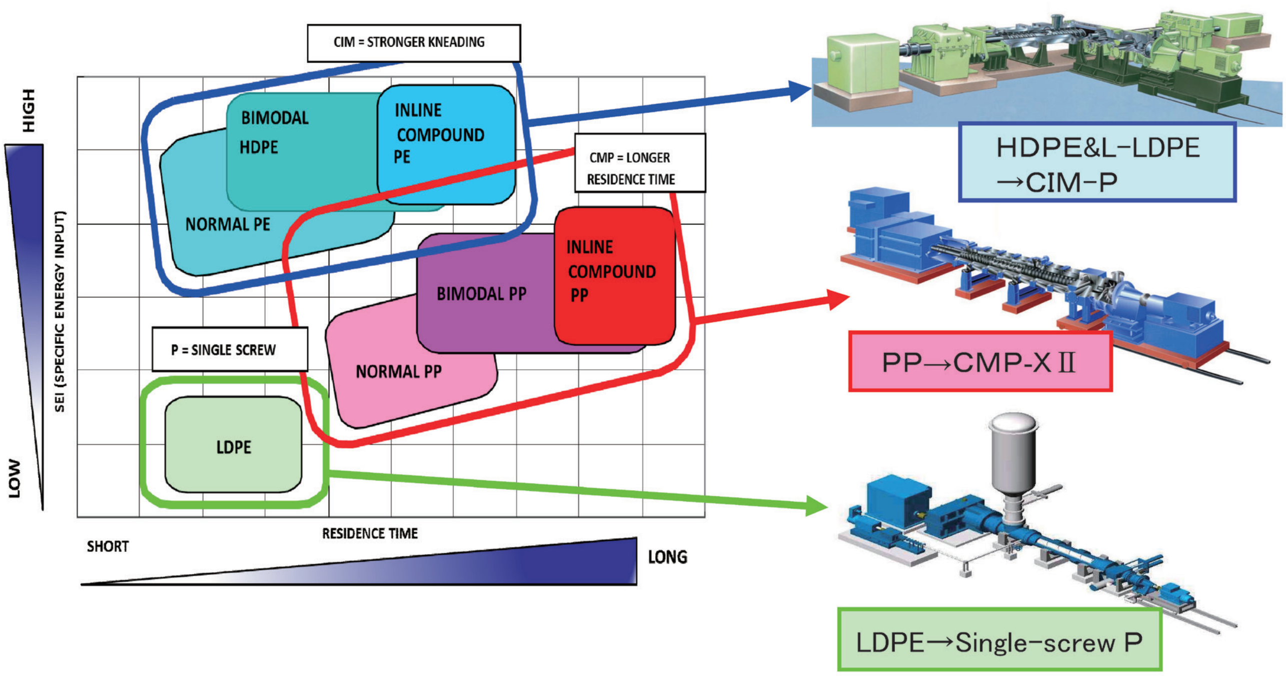


Fig. 3 Application of extruder model for polyolefin

2) Further Energy Saving and Labor Saving

Recently, the lower life-cycle cost and the energy saving/automation are getting more important in customers' evaluation. JSW has repeatedly developed focusing on the technology that can reduce the power consumption by use of gear pump-less extruders, increase mechanical reliability of main parts such as screws and gear box, provide long service life of consumables such as cutter blades and die plate. JSW has also developed an automatic wet-start system that reduces resin purging works to improve operators' safety, and we are currently working on the standard adoption of this technology.(4) Especially in recent projects, there are many cases where operators lacking experience, due to the region of the local plant. This also makes the automated operations a highly important factor in the goal of ensuring safety, for which our efforts have been favorably received by our customers.

2.2 Compounding Extruders (Twin-Screw Extruder TEX Series)

2.2.1 Counter-Rotating Twin-Screw Extruders

The history of twin-screw extruders used for compounding at JSW started with the introduction of technology of non-intermeshing counter-rotating twin-screw extruders, DSM manufactured by Welding and of intermeshing co-rotating twin-screw extruders from Kraussmaffei. At the time, DSM was mainly used for PVC and ABS extrusion, with some 80 units sold during the 15 years from 1965 to 1980. Development of the own twin-screw extruder TEX Series started in 1978. The first prototype model was an intermeshing counter-rotating twin-screw system with a 65-mm outer screw diameter that was installed in the Research and Department center of JSW Hiroshima Plant where it was used to collect basic experimental data and for verification test of customer requirement. Photo 10 shows the TEX65, the first model provided as a production machine.

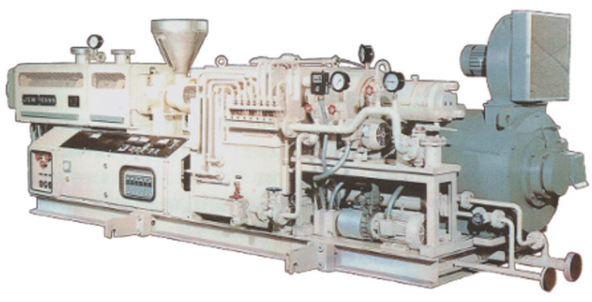


Photo 10 Primary TEX65 (Counter-rotation)

Due to being a one-stage (independent) system, the TEX Series provides system simplification, less footprint and energy saving in comparison with two-stage (tandem) systems consisting of a CIM mixer and a single-screw extruder. The TEX Series has numerous other merits to add functions such as devolatilizing and dewatering that contribute to the processes development. Specifically, the overall barrel L/D (dimensionless length of barrel length L in relation to barrel diameter D) of the TEX Series is 30 or more in comparison with the approximately 5 to 7 of the CIM mixer at the time. This also allowed for two or more vents to be freely mounted to the equipment. These features were used in 1984 to provide the TEX305S-32(O)-3V for the devolatilizing process of solution-method L-LDPE, a model that achieved a production rate of approximately 10 tons/hour (Photo 11).

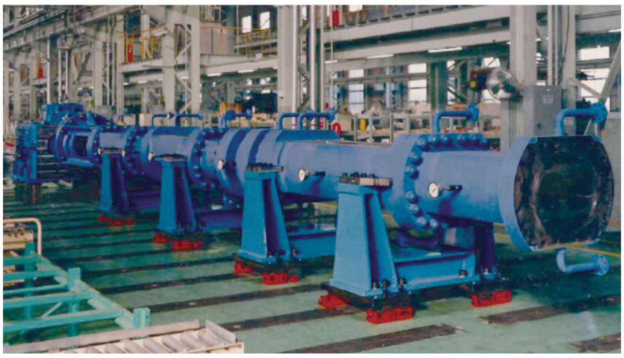


Photo 11 TEX305S-32(O)-3V for devolatilizing process

2.2.2 Transition from Counter-Rotating to Co-Rotating Systems

Around 1985, the need in the compounding market for increased capacity and homogeneous mixing/dispersion of composite material was growing. For this reason, a switching system was adopted for the TEX Series, allowing the use of either counter-rotation, which features high shearing, or co-rotation, which provides excellent operation stability and screw self-cleaning, to provide selection of a rotation direction in accordance with the process requirement. This allows the optimal use of the features of the plastic material to achieve even higher quality production. Additionally, screws and barrels are each designed to be segmented and divided into blocks to provide flexible compatibility with the desired process. Other merits include the abilities to only replace single parts of screw and barrel that are affected by wear or corrosion, and to form the optimal screw shape by combining the wide variety of segment screws (Photo 12).

Photo 12 Segment type screw elements compatible with hexagon screw shaft (Applied until Fifth generation of TEX)

Around 1988, compounding technology using the excellent mixing performance of twin-screw extruders for materials such as polymer alloys and engineering plastics compounds became commonplace, resulting in numerous customers purchasing TEX Series. Additionally, the increasing the market demand for higher throughput rate resulted in the increasing of screw channel depth and addition of free volume. Around this time, the TEX Series was in its fourth generation with a dramatic increase in extrusion capacity. Research and development of mixing technology for polymer alloys and other reactive processing through chemical reactions were increased in activity and this process requires effective self-cleaning of screws, this was resulted in a change of the main type of twin-screw extruders from counter-rotating to co-rotating, with increasing sales of the TEX Series around 1990. Fig. 4 shows the number of TEX Series units sold annually and clear tendency of the shift from counter-rotating to co-rotating models.

2.2.3 Co-Rotating Twin-Screw Extruders

Although sales of TEX Series temporarily declined in 1993 due to the period of economic stagnation, JSW developed various technologies to achieve differentiation during this period. One of

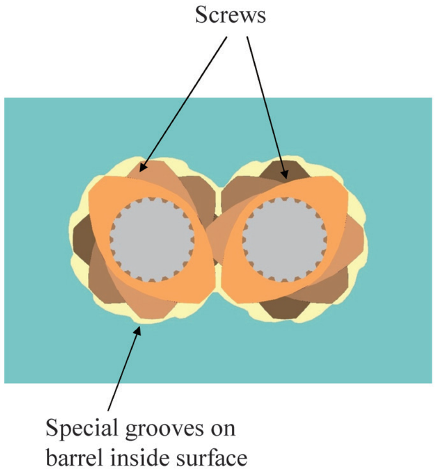


Fig. 5 Cross-sectional shape of NIC

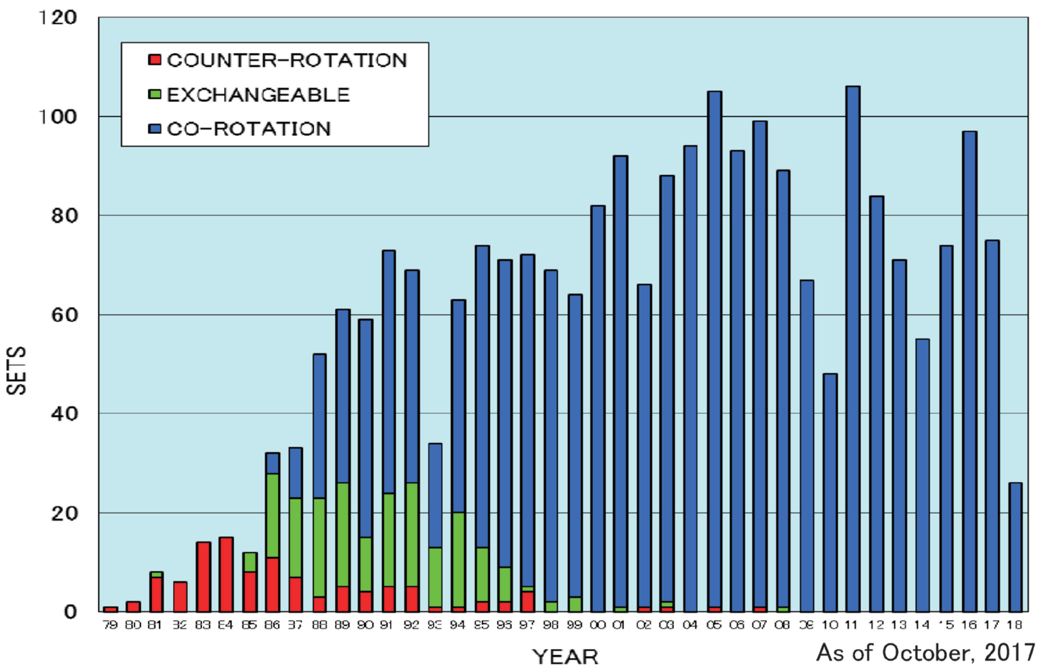


Fig. 4 History of number of TEX series unit

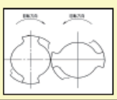
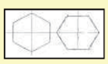
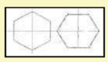
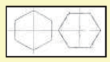
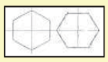
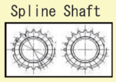
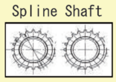
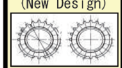
these important developments was a special kneading barrel that improved the mixing/dispersion performance of the TEX Series. This unique kneading barrel, named NIC, incorporates specially shaped grooves on the inner surface of the barrel for extensional flow of resin, which serves to improve the mixing/dispersion performance (Fig. 5).[5][6] This technology has been proven to be effective in various applications for mixing/dispersion of resin materials with two component materials or more having a high viscosity ratio such as polymer alloys and blends, and for the master batch field where particulate filler is mixed/dispersed in the resin.

JSW has also developed the twisted kneading disk (TKD) that improves mixing/dispersion performance and conveying ability for filler compounding.[7][8] A feature of this disk is the excellent conveying ability obtained because of the relatively low leak flow between disks in comparison with conventional kneading elements due to the twist provided at the tip of the conventional kneading element (Photo 13). As this excellent conveying ability serves to prevent the high pressure in the barrel, it also serves to prevent the secondary agglomeration of filler. Additionally, reducing the shearing action repeatedly given to the resin due to leak flow generation serves to reduce the resin temperature and maintain the polymer viscosity at a high level such that it can be readily kneaded with the filler to provide excellent mixing /dispersion effectiveness.

Photo 13 TKD screw element

From 1994 to 1997, the TEX Series was further developed from the sixth generation TEX-XCT to the seventh generation TEX-α. The main developed technology was higher torque and deeper screw channel, in order to achieve these technologies, it was necessary to also develop a screw shaft with a spline shape. In comparison with the first generation of TEX, torque was increased by more than double, thereby also increasing the extrusion capacity by some two to three times. Table 1 shows the technical development of the successive generations of the TEX Series. The TEX Series was first released in 1979 and has evolved to the eighth generation with the TEX-α II. The amount of units delivered exceeded 1,000 in 2000, with the devolatilizing

Table 1 Technical development of successive generation of TEX series

Generation /Type	1st Gen. S	2nd Gen. SS	3rd Gen. C	4th Gen. HCT	5th Gen. XCT	6th Gen. α	7 & 8 Gen. α II (i-TEX)	9th Gen. α III
Year	1979-1984	1985	1986	1987-1989	1990-1993	1994-1995	1996-2011	2012-
Gear Box	Counter Rotation	Co & Counter Changeable	Co-rotation	Co-rotation High Torque	Co-rotation Super Torque	Co-rotation Super High Torque	Co-rotation Super High Torque High Speed	Co-rotation Super High Torque High Speed
Screw	Solid Screw 	Shallow Channel 2&3 lobe segmented screw Hexagonal Shaft 	Shallow Channel 2&3 lobe segmented screw Hexagonal Shaft 	Deep Channel 2 lobe segmented screw Hexagonal Shaft 	Deeper Channel 2 lobe segmented screw Hexagonal Shaft 	Deeper Channel 2 lobe segmented screw Spline Shaft 	Deeper Channel 2 lobe segmented screw Spline Shaft 	Ultra Deep Channel 2 lobe segmented screw Spline Shaft (New Design) 
Barrel	Random & Long	Block	Block	Block	Block	Block NIC (Option)	Block NIC (Option)	Block NIC (Option)
Control	—	—	—	—	—	EXANET L. I. W Feeder	EXANET L. I. W Feeder NET100	EXANET L. I. W Feeder NET100
TEX65Torque [N·m] (Ratio)	1911 (100)	2489 (130)	2489 (130)	3185 (167)	3499 (183)	4018 (210)	4803 (251)	6741 (353)

extruder TEX400 made available that same year (Photo 14). It has a screw diameter of 443 mm and an overall screw length of 17 m, such that they are still world-class biggest twin-screw extruders. In 2005, the annual sales broke through the 100 units followed by exceeding 1,500 total units delivered in 2006.

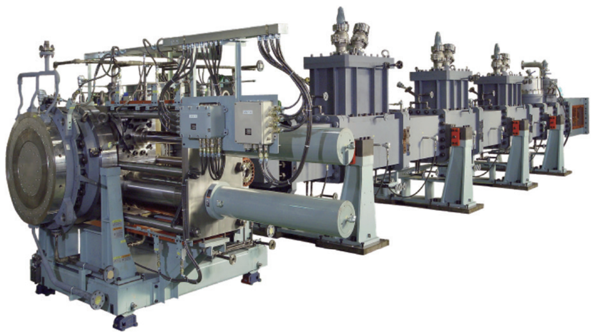


Photo 14 World-class biggest Twin-screw extruder TEX400

Fig. 6 shows the position of the TEX Series among JSW plastics machinery products. JSW has not only focused on the TEX Series extruders but it has also concentrated on research and development of auxiliary equipment. JSW developed and commercialized the material feeding system, gear pump, various pelletizing equipment and up and downstream equipment for twin-screw extruders.

Furthermore, various new processes have been developed in the field of fiber-reinforced thermoplastic resin composite molding over the past few years. The processes involving LFT-D (direct long fiber thermoplastic), which has excellent moldability for large-sized structural components, is particularly promising.

In a LFT-D process, GF (glass fiber) or CF (carbon fiber) roving is fed directly to a TEX twin-screw extruder. The TEX has a special kneading screw for the compounding while maintaining the longer fiber length. The material is extruded from the die as a sheet or lump and cut to a specific length while kept in a molten condition. Finally, the material is molded into the final product with a press molding machine (Fig. 7).

JSW delivered a TEX twin-screw extruder to the National Composites Center (NCC), which was established on Higashiyama Campus of Nagoya University in 2013. The extruder represents an essential part in LFT-D systems for CFRTP (carbon fiber reinforced thermoplastic composites) and is currently being used for the development of technologies related to the LFT-D for CFRTP.

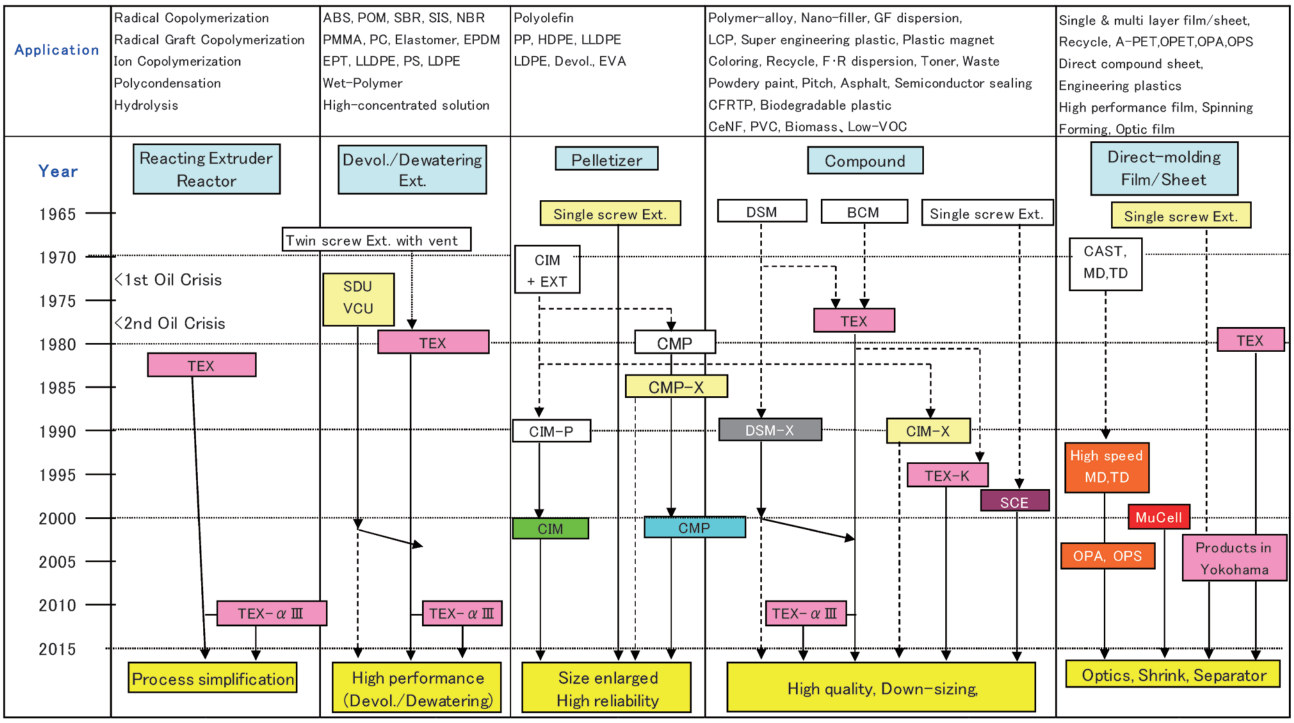


Fig. 6 Development history of JSW plastic machinery products

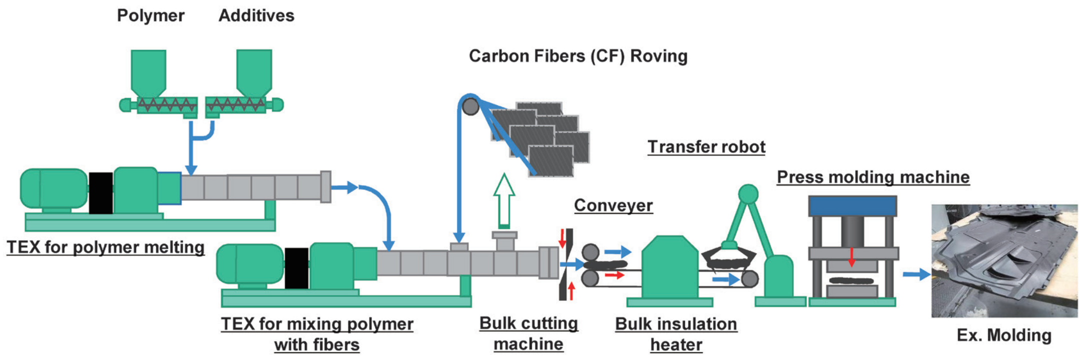


Fig. 7 Schematic flow of LFT-D system

2.2.4 Development of TEX-α III Series (9)

Fig. 8 shows the development of the representative throughput of olefin compound for the TEX65. The throughput of the small-model TEX Series improved dramatically from 1997 to 2000. As market needs for downsizing and increased capacity were growing, throughput was advanced to greatly exceed the first generation by some 10 times comparing with the same diameter now. However, the demand for higher throughput and improved operability in order to respond to the trend of wide variety of products with small volume of production are still increasing rapidly even now. In order to meet these needs, JSW developed the new TEX-α III series, which incorporates numerous new design and production technologies (Photo 15), in 2011.

The TEX-α III provides 36% more driving torque than the TEX-α II making it a top international level high-torque compounding twin-screw extruder. The product line-up consists of nine sizes from the TEX25-α III to the TEX120-α III (The latest size TEX34-α III was lined up in 2017).

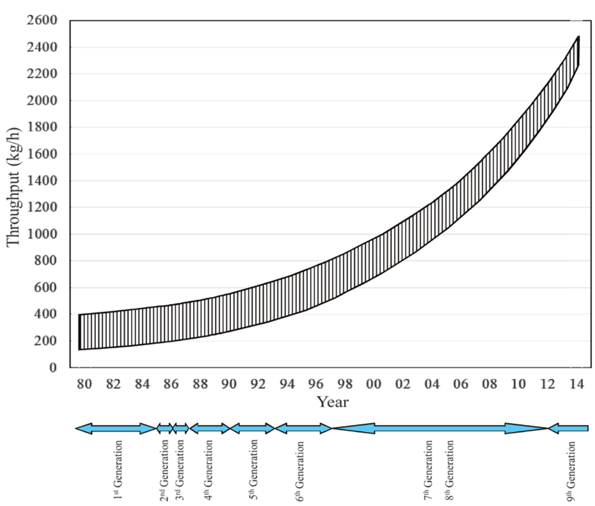


Fig. 8 Throughput changes of Olefin compound with TEX65

Target processes of the TEX-α III are compounding of fillers, GF, CF, and similar materials for engineering and super-engineering plastics, and compounding requiring high-torque operation such as for TPV. Side feeder (SF) is commonly used for these processes including general purpose plastics. Fig. 9 shows how use of

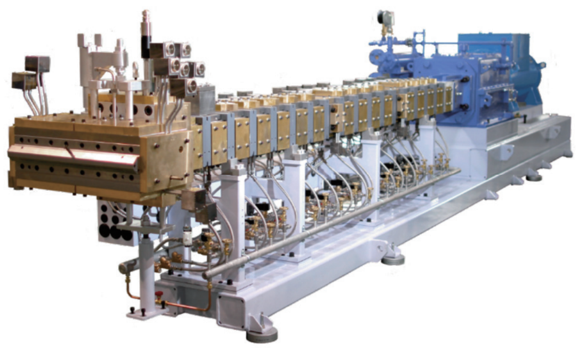


Photo 15 TEX-α III Series (54α III)

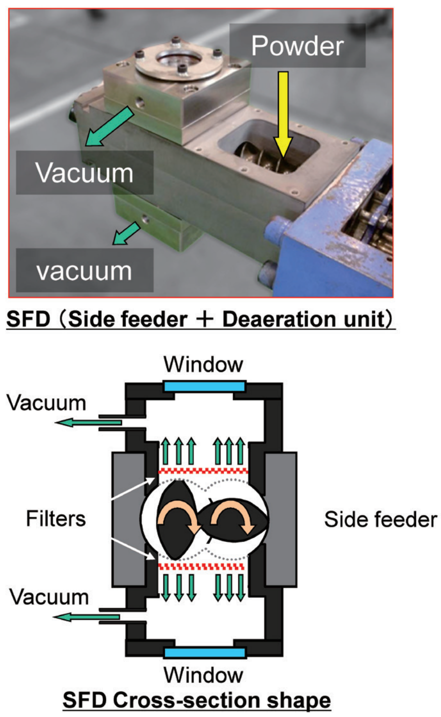
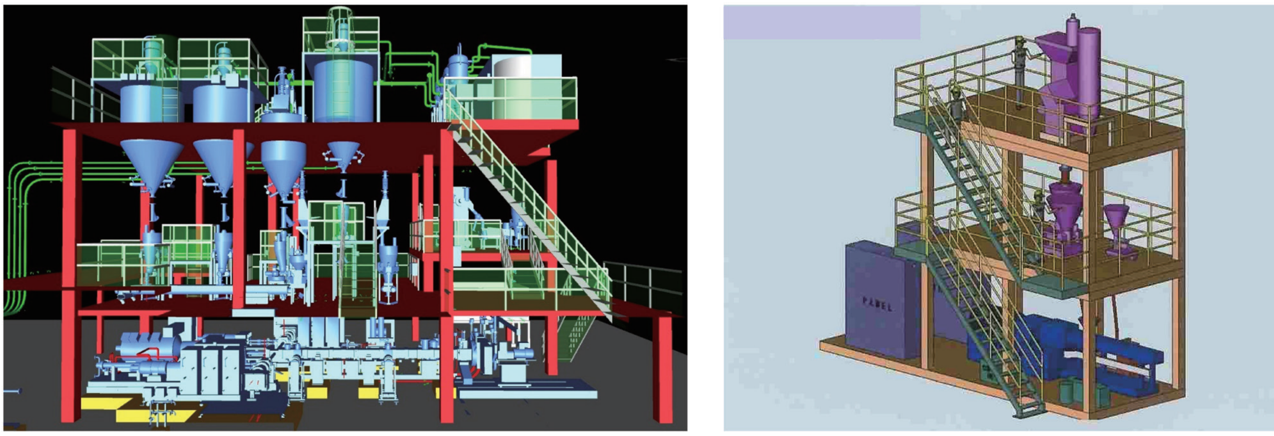


Fig. 9 SFD (Side Feed Deaerator)

the new side-feed deaerator (SFD) enables highly concentrated filler compound and the ability to achieve process development even at a low discharge polymer temperature.

The TEX Series enables turnkey systemization including engineering from upstream to downstream. JSW has also developed a module skid system to provide streamlined installation



Conventional type Module skid type

Fig. 10 Conceptual drawings of Turn-Key system

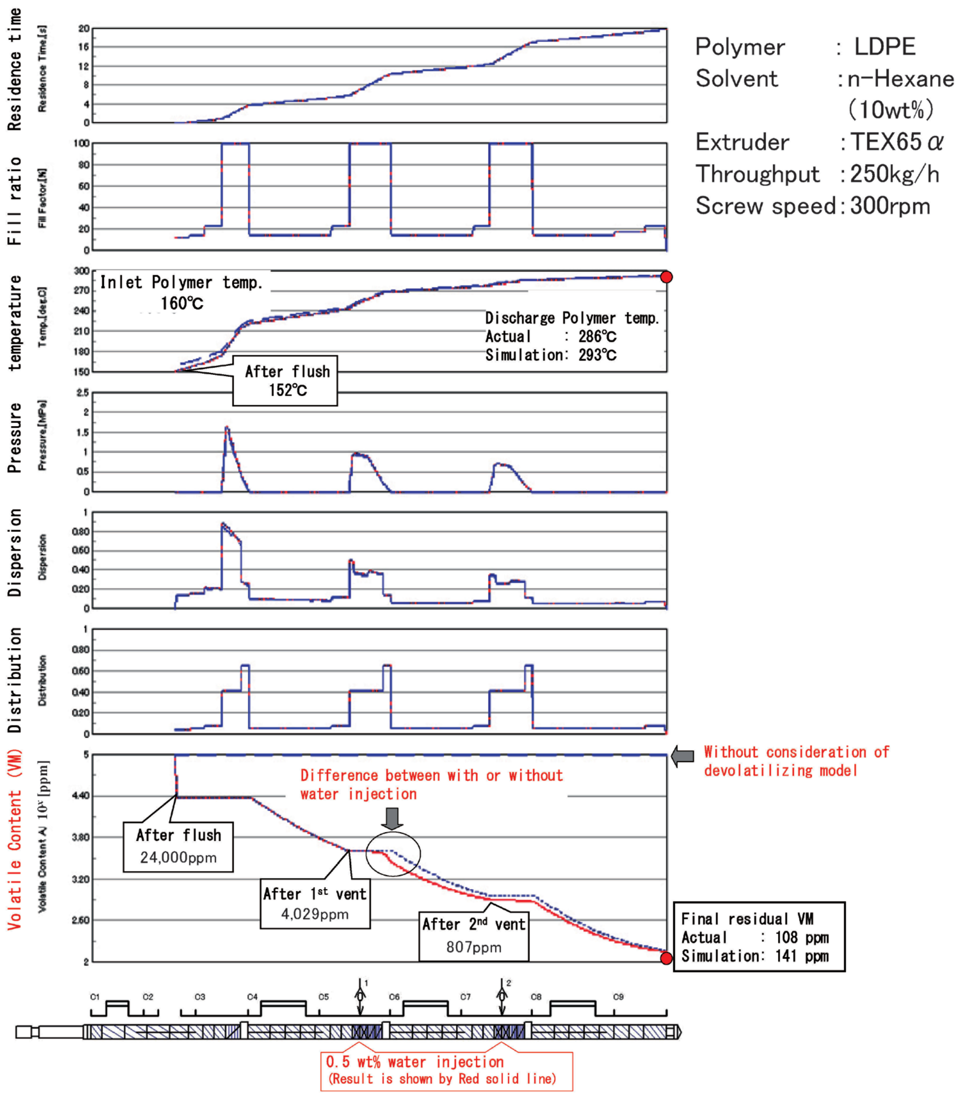


Fig. 11 Simulation results of TEX-FAN with analysis for devolatilizing process

work and reduces costs, needs that are especially important for overseas customers. Fig. 10 shows conceptual drawings of turnkey systemization.

2.2.5 Development of Simulation Technology

One trend in recent years is the development of Computer Aided Engineering (CAE) technology. Starting from before 1990, world-leading universities and research institutions developed methods for analyzing the behavior of resin flow inside twin-screw extruders. As computer processing speed was dramatically improved from 2000, even analysis using calculations that had required a long time using large computers could now be performed using personal computers, resulting in the rapid advancement of simulation technology.

In 2003, JSW commercialized own unique flow analysis software for twin-screw extruders named TEX-FAN so that it could be used for research and experiments, [10] as well as for designing screw configuration of commercial machines. In 2006, JSW created simulation models for the devolatilizing process[11][12] and developed a new version upgrade of TEX-FAN that included this function (Fig. 11). This was a pioneering attempt, in the market with this devolatilizing simulation enabling rapid analysis being used for research and development, and for investigation of scale up to commercial machine size for devolatilizing. A new version of TEX-FAN containing a 3-D analysis function was also released in 2014.[13]

Recently, new analysis methods such as the particle method, have been gaining attention. The particle method (Fig. 12) provides analysis of non-filled regions inside an extruder that cannot be covered the finite element method (FEM), and there are high expectations that it will serve as a strong tool for understanding resin flow behavior inside twin-screw extruders in the future.[14][15][16][17][18][19][20]

2.2.6 Future Prospects of the TEX Series

Until now, the TEX Series has been developed in order to improve the functionality and performance of compounding products, in the future, TEX-α III is expected to develop even more so as to be used mainly in areas where high-torque machines are needed such as for engineering plastics and super-engineering plastic compounds. Additionally, sophisticated elastomer compounds such as TPV, which is widely used in vehicle components, has also become a target for the TEX Series. The entry into fields that previously could not be produced using twin-screw extruders and new materials other than plastics is also being attempted.[21]

This is technology that will shift products currently manufactured by batch method, such as using paddle mixers or a reaction vessels, to a continuous production method by using twin-screw extruders. Although conventional batch methods using a reaction vessels or similar equipment can provide a long residence time in order to achieve a thorough reaction, this long residence time also serves to negatively affect to the productivity and results in other issues such as the poor working environment when removing material from the reaction vessels. Although the residence time of twin-screw extruders is short in comparison with batch methods, they can improve reactivity by providing optimal screw designs and barrel set temperature. Fig. 13 shows examples of a batch method and a continuous method using TEX.

Additionally, JSW aims to further expand the application fields for large-size units such as devolatilizing and dewatering processes for plastics, rubber, and elastomers. In addition to the TEX with its dewatering function, JSW has already been manufacturing and selling products for

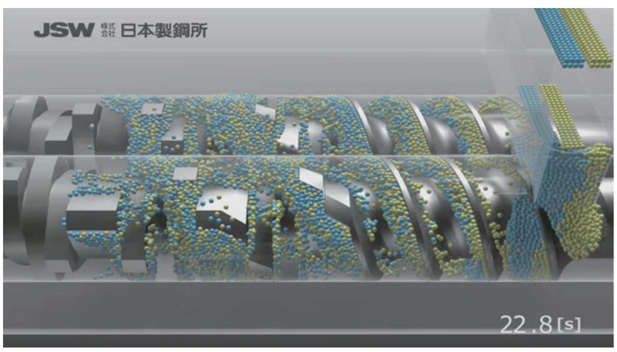


Fig. 12 Particle method Analysis

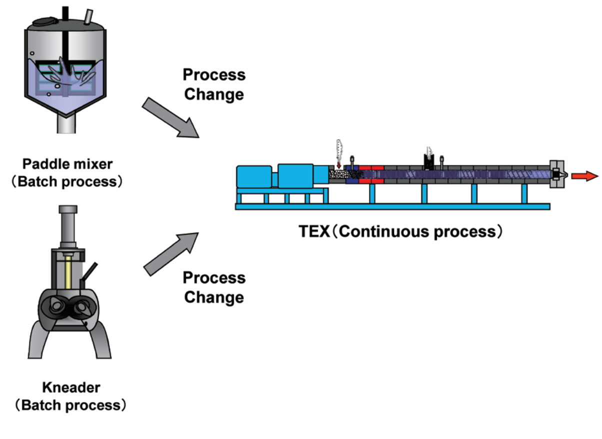
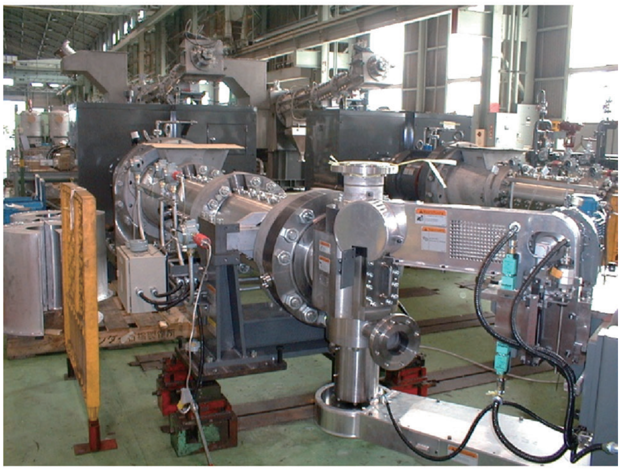


Fig. 13 Process change from Batch method to continuous method using TEX

dewatering such as the SDU (squeezer) and VCU (expander) since 1970's. Photo 16 shows R305S as SDU and R305V as VCU. In 2014, JSW developed a new rubber dryer that is a combined machine with both SDU and VCU functions. The laboratory unit of this new rubber dryer (R90DE) was installed at the JSW Technical Center to enable testing using actual rubber material from customers. Photo 17 shows a new rubber dryer R90DE. As this new rubber dryer is a combined machine, it provides a compact design that saves layout of production plant. Being a single-screw type helps to prevents the rubber discharge temperature from rising in comparison with dewatering by conventional twin-screw extruders. Additionally, the screw discharge end is supported by the bearing so that screw and barrel contact is prevented. The moisture content of normal synthetic rubber can be reduced to 2 to 3% at the outlet of this new rubber dewatering extruder. In the future, we will research and develop this new rubber dryer as well TEX with dewatering functions.

R305S(SDU305)



R305V(VCU305)

Photo 16 SDU (Squeezer) R305S and VCU (Expander) R305V

Photo 17 New Rubber dryer R90DE

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 was the first one manufactured by JSW. Meanwhile, we started to develop biaxial film stretching machines in 1962. We made the technical alliance for casting and transverse stretching machines of Dornier, Germany in 1970 and began to produce the biaxially oriented film production equipment. Since then, we have continued our original technology development for the film and sheet business. In 2001, we integrated the division of film and sheet production equipment in Yokohama Plant into the one in Hiroshima Plant, which allow us to develop and produce the film and sheet equipment consistently from the extruder to the stretching machines.

Following the assignment of film and sheet business from Mitsubishi Heavy Industries in 2006, we additionally obtained the technologies for biaxially oriented polypropylene (BOPP) film production, high-capacity extrusion and non-oriented polypropylene (CPP) sheet production.

And in April 2015, we acquired the business related to simultaneous biaxial stretching equipment from Hitachi Plant Mechanics Co., Ltd.. We finally possess the total technologies which can meet the demands for either the sequential biaxial stretching films or the simultaneous biaxial stretching films.[22]

2.3.2 PET film production equipment

In the 1970's, we started manufacturing the production equipment for films of 5 meters wide at 150m/min. In the 1980's, magnetic tapes became a major application of films and the production equipment were getting wider and faster to 7 meters wide at 350-400m/min. After that, we experienced a sharp downturn in demand for magnetic tapes and increased demand for thick PET films used for base materials of liquid crystal display (LCD) which required a specification around 8 meters wide and 200 μm thick or more.

As PET has a high moisture absorption and heat-sensitiveness, it requires preliminary drying and needs to avoid thermal deterioration and stagnation. In addition, many users would like to recycle the crushed trim edges generated from the film manufacturing process. To meet these challenges and needs, we first adopted the twin screw extruder TEX120 to the biaxially oriented film production equipment in 1987 (first TEX for recycling applications in 1983).

TEX has an extremely high feeding stability of fluffs and flakes as compared to a single screw extruder and can efficiently remove moisture contained in pellets due to high devolatilizing performance. By using TEX, we can prevent a decrease of the intrinsic viscosity (IV value) caused by hydrolysis, which allows us to directly feed undried PET into TEX and greatly shorten the process line. Fig.14 shows a typical direct extrusion process flow of undried PET. A great number of TEX ranging from TEX30 to TEX180 (extrusion capacity at approx. 4,000 kg/h) have been delivered for PET application.

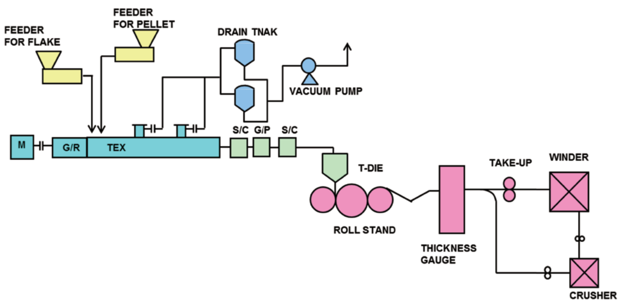


Fig. 14 Typical Direct Extrusion Process Flow for Undried PET

2.3.3 Biaxially oriented polypropylene film production equipment (BOPP equipment)

Since higher productivity is required in BOPP equipment, we continue research and development on each device to further improve production efficiency even after acquiring the film and sheet equipment business from Mitsubishi Heavy Industries.

(1) Increase in production line speed

The running speed has the most influence on productivity. It is going on increasing year by year from approx. 400 m/min around 2000 and exceeded 500 m/min at present.

(2) Extruder

For the standard BOPP line, JSW began to adopt the twin screw extruder (TEX) in 2006 taking advantages of TEX's high throughput capacity, low temperature extrusion and space saving design in place of the tandem type single screw extruder which was adopted in Mitsubishi Heavy Industries. And fluffs (edge trims) and flake materials can be directly fed into TEX due to high feeding rate and excellent compounding performance, which allows for production at lower cost and lower energy. Fig. 15 shows the standard sizes of tandem type single extruder and twin screw extruder.

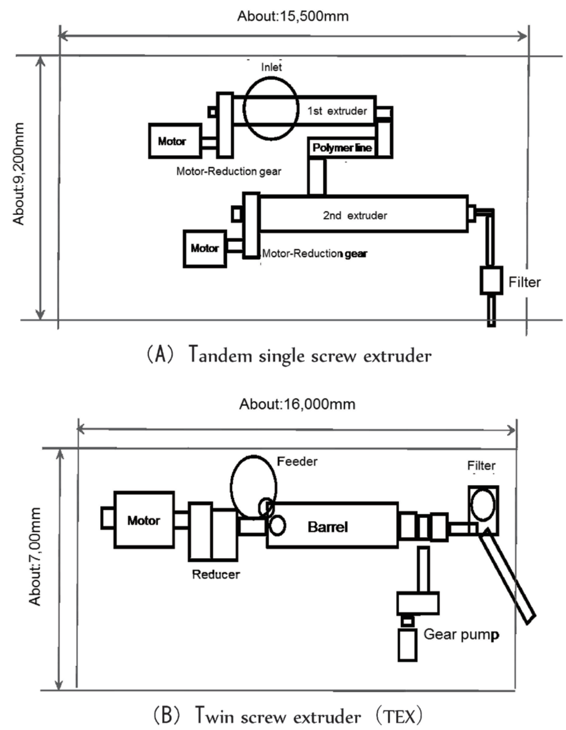
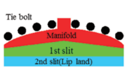
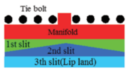
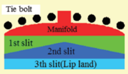


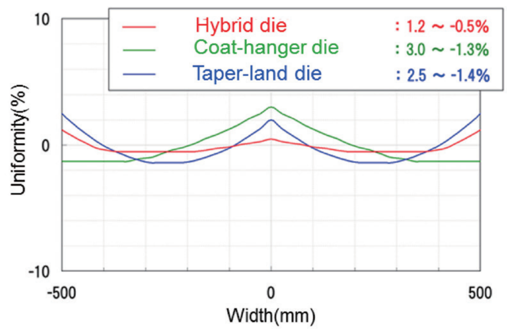
Fig. 15 Comparison in sizes of tandem single screw extruder and twin screw extruder (max. capacity approx. 6,000 kg / h)

(3) T-die

JSW originally provided the coat-hanger die for shorter residence time and Mitsubishi Heavy Industries provided the taper-land die for better lip opening control. In 2008, JSW has developed the hybrid die to combine the advantages of the coat hanger die and the taper-land die. The hybrid die is excellent in uniformity of thickness and physical properties across the full width and we have achieved large sales since 2009 [23] (Refer to Table 2, Fig. 16).

Table 2 Comparison of flow path and other features of each die

	Flow passage geometry	Uniformity (Thickness accuracy)	Residence time (Less degradation, smooth color change)	Lip opening (Uniform and smaller)
Coat-hanger		○	◎	△
Taper-land		○	△	◎
Hybrid		◎	◎	○~◎



(A) Thickness accuracy

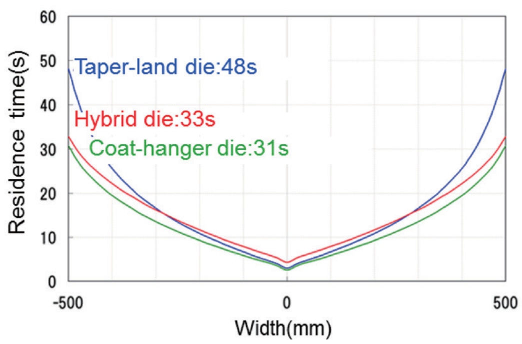


Fig. 16 Thickness uniformity and residence time distribution of die

(4) Transverse direction stretching unit (TDO)

The conventional clip in TDO unit was opened and closed by physically pushing the clip lever. However, in order to prevent noise, wear and damage of the clips at higher production speed, we have adopted the magnet type opener/closer. Recently, the clips of optimized shape for magnetic force are contributing to stable stretching at high production speed (Shown in Fig. 17, Fig. 18).

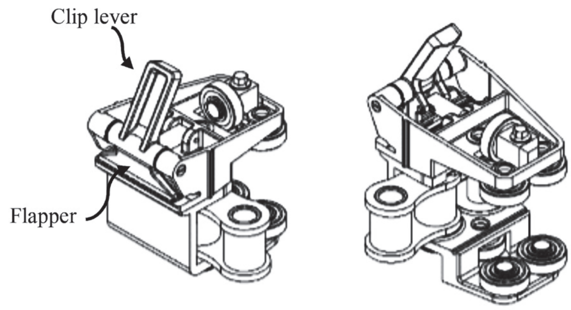


Fig. 17 Clip for the transverse stretching

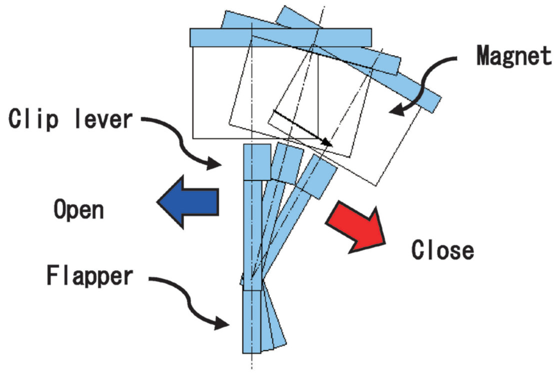


Fig. 18 Mechanism of magnet opener / closer

In the TDO oven, it is important to heat the film efficiently up to the stretching temperature. Originally, the hot air outlet of the nozzle was a slit type in general, but at higher production speed, the heat transfer coefficient is reduced by the accompanied air flow along the running film surface. Therefore, the multi-hole nozzles have been adopted recently to minimize the influence of accompanying flow and the nozzle hole design and arrangement have been studied to further improve the heat transfer coefficient. Figs. 19 and 20[24] show a comparison in air pressure distribution on the film surface and heat transfer coefficient between the conventional and improved nozzles. The conventional nozzle has linear hole arrangement at equal spaces and the improved nozzle has staggered hole arrangement. With the conventional nozzle, the air pressure is not uniformly distributed because jet flows from nozzle holes interfere with each other. On the other hand, with the improved nozzle, air pressure is more uniformly distributed as shown in Fig. 19 and the heat transfer coefficient is increased by 15% compared to the conventional nozzle.

In order to further improve temperature control accuracy, we have currently developed a separate temperature control system of the upper and lower nozzles.

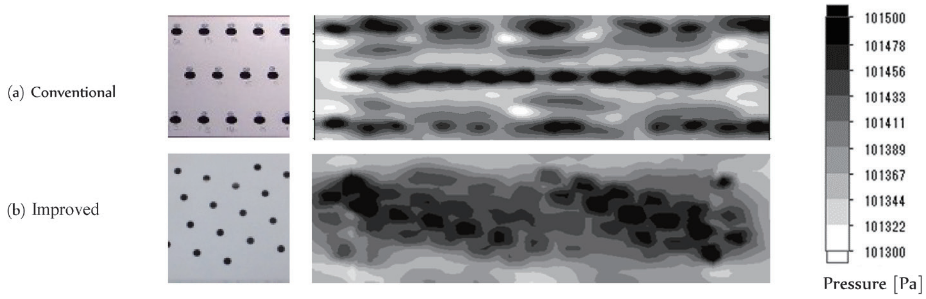


Fig. 19 Comparison of air blow pressure to the film surface depending on nozzle hole shape and arrangement (simulated values)

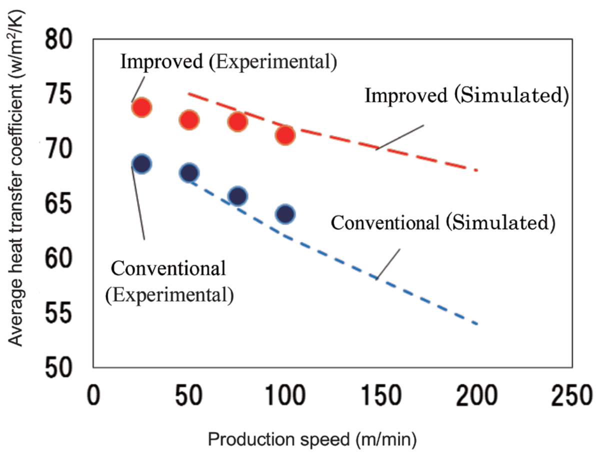


Fig. 20 Comparison of heat transfer coefficient depending on nozzle hole shape and arrangement
(Air blowing speed: 20 m / s, temperature: 120°C)

(5) Take-up & winding unit

Higher production speed has a great impact on wound film appearance in the take-up and winder. To minimize vibration in winding process and obtain product rolls in good shape even at higher production speed, we continue to improve the contact roll (rider roll), the narrow gap roll, the damper unit for contact roll and the frame rigidity.

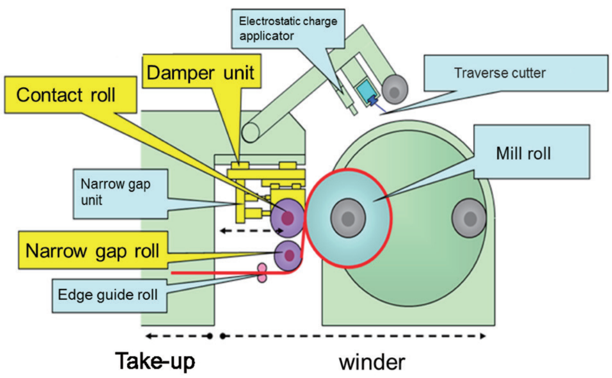


Fig. 21 Diagram of take-up and winding device

2.3.4 Separator film manufacturing equipment

High-capacity and high-power lithium ion batteries are increasingly used in smart phones / tablet devices, electric power tools, electric vehicles and many other devices. As for the separator film for lithium ion battery, the micropores in the film have a great influence on the battery performance and the safety of the battery. So, the key point is how to control the micropore distribution and other properties such as strength and heat resistance.

There are two kinds of manufacturing methods for the separator film. "Wet method" is a method to remove paraffin oil to make micropores in the film made by homogeneously mixing high molecular weight polyethylene (PE) and paraffin oil. On the other hand, in the "Dry method", micropores are created by longitudinal stretching after crystallization while orienting PE or PP in casting process.

(1) Wet-method separator production equipment

In the wet method, a large amount of liquid paraffin (LP) is added and homogenized in the high molecular weight PE as base resin. LP has a role to swell PE to facilitate plasticization and form micropores in the film after removal of LP. Since the mixing ratio of LP is as high as 60 to 70 wt%, twin screw extruder TEX with high mixing performance is adopted in order to uniformly mix and disperse LP in PE.

JSW entered the market of wet-method separator production equipment in 2004. We initially delivered only TEX in the process, but now we supply total separator production lines to foreign countries where the demand for separator is rapidly growing. The capacity of the extruder continues to increase year by year and it has more than tripled between 2005 and 2015. The production line speed also has nearly doubled as compared to the time when we entered the market. Fig. 22 shows a typical flow of the wet-method separator production line.

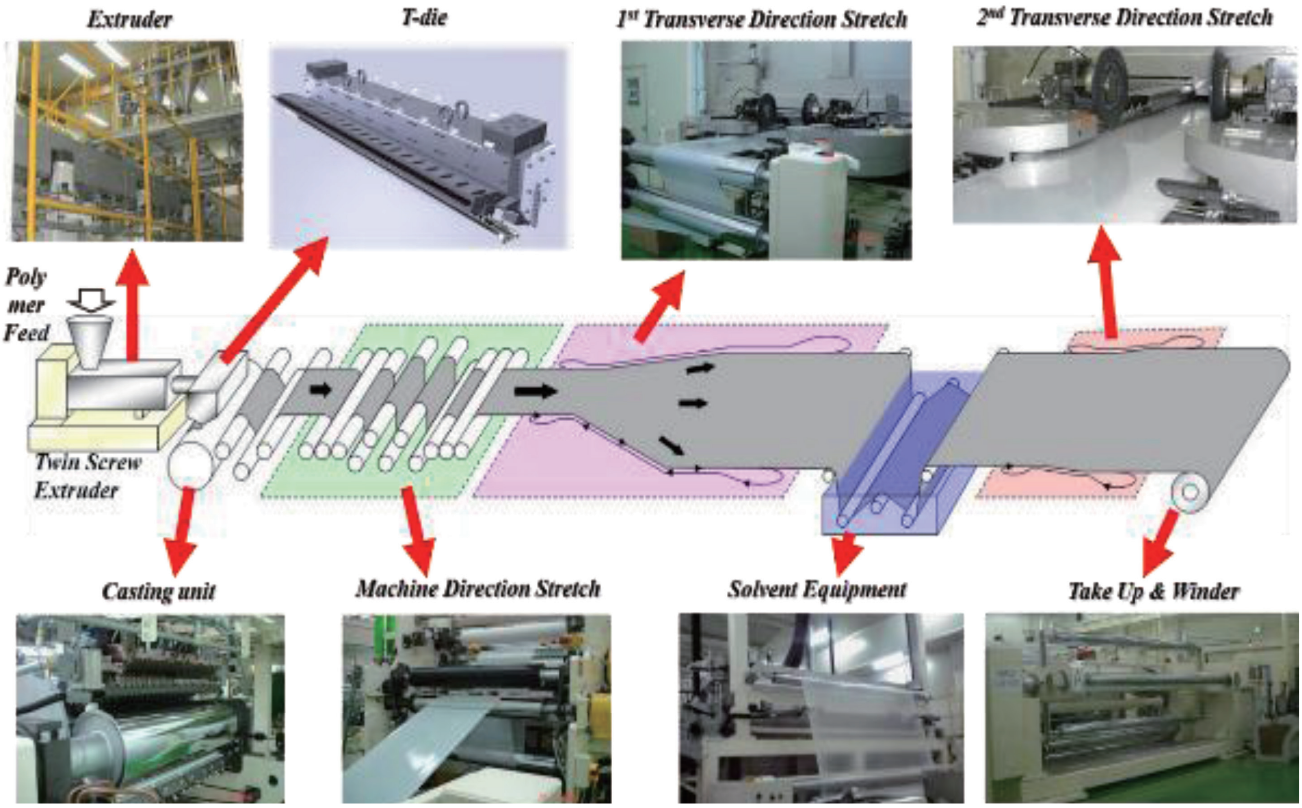


Fig. 22 Equipment Outline of separator production line

The separator production line consists of a TEX, a casting unit (CAST), a machine direction stretching machine (MDO), a first transverse stretching machine (1st TDO), an extracting tank (solvent equipment), a second transverse stretching machine (2nd TDO) and a take-up and winding machine. In the simultaneous biaxial stretching process, MDO and 1st TDO are replaced with a simultaneous stretching equipment. The sequential biaxial stretching process has a higher production efficiency at higher production speed compared to the simultaneous stretching process. On the other hand, the simultaneous biaxial stretching process offers an excellent isotropy in the film and advantages for thin film forming.

(2) Dry method separator production equipment

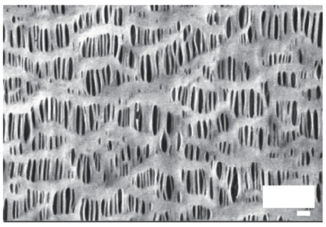
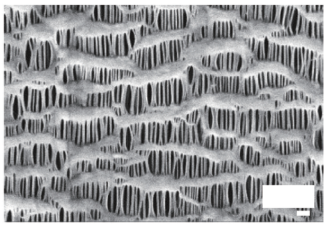
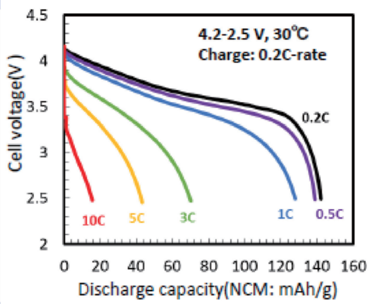
The dry method uses polypropylene (PP) which has a higher heat resistance than PE. And as a major difference from the wet method, micropores are formed by intercrystalline stretching in PP. JSW have delivered a number of cast sheet manufacturing equipment including single screw extruder for the dry method processes since the first delivery in the 1990s.

A higher heat resistance of PP increases the shutdown temperature of separator and deteriorate the function of separator as a safety device in the battery. For this reason, PP and PE sheets are generally manufactured separately and laminated to ensure the shutdown function with PE sheet and improve heat resistance with PP sheet.

In the dry method process, it is difficult to control crystal orientation in casting process and to control micropore forming in stretching process. For these factors, it was difficult for us to get orders for the entire process. However, as shown in Table 3, we recently succeeded in obtaining separator films which have good performance equivalent to commercial products in the trials using our full-line pilot equipment[25]. For the future, we aim to further improve production efficiency and allow to manufacture thinner films in the dry method separator production equipment.

Table 3 Comparison of dry method separators

※Converted value to 25μm, ※※Evaluation at Industrial Research Institute Kansai

<table>
<tr><th></th><th colspan="2">Single layer sample(PP)</th><th>Laminated sample</th></tr>
<tr><td rowspan="2">SEM
(image)</td><td rowspan="2"></td><td>Battery Characteristics (C rate)※※</td><td rowspan="2"></td></tr>
<tr><td rowspan="4">

【Battery composition】
LiNi0.33Mn0.33Co0.33O2:AB:VGCF:PVDF=91:2:2:5wt.%
Guraphite: AB:VGCF:Acrylic=93:2:1:4wt.%
【Electrode configuration】
Ternary System/Graphite CR2032Coin-cell Battery Capacity:2.5mAh/cell N/P=1.1 (Anode2.5mAh/cm2、Cathode2.8mAh/cm2)
【Test Condition】
High rate discharge test:Cut off:4.2-2.5V、Test condition:30℃ (Charge0.2C-rate、Discharge0.2C, 0.5C,</td></tr>
<tr><td>Thickness
(μ m)</td><td>11.3</td><td>35.1</td></tr>
<tr><td>Porosity (%)</td><td>51.8</td><td>53.4</td></tr>
<tr><td>Gurley value※
(sec/100cc)</td><td>419.0</td><td>307.7</td></tr>
</table>

2.3.5 Simultaneous biaxial film stretcher

Hitachi Plant Mechanics Co., Ltd.(HPM) began to develop a simultaneous biaxial film stretcher for polypropylene (PP) in collaboration with a user in the 1960s and had extended a reach of the dedicated equipment for polyamide. They entered the market of separator film stretching machines around 2000 and the stretching performance was highly evaluated.

Meanwhile, the simultaneous biaxial film stretcher began to be considered for optical film processes (phase-difference film). In 2005, HPM have developed the simultaneous biaxial film stretcher with unique mechanical stretch ratio changing device for flexible film stretching [26].

Photo 18 shows the appearance of a simultaneous biaxial stretching equipment in JSW laboratory and Fig. 23 shows the link mechanism of the simultaneous biaxial film stretcher.

Photo 18 Appearance of simultaneous biaxial stretcher in JSW laboratory

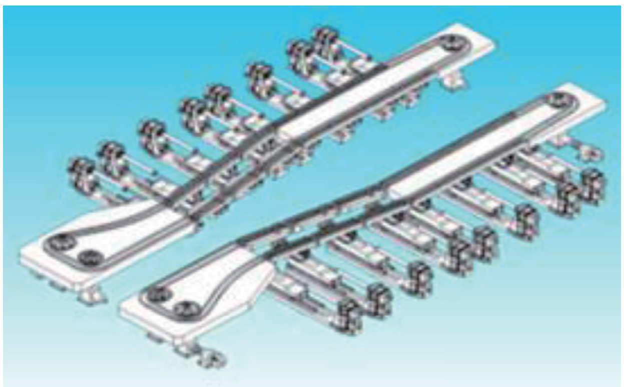


Fig. 23 Link mechanism of simultaneous biaxial film stretcher

(1) Features of the simultaneous biaxial film stretcher [27]

① High stretching ratio

The link mechanism allows for higher film stretching ratio compared to the conventional systems by the product of MD (machine direction) and TD (transverse direction).

② Faster line speed

Using the high performance servo motor, it is possible to control the line speed at the inlet and the outlet respectively and increase the line speed.

③ Strong clamping clip

In order to surely grasp even a film containing a lot of liquid paraffin such as separator films, the clips are provided with spring force and self-lock mechanism as well as slip prevention in the film grips.

(2) Future prospects

The simultaneous biaxial film stretching equipment has advantages in stretching the film in MD and TD in one process to vary physical and optical properties of the cast film at once and stretch the film without making scratches on the film surface by roll contact.

In the future, as the demands for high-value added films for optical applications will increase, we need to further improve the productivity and stretching accuracy in the simultaneous biaxial film stretching equipment. And it is also necessary to meet the requirements for high-temperature materials along with the increasing demand for heat-resistant films.

2.4 Blow Molding Machine

2.4.1 Introduction

Technological transition of JSW Blow Molding Machine is shown in the Fig. 24. In November 2006, JSW made Tahara Machinery Ltd. a subsidiary to strengthen and expand the blow molding business. There, Tahara is in charge of small machines of the blow molding machine business, JSW is in charge of blow molding machine for PFT (Blow molding machine for manufacturing automobile fuel tank) and medium and large size machine. JSW aims at further expansion of blow molding machine business utilizing each specialty field. Technical trends and newest technologies of blow molding machines for PFT and medium and large blow molding will be introduced.

2.4.2 PFT machine Market trends and newest technology trends

About 70% of the total plastic fuel tank for automobile fuel (PFT) is a plastic tank, and changing to plastic tends to continue in the future. Gas barrier performance is essential for PFT applications, so PFT is a multilayer structure of four kinds and six layers requiring a barrier material for the intermediate layer. EVOH of barrier material has a problem of heat deterioration and cannot be molded by an intermittent (accumulator) method used for large molding, so that it becomes a continuous extrusion type blow molding machine.

Since launching molding machines in 1998, JSW has delivered 61 units (12 double station machines, 49 single station machines) as a production machine to date. As a second-generation PFT machine from 2008, we have developed and launched technology of

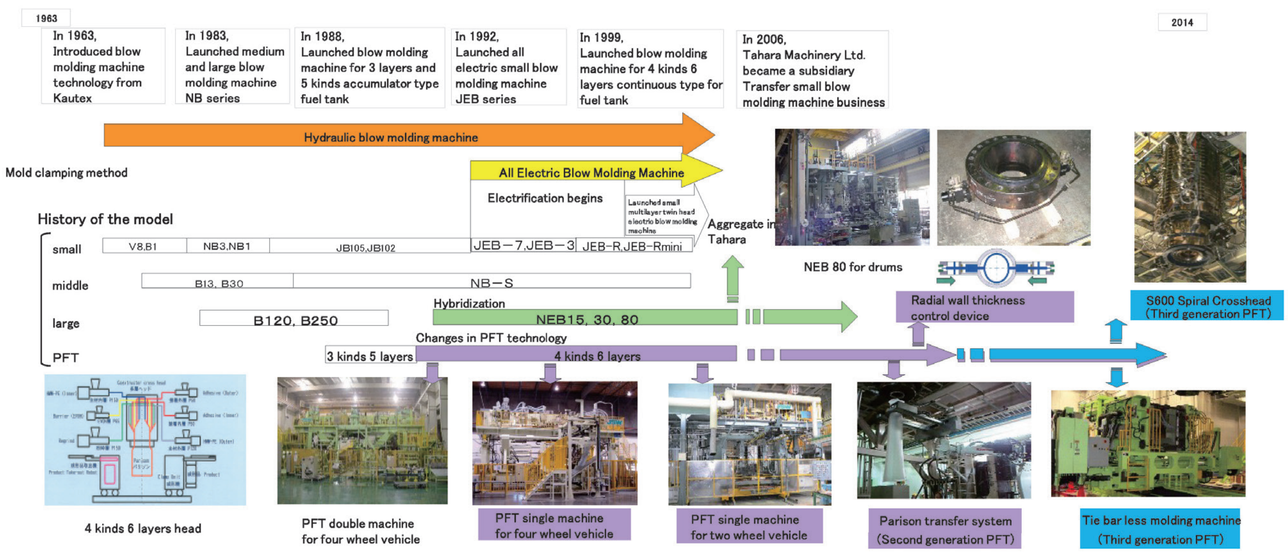


Fig. 24 JSW technological transition

transferring the parison by a robot, and a uniform and lightweight (Radial Wall Thickness Control Unit) technology of the thickness of molded product by changing the wall thickness in the circumferential direction. Currently, we are expanding new technology as third generation PFT and introduce its newest technology.

① NHB-120 type Tie bar less hybrid clamping device (29)

The conventional mold clamping machine was hydraulically driven only, but the new mold clamping machine launched in 2011 was a hybrid drive mold clamping machine combining electric drive and hydraulic drive, realizing energy saving, high cycle, light weight and compactness. Fig. 25 and Fig. 26 show the features of the hybrid drive molding machine and difference between it and conventional drive system.

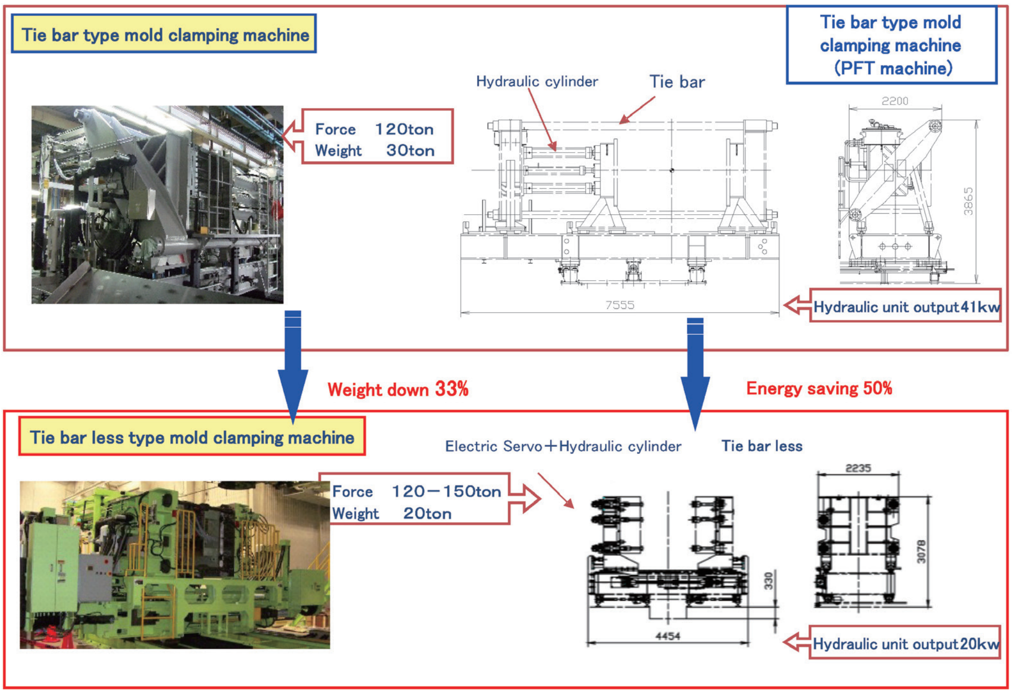


Fig. 25 NHB-120 type Tie bar less hybrid clamping device

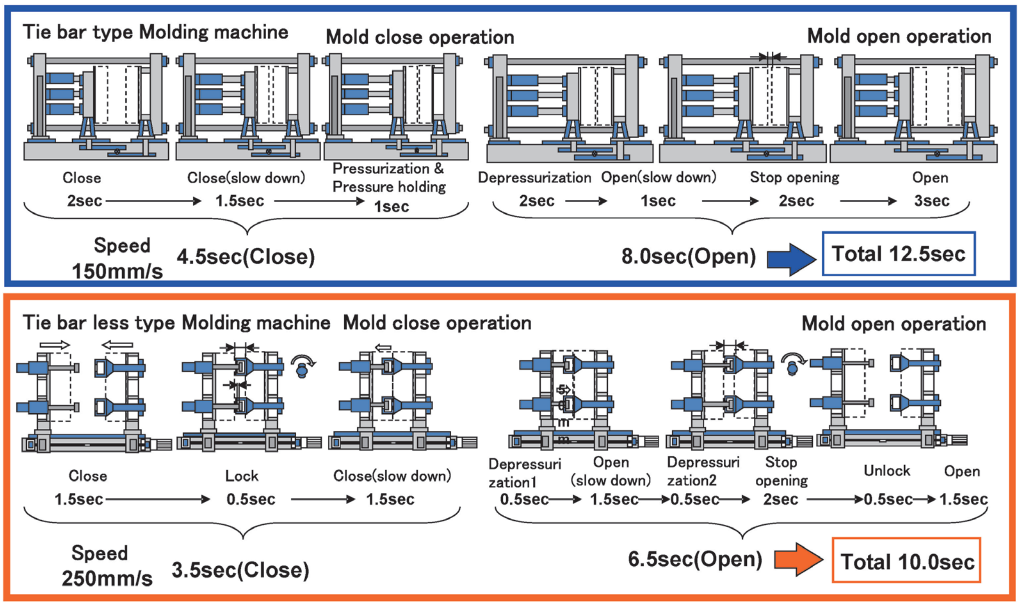


Fig. 26 Comparison of clamping operation

② Spiral cross head [29][30]

In the PFT blow molding machine, a parison of four kinds and six layers is formed by a cross head. Conventionally, the internal resin flow path of the cross head has adopted a relatively large size called a coat hanger type. In 2009, we began developing a spiral-type cross head in order to respond to environmental design such as energy saving and reduction of used resin quantity. The spiral cross head launched in 2010 after various analysis and verification tests can obtain significant improvement effect on thickness accuracy, resin replacement property, weight reduction of head body, power consumption reduction as compared with the conventional type and it is on sale as a standard cross head.

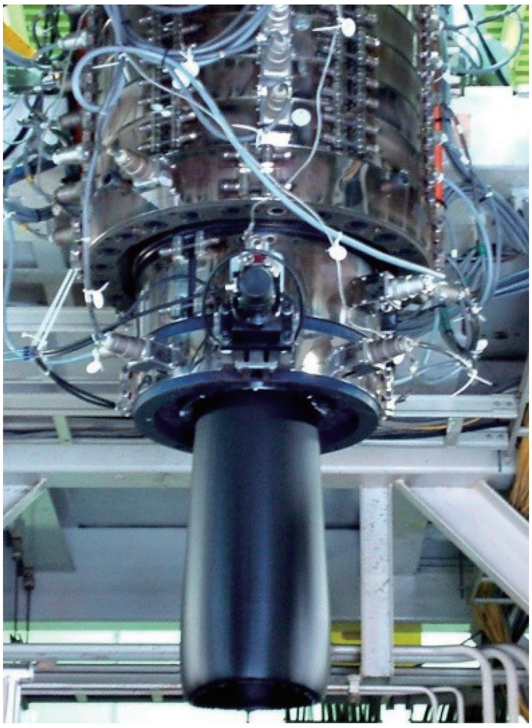


Fig. 27 Spiral cross head

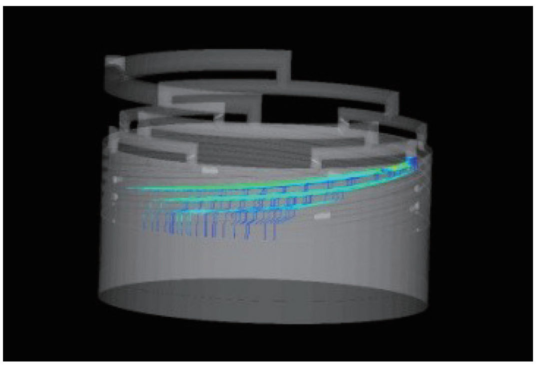


Fig. 28 Flow path analysis

③ Low Temperature High Dispersion Screw

In molding with four kinds and six layers of fuel tank using EVOH as a barrier material, it has a recycling layer of flash. The flashes in the molding of four kinds and six layers contain four kinds of resins, and it is important to finely disperse the EVOH contained in the flashes in the extrusion of the recycled material. EVOH itself is poor in strength, and when EVOH of large mass is present in the molding material, it becomes an internal defect, so it needs to be miniaturized and uniformly dispersed to such an extent that it does not affect the strength. Therefore, a screw of a special shape is required for the extruder of the recycling layer. At present, we can achieve the target value of particle size of EVOH miniaturized with JSW screw of 10 μm or less.

④ Radial direction wall thickness control unit [28]

Homogenization of the wall thickness of the molded product has the following advantages.

a) Reduction of materials used
b)Weight saving
c)Reduce cooling time

The wall thickness control in the axial direction which is the standard device is the wall thickness control in the outflow direction of the parison, and in the Control of wall thickness difference in the circumferential direction of the corner part of the molded product where the parison is most elongated and the wall thickness tends to be thin, It is impossible to deal with it, and a wall thickness control unit dedicated to the radial direction is required. Fig. 29 and Fig. 30 show the appearance of this machine. The feature of this machine is that the die ring with flexibility is displaced by 0 to ± 2 mm by a hydraulic cylinder of servo valve via the adapter shaft. As a result, it is possible to adjust the wall thickness in the parison circumferential direction, so that the wall thickness uniformity of the corner portion of the molded product is achieved. At present, we are developing a new type radial wall thickness control unit for further uniforming the thickness of the molded product and reducing its weight.

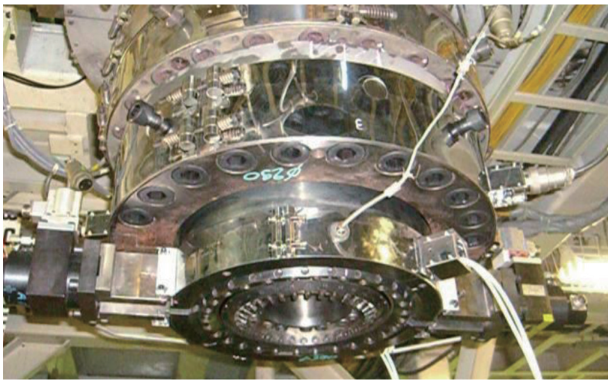


Fig. 29 External view of radial wall thickness adjustment device

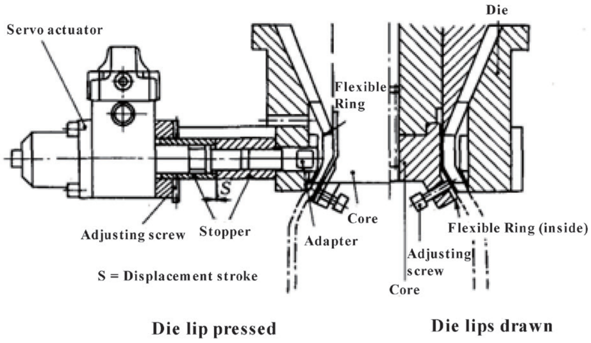


Fig. 30 Radial wall thickness adjustment device
(Ring deformation method)

⑤ Internal insert molding technology

In recent years global warming prevention measures have been required on a global scale, fuel tanks are required to deal with, as the emission control of hydrocarbons represented by PZEV (Partial Zero Emission Vehicle) program of CARB's (California State Air Resources Bureau) has been strengthened. And attach the components such as the pump unit, valve and tube from the outside to the tank. Therefore, it is compliant with the regulation by ensuring the sealability at the attachment portion and restricting the permeability of hydrocarbons by the material of the component parts. On the other hand, since it is unnecessary to give special consideration to the component parts by suppressing the number of openings of the tank by installing the component parts in the tank, and the practical use of internal insert molding in which the attachment to the inside of the component parts is performed at the same time is advanced at the time of molding the multi-layer fuel tank, therefore, because it is requested by the machine side, JSW is working on differentiation technology such as internal insert equipment, mold synchronization control, twin sheet molding, with customers.

⑥ New control system

Recent large-sized blow molding machines have diversified systems and complicated molding method. Therefore, in order to facilitate operability and to implement system monitoring and process control, we adopted SCADA (Supervisory Control And Data Acquisition) which is widely used in the plant world and decided to use a panel computer as HMI (Human Machine Interface).

As a result, the operator can easily set complicated molding conditions (recipe) while monitoring various processes of the molding machine, and it is now possible to store molding conditions and process data infinitely (Actually up to capacity of HD).

Remote diagnostic function can be added to this system, and it is possible to browse the local PLC online while staying inside the company. As a result, it is possible to check the status of the equipment and the process data in real time, and it leads to an early solution at the time of trouble.

In the coming days, we plan to add a general flick, pinch-in and pinch-out function to HMI on smartphones and tablets, also we plan to install another tablet and enable operation HIM from everywhere around the machine.

2.4.3 Market Trends and Newest Technology of Middle and Large Blow Molding Machines

Since 1965, high-density polyethylene kerosene cans have been approved as a dangerous transport container, and development of large-sized blow molded products become active since then, product range of large blow products such as solar system related parts around 1980, plastic drum cans, IBC used for dangerous transportation in 1995 expanded. In order to deal with the drawdown phenomenon where the parison stretches under its own weight, ultra-high molecular weight polyethylene (UHMWPE) with high melt viscosity and drawdown resistance has come to be used as a material. In addition, large-sized blow molding became possible by the introduction of an accumulator which stores resin and extrude it at a stroke. We introduce the state of the latest JSW technology related to these large blow molding technologies.

① Extruder for middle and large blow molding machine (screw) [28]

Technical issue of extruder of large blow molding machine includes,

a) High thrust overcoming backpressure generated by high viscosity of UHMWPE
b) Prevent excessive resin temperature rise in order to shorten production cycle time and suppress distortion after product cooling
c) Homogenization of kneading (uneven thickness problem)
d) Extrusion stability without large pressure fluctuation (cycle stability)

The JSW screw shape develop making full use of in-house testing machine validation and analytical techniques in response to those requests. The screw developed for the ultra-polymer is a screw that realizes high kneading by suppressing heat generation at the resin temperature while ensuring the extrusion amount. The pitch number (L/D) of the screw tends to increase as the quality of the molded product is improved, and in recent years it is in the range of 25 to 32.

② Accumulator cross head [28]

The accumulator head which has been used for a large-sized blow molding machine has a ring-shaped piston, and when the molten resin reaches the set capacity in the resin storage chamber in the head, it extrudes in a parison shape in a short time with a hydraulic cylinder. Most of the heads are of a cross head type which supplies molten resin from the extruder from the side wall of the head because the shaft of the wall thickness control unit that connects the hydraulic cylinder and the core is inserted in the center part of the core.

Fig. 31 is an overall sectional structural view of a large accumulator head.

Technical task of accumulator head includes,

a) Reduction of color change time of materials and prevention of retention pyrolysis inside.
b) Preventing weld line appearing on the parison
c) Disassembly cleaning property (maintainability)
d) Wall thickness accuracy of parison circumferential

In order to cope with these problems, the flow path in the head is changed from the conventional coat hanger type to the spiral type like PFT.

Also, we have developed and launched a multi-layer accumulator head that compactness of equipment and controllability were improved by forming multilayers in advance in the resin storage chamber inside the head and molding the parison for multi layered demands.

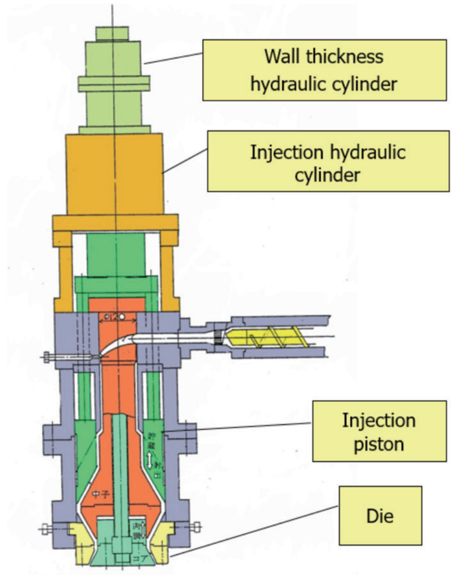


Fig. 31 Large Accumulator Head

③ Electric molding machine

We developed and sold all electric blow molding machine with JEB series in the small blow molding machine. Even in the medium to large size, we launched the NEB series of energy-saving and clean medium-sized (Clamping force 15 to 30 Ton) electric blow molding machines in 1995. This machine was a molding machine that electrically driven by using a toggle mechanism adopted in an injection molding machine. After that, we developed a large-sized blow molding machine NEB 80. This blow molding machine is a machine which changed the drive mechanism of the molding machine from the toggle type to the direct acting type improved speed reduction at the time of mold complete closing. Currently, in order to realize further enlargement, we are also launching a molding machine of electric and hydraulic hybrid. We will continue to develop energy-saving and compact molding machines.

2.4.4. Future prospects for blow molding machines

In the future blow molding machine market, environmentally friendly machines such as "energy saving", "resource saving", "high cycle" and "space saving" are required. Therefore, we are currently updating our in-house testing machine. This machine with the newest technology can specifically introduce to customers "energy saving" "resource saving" "high cycle" "space saving" which is a differentiation technology from competitors. In the future, it is expected that the number of production bases in Europe and domestic leading tank manufacturers will expand on a global scale and demand from Asian local tank manufacturers will increase. We intend to increase sales orders and to promote sales expansion and new technology development with a new test machine to achieve the goal of "the world's No. 1 blow molding machine maker".

2.5 Extruder Control Systems

2.5.1 History of Extruder Control Systems

The control system of an extruder began with a relay circuit for controlling operation stoppage and interlocks, and a controller for process control, both of which were installed in a control panel. Around 1985, advancements in LSI technology brought forth the integration of logic and analog control, resulting in the introduction to the market of controllers capable of centralized supervisory control, as well as industrial PCs. With the majority of customers of large extruder (pelletizers) being plant-oriented large petrochemicals companies, control changed from the use of a distributed control system (DCS) to use of PC-based control equipment (PC station). JSW adopted use of the SCADA package starting from 1997 in order to develop supervisory control systems, resulting in the development of custom screens for easy operational supervision, and the use of touch panels for on-site operating panels led to the development of screens that are safe and start up smoothly. Although the configuration of system devices have remained basically the same since then, in recent years, the functions of individual control devices have been undergoing improvements. For example, the installation of smart transmitters, which have a built-in communication function in its instrumentation device, to extruders enables the adoption of a control system with a function for communicating with these instruments. Additionally, control systems that use programmable logic controllers (PLCs) require system redundancy (duplex or triplex) and must be compatible with a system to which safety PLCs are installed. Fig. 32 shows the history of pelletizer control systems.

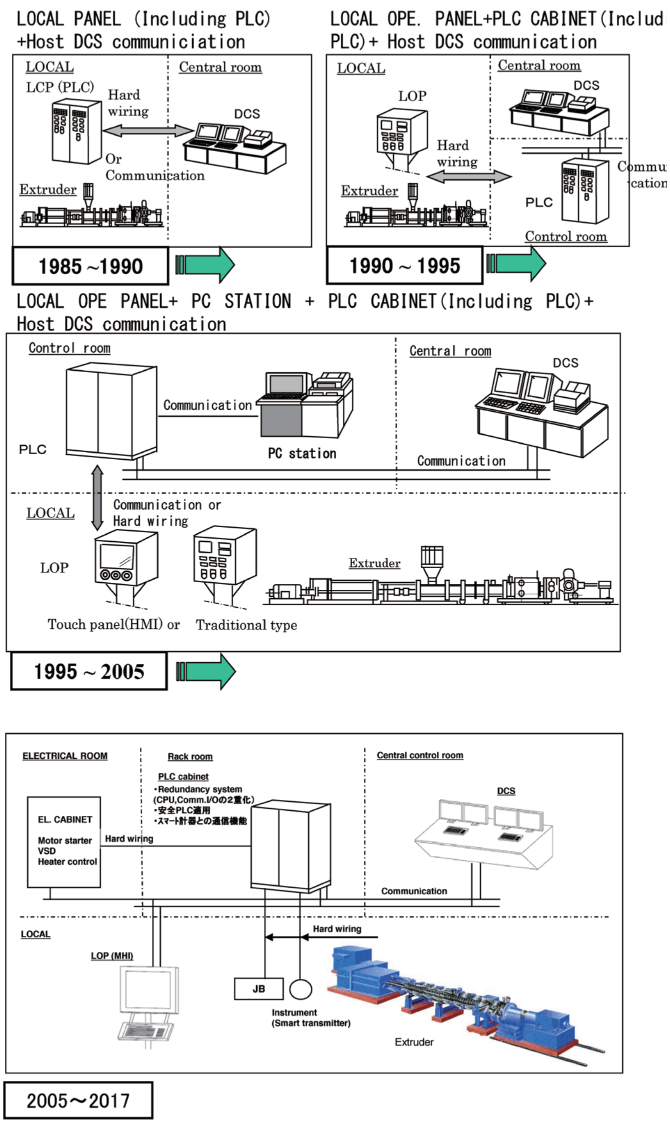


Fig. 32 History of large Extruder control systems

Conversely, customers of extruders for compound manufacturing, do not tend to strictly follow their own companies' standards, but rather prefer the most optimal control system suggested by the manufacturer, resulting in products equipped with JSW controllers being a main force in the industry. Together with the generation update since the fifth generation TEX Series, EXANET, which is a dedicated controller, has also resulted in great product advancements such as color screens, high-speed processing, and touch panels. The next-generation controller, EXANET5000, with multi-touch functions as well as improved operating functions, will be released in 2018 and JSW will be proposing user-friendly extruders.

Fig. 33 shows the history of EXANET controllers.

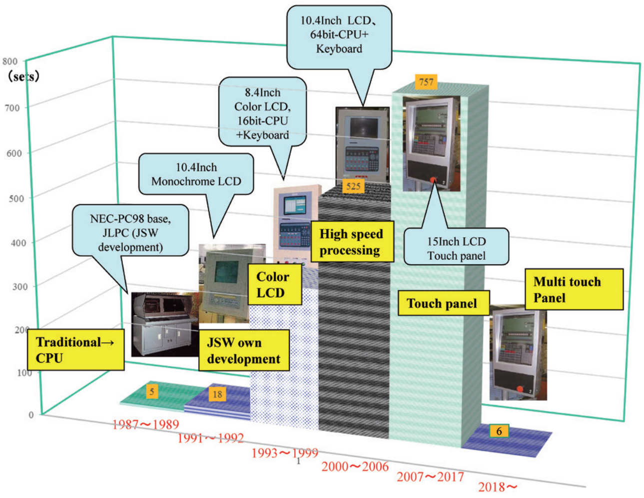


Fig. 33 History of EXANET Controller

2.5.2 Future Prospects for Extruder Control Systems

The growth and development of the Internet environment has resulted in an environment in which all devices, regardless of whether inside or outside of a plant, are linked in real time.

This environment requires early failure detection technology in order to readily check operating conditions by remote maintenance. Although the current technology is at a level where it can provide these functions, an issue for future study at JSW is that of operating methods that can ensure information security.

JSW will be improving the functions of our extruders by equipping them with predictive maintenance functions using this type of leading-edge IT technology.

3. Conclusions

The history of over sixty years and future prospects concerning polyolefine extruders, compounding extruders, film/sheet production equipments and blow molding machines were described as above. It is more than probable that the era of plastics will continue in the future backed by worldwide prosperity especially in the BRICs countries, impact of Shale gas and the U.S. market recovery, however the circumstance surrounding us have been significantly changing such as inflating oil prices, further spread of globalization, rapid evolution of IT, tightening of RoHS regulation and growing concern of environment. Plastics machinery industry will probably have a tough road ahead. At this difficult time, JSW 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 manufactures of plastics molding/processing machine while respecting the good tradition established by our seniors in the plastics machinery division.

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