Twin Screw Extruder "TEX" in a Wide Variety of New Processes

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Synopsis

The twin screw extruders "TEX" have originally been developed for plastics compounding and have been significantly improved together with active demands for further development and rationalization in the plastics manufacturing processes. Because of the high flexibility, such as the changeable operation conditions, and excellent mixing function, TEX series have been increasingly applied to a wide variety of new processes including reaction, devolatilization, and concentration of surfactant additives. We introduce new mixing processes with the advantages of TEX in comparison with conventional processes using batch mixers.

Introduction

When first introduced in 1978, TEX twin screw extruders were primarily used for molten plastics mixture purposes. While various polymer producers and compounding producers are very active in plastics processing technology development and its improvements, processes using TEX has been significantly extended. Nowadays, it is widely used in compounding, polymer alloying, devolatilizing, dewatering, and reaction applications. In recent years, in addition to conventional applications, TEX has been used for applications where twin screw extruders have not been used before. For instance, a reactive and devolatilizing process for surface active agents previously manufactured using conventional batch reactor vessels, has been shifted to continuous process by using TEX technology. Moreover, several conventional mixing processes using intensive batch mixer and roll mixer have been changed to continuous process using TEX technology. In this paper, we will introduce how conversion to new mixing process from conventional batch mixer has been demonstrated by using features of TEX technologies.

Changes made on TEX technology

The first TEX proto type twin screw extruder with counter-rotating, intermeshing design was named TEX65 (screw diameter 65mm). Photo 1 shows appearance of the first generation TEX65.

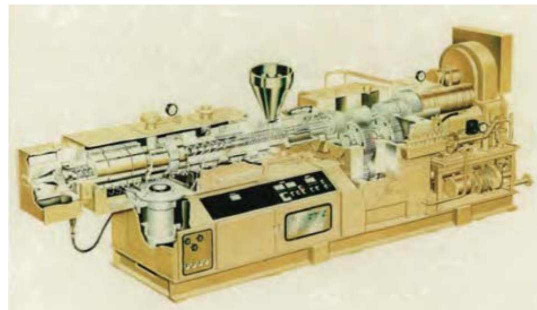


Photo 1: First generation TEX65

TEX series were initially developed mainly for compounding applications but gradually started using for various applications. In 1984, devolatilizing machine TEX305S has been delivered for solution L-LDPE devolatilization application (Photo 2).

Photo 2: TEX305S for devolatilizing

Since then TEX series have made its evolution to present 9th generation, which is called TEX-αⅢ, released in 2011 by adopting the latest design and production technologies. Development of the 9th generation TEX-αⅢ, which has the world's highest level torque made the technology more frequently to be used for engineering plastics and super engineering plastics compounds applications. Also, in high-performance elastomer compounds such as TPV, which is much used in automotive components, use of TEX technology is remarkably increased. Therefore, we are seeking opportunity in areas of plastics where twin screw extruders were not used, also new materials other than plastics.

This is a technology to shift to twin screw extruders with continuous production from conventional batch type (non-continuous) mixers. Conventional batch mixer has a feature of making residence time as long as required and sufficient reaction and mixing can be achieved. On the other hand, due to long residence time, productivity is inferior to continuous and there are some environmental and safety issues due to manual handling of material. In case of twin screw extruders, this will be a continuous process and enhanced productivity and improved work environmental and safety can be expected. There is a slight concern of insufficient reaction due to shorter residence time than batch mixer, but it is possible to overcome the concern and improve reactivity by means of optimization of screw configurations, barrel configurations and barrel temperature settings.

Batch versus continuous mixers

Batch mixers are classified between low and high viscosity material mixers and used depending on material viscosity. Here is a comparison between batch mixer and continuous mixer, namely TEX and its process.

Batch mixer: For low viscosity materials

In general, reactor vessel is famous for paddle type blender. The vessel itself has jacket structure and materials are heated by injecting hot oil or steam into jackets. Also there is a blending blades located inside of the vessel and by blending, materials are molten, mixed and reacted. Materials are fed from material inlet on the top of vessel and spending certain time and proceeding with reaction and mixing. Due to structure of blending blades, torque and strength of blending blades are not high and there is a limitation of mixing high viscosity materials. Therefore, it is only used mainly for low viscosity materials, basically, liquid materials. By blending blades, high speed disturbed flow turbulence is generated among a fluid that makes main material and sub-materials such as additives and oils can be blended fairly with a flexibility of mixing duration setting as you like. However, in order to get fair blending, sometimes residence time is required for a few hours and this is an issue for poor productivity. Also, feeding materials and discharging products are done manually, this will be a concern of high cost due to less automated and less productivity. Specially, when it comes to discharging high viscosity materials after mixing, materials may stick to inside of vessels that makes difficult to discharge and such removal and cleaning for material transition will take some time. This will be an environmental and safety issue. Also, more manual work will cause higher defect risk on product due to human error.

Batch mixer: For high viscosity materials

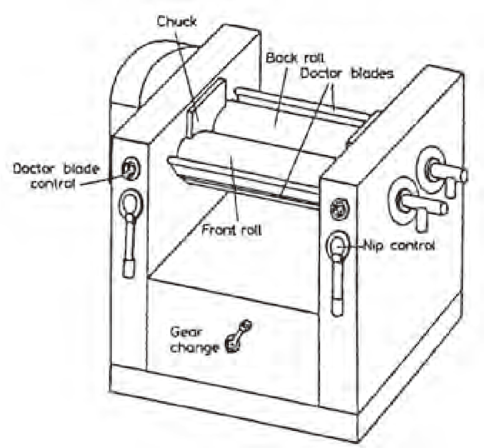
In batch type high viscosity material mixers, there are two types, namely twin roll mill and closed batch mixer. Twin roll mills are still widely used as laboratory and R&D purpose mixer while for production, closed type mixers are used.

Twin roll mill is an origin of all the closed type mixers. As shown on Drawing 1, the structure is to have two rolls with counter rotation which are installed horizontally and surface is polished. Materials are inserted between rotating rolls that provide shear and mixing.

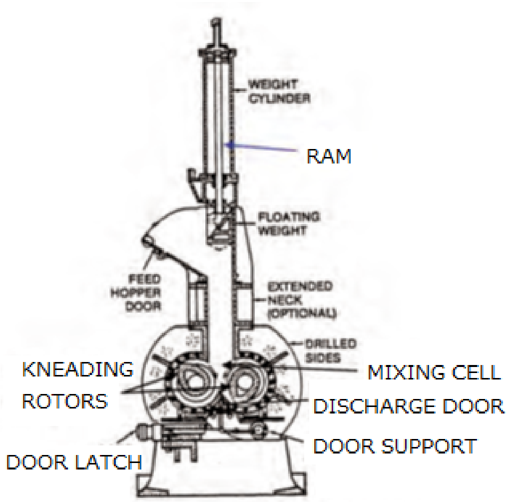
Closed type mixer is generally called as intensive mixer and represented by Banbury mixer. Its fundamental principal is same as roll mills but its mixing performance is far stronger than roll mills. As shown on Drawing 2, mixing cell with closed cross sectional "8" shaped with two parallel kneading rotors built-in, hopper, ram for pressurizing materials and outlet door for either falling of sliding discharge.

Material is mixed by shear between two kneading rotors rotating like roll mills. Mixing strength can be adjusted by pressurize system called ram that can move up and down. The mixer is capable to change mixing level by using kneading rotor configuration, speed, ram pressure and mixing cell temperature, etc.

Since mechanical structure is robust, it is capable to sustain torque and mechanical strength and is suitable for low temperature mixing of high viscosity material and mixing involving plasticizing of solid materials. However since it is batch type similar to reactor vessel, material discharge needs to be done by hand and there are issues for productivity, environment and safety. Also, similar to reactor vessel, operation is mainly done by manually and there will be a concern of stable quality of mixing product as it is depending on operators experience and skills.



Drawing 1: Twin roll mill



Drawing 2: Banbury mixer

Continuous mixer: Twin screw extruder, TEX

In case of twin screw extruder, residence time is determined by throughput per hour, and L/D, which is a ratio of, machine size; i.e., length (L) and screw diameter (D). L/D has a limitation and in general, it is difficult to get the same residence time as reactor vessel and Banbury mixer. To overcome this, applying necessary energy onto mixing product by optimizing screw and barrel configuration is a supplement for shortage of reaction time.
Since continuous mixers have significant advantage for users, they are active in process development by using additives to expediting reaction and mixing in shorter time. The structure of TEX, which is co-rotating and intermeshing type has superior self-cleaning capability and discharge for material transition can be done easily. This can overcome challenges of product discharge and self-cleaning of batch mixers.

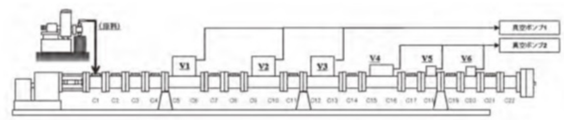
Process using twin screw extruders possible to get stable product quality continuously by feeding material automatically by feeder, making integrated controls onto twin screw extruder controller for feeding material and necessary parameters for operation conditions of extruders and discharged product reaction and mixing controls. That will help reduction of off specification products and increase productivity drastically.

In the next section, we will introduce example of changing process from conventional production process using reactor vessels and Banbury mixers to TEX twin screw extruder for enhanced productivity and improved quality.

Example of changing process from batch process to twin screw extrusion process; Devolatilization process for specialty purpose additives

Devolatilization is typically required to remove by-products from produced material from reactor vessel. Thin film evaporators are often used and produced high purified products by taking long time. The process has an issue of productivity and in order to avoid off-product during grades change, there were studies for better efficiency production system. Also, operational environment upon grade change needs to be improved in the recent years. Therefore, enhanced productivity by use of continuous twin screw extruders has brought attentions.

Drawing 3 shows equipment outline for TEX twin screw extruders upon experiment of material used for actual process. Material is liquid and fed into TEX continuously by plunger pump which can keep quantitative. Supplied material including by-products heated by shear heat by rotating screw and external heating by heater inside of TEX and devolatilized by reduced pressure grades and transformation to thin film at vent. In order to reduce residual concentration of by-products below target, multiple vent ports are located on extra long L/D extruder. Production with targeted residual concentration of by-products is made possible by improving devolatilizing efficiency significantly by setting off shorter residence time than thin film evaporator with use of intermittent compressional heating by screw and swelling (foaming) resulted from decompression at multiple vent ports and use of screw configuration that increased vacuum exposure area.



Drawing 3: TEX devolatilizing process

It is obvious that devolatilization zone length (L) and exposure area under vacuum atmosphere (S) has large effect on outlet volatile content as shown from the well known equation below.

$$\ln \frac{C_0 - C^*}{C - C^*} = K\, D\rho\, \frac{S L N^{1/2}}{Q}$$

Aspects affecting to efficiency of devolatilization can be mainly heating applied on the materials and exposure area under vacuum atmosphere. Chart 1 shows relationship between screw speed and residual concentration of by-products. As the screw speed increases shear speeds increase also that makes heating value increased and easier to evaporate solvents. Also, increased renewal of polymer surface makes solvent easier to evaporate under vacuum atmosphere and because of improved devolatilizing efficiency, residual concentration of by-products among products is reduced. However, excessive application of heat for improved devolatilization efficiency will be a concern of degradation of quality.

Chart 2 shows relationship between different exposure sized screw configurations under vacuum venting and residual concentration of by-products. Use of screw elements that makes larger exposure areas, improves devolatilization efficiency without applying excessive heat and achieved low by-products residual concentration of less than 300 ppm lowering extrusion product limited polymer temperature of 160°C. In this case, larger exposure area screw has twice as large area than smaller exposure area screw.

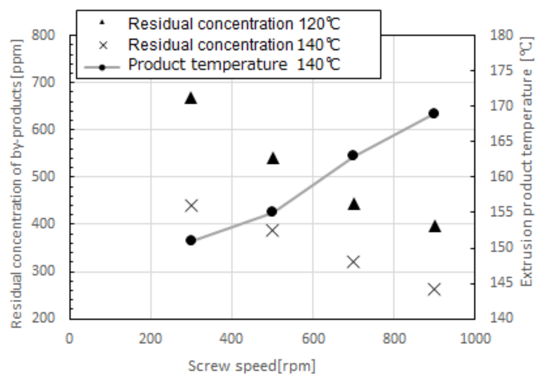


Chart 1: Relationship between screw rpm and residual concentration of by-products

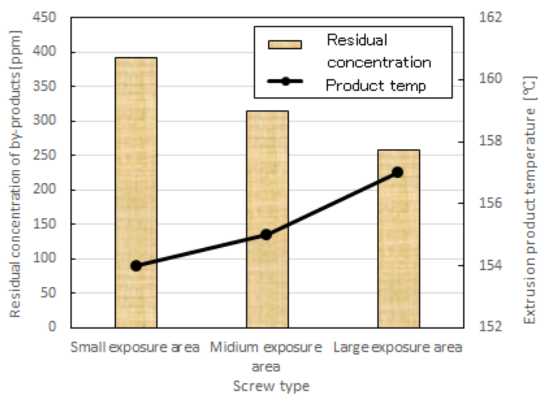


Chart 2: Relationship between screw configuration and residual concentration of by-products

Example ABS+SAN compounding

From the past, twin screw extruders are used for mixing of ABS (Acrylonitrile Butadiene Styrene Resin) and SAN (Styrene Acrylonitrile Copolymer). However such are still produced by batch process such as Banbury mixers. Banbury mixers are capable for melting and mixing solid material with viscosity such as ABS. By mixing parallel kneading rotors as per Drawing 2 with extra time for mixing under low speed, it makes possible to mix uniformly under low polymer temperature.

However, for the purpose of shifting process to continuous production by use of twin screw extruders for better productivity, we have demonstrated an experiment.

Such experiment was demonstrated by TEX54α Ⅲ made by JSW. ABS and SAN materials are fed into twin screw extruders quantitatively and continuously by gravity feeder. The quality of mixing of ABS and SAN is evaluated by number of unmolten objects (so called gels) with the size larger than 100 μm on a sheet surface made from sample pellets produced by evaluation type extruder. In order to achieve equivalent mixing performance with Banbury mixer, eccentric 3 lobe kneading elements are used as shown on Photo 3. This screw element has an effect of lowering local pressure generated inside of barrels and kneading tip position. Also, in case of mixing high viscosity ABS and relatively low viscosity SAN, extra precaution on screw configuration is required as mixing dispersion is challenging. Guideline for mixing dispersion is shear stress represented by:

$$\tau = \gamma \times \eta \text{ (shear rate x shear viscosity)}$$

By keeping viscosity of mixing products will make higher shear stress and increase dispersion performance. Since mixing of ABS is disturbed by lowering viscosity from progressed melting of SAN, screw configuration is intended to mix ABX by keeping viscosity of SAN with use of 3 lobe kneading elements.

Photo 3: Eccentric 3 lobe kneading elements

Chart 3 shows extrusion polymer temperature with eccentric 3 lobe kneading elements and conventional kneading elements. Polymer temperature in case of changing screw speed is indicated also. As shown on Chart 3, polymer temperature was effectively reduced with eccentric 3 lobe kneading element rather than screw configuration with conventional kneading elements.

Also, limited polymer temperature of 290°C was achieved by parameters with lower screw speed. By using latest TEX series which has ultra high torque, speed can be reduced by 10% and that made possible to lower polymer temperature.

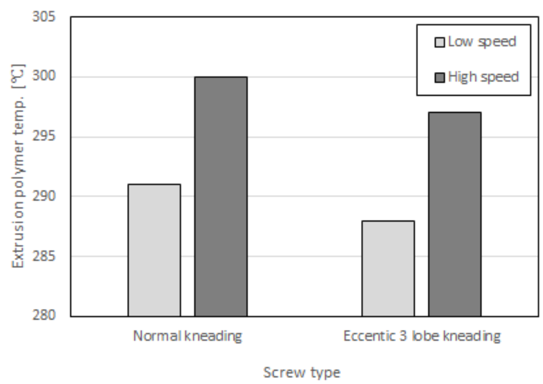


Chart 3: Relationship between screw configuration and polymer temperature.

Chart 4 shows relationship between screw configuration and number of gels from sheet evaluation. It also show relationship between screw speed and number of gels. Targeted gel number was achieved by use of screw configuration including eccentric 3 lobe kneading elements. Since equivalent mixing performance has been observed with products made from conventional batch mixer, the experimental result has been applied to actual production machine. This is the first achievement thanks to JSW's unique technology of eccentric 3 lobe kneading element and use of TEX α-Ⅲ technology which has the world highest level torque.

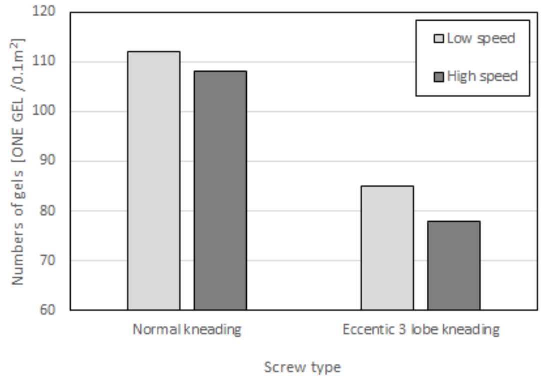


Chart 4: Relationship between screw configuration and number of gels on sheet

Example: Compounding of plant derived material

In recent years, compounds made from plant derived, environmentally friendly materials are getting attractions. In this paper, we will report one instance that fiber made from a plant derived material is used as sub-material and compounded with main material of olefin. Conventional batch process has been demonstrated by its laboratory experiments for optimization of blending olefin, fiber and additives. In order to aim continuous mixing of such materials, we came to a need of performance evaluation of mixers and we have studied improvement of productivity and fiber dispersion by using twin screw extruder technology.

Experiment was conducted by using JSW made TEX30α. Optimized material is fed into twin screw extruder quantitatively, and continuously through gravity feeder. There was no improvement on dispersion for process of mixing molten olefin and fibers after melting and adding fiber (Process 1) because of inefficient application of shear towards fibers due to reduced viscosity from molten olefin.

On the other hands, a development was made to molten mixing fed fibers before melting olefin and breaking down fibers in the extruder and after that mixing olefins fed from side feeder (Process 2). Chart 2 shows experimental operation parameters by using TEX30α. Samples obtained from experiments have been hot pressed and converted to thin film of approx. 0.15 mm thickness and observed fiber dispersion as per Photo 4. It is a comparison of dispersion between fiber mixing process after melting olefin (Process 1) and melt mixing process of olefin and breaking down fibers before olefin melting (Process 2). In result, the less white spot is the better dispersion and it is assumed that fiber dispersion is better for Process 2. Chart 5 is a result for comparison of specific energy (required power per mass rate) on individual experimental processes. Here is specific energy equation:

$$\text{ESP[kWh/kg]} = \frac{\text{kW}}{\text{kg/h}}$$

From the result, it can be concluded that process (Process 2) breaking down plant fiber before melting olefin has better dispersion performance as per Photo 4 as specific energy is improved by approximately 14% than Process 1 and giving sufficient energy input to fiber and olefin.

Photo 4 Fiber dispersion on each mixing processes

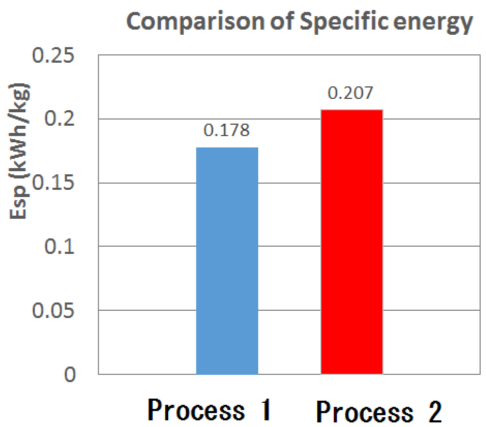


Chart 5: Comparison of specific energy

Conclusion

Twin screw extruder TEX series have made achievement of high torque, high speed and kept on developing its hardware. TEX is expected to be utilized for various application because of such the world leading performance. One of potential applications is for those where twin screw extruder technologies were not used so far. Such application should have potential benefit of enhanced productivity by means of process upgrade and improvement on environmental aspects and suppliers are encouraged to meet with such demands. We will be committed for further improvement of TEX series and upgrading of process technologies.

References

1）Sumida, Tomomitsu, Saga, Tojyo, Shimizu, Kodate, Ishibashi, Kakizaki, Inoue JSW Technical Report Vol. 64 (2013)
2）Ministry of Health, Labor and Welfare of Japan Workplace Safety, anzeninfo.mhlw.go.jp/
3）Kimimasa Ito: Compounding (1993)
4）“Devolatilization of Plastics”, VD–VERLAG BmbH (1980), p16
5）Dr. Sunghoon Kim, Dr. Costas G. Gogos: Polymer Mixing Study Polymer processing Institute (1998), p102