



Research Article

ISSN : 0975-7384
CODEN(USA) : JCPRC5

Study on the precision co-extrusion technology for PET recycling

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ABSTRACT

The recycling of polyethylene terephthalate (PET) is of significance to the construction of ecological environment, so the recycling technology and relevant equipment has a broad prospect of application. The disadvantage of traditional PET recycling process is analyzed in this paper, the PET precision co-extrusion process is proposed, and the co-extrusion device is designed. Experimental results show that the co-extrusion technology can meet the requirements of large-scale, continuous, precise and high-quality melting and extrusion process of PET recycling.

Keywords: PET, Co-extrusion, Recycle, Screw, Extruder

INTRODUCTION

PET, due to its outstanding properties, has been applied widely. But as known to all, the PET products are difficult to decompose, which generally needs 500 years. This has brought serious "white pollution" to the earth. In addition, as PET derives from petroleum, its production and preparation need the consumption of petroleum. The PET wastes can be recycled and processed into chemical fiber raw materials, the bottle blank tape raw materials, and PET plastic-steel belts etc. These materials can be further used to make clothes, motorcycle helmets, fishing lines, packaging lines, zippers, plates, shells, electronic panel, food packaging and so on. According to statistics, 1 tons of waste PET bottles can produce 0.98 tons of recycled PET fiber, which can save 6 tons of petroleum and 3 cubic meters of landfill space. From the perspective of saving energy and resources, environmental protection, the PET recycling technology has a broad prospect, and the increasing consumption of PET bottles also provides sufficient impetus for the recovery of PET [1-3].

The PET recycling technology has been developed better and better across the world. There are mainly two methods: chemical recovery and physical recovery. Compared with the method of chemical recovery, the physical recovery has made less secondary pollution on the environment. It is easier to implement the process and realize large-scale industrial production. Thus the method of physical recovery has been widely applied. A Japanese chemical company successfully developed the recycled PET modifiers "AR-P-1000" and "AR-P-1100". Stable at the room temperature, the AR-P recycled modifier is very suitable for all plastic molding processing equipment and can improve the viscosity of recycled PET and the flow properties of PET melts. It is conducive to manufacturing of the PET high-quality precision extrusion products [4, 5]. In 2007, the German Battenfeld Extrusionstechnik company developed a new PET single-screw extrusion system. The extruder was equipped with specially developed planetary geared degassing parts which can be directly processed without drying materials. The productivity of the system is 800- 1000kg/h [6]. Recently, the Petainer company used to be attached to the Rexam group has announced that it will manufacture recycled vodka-PET bottles for the Galatea company. It is said that, the high-quality PET bottles are better than the glass ones in weight and materials, and their carbon trace have been reduced more greatly than those of the same glass packaging, which can reduce 77% of greenhouse gas emissions and save 58% of electric power. In addition, as the upgraded products, the quality of the PET bottles are not inferior to that of the original glass ones, which can also reflect the quality of Sailor brand [7].

At present, many developed countries, such as the United States, Japan and Germany, have made much research on the high-quality precision extrusion recycling technologies like the automatic sorting technology, efficient cleaning, melting equipment, developing "bottle to bottle" technique, and made a great achievement.

EXPERIMENTAL SECTION

In recent years, Beijing University of Chemical Technology, Zhejiang University, Donghua University, Chinese Academy of Sciences, Chenguang Institute and other colleges and universities, chemical engineering institutes, environmental protection departments and manufacturers have joined in the research of the recycling technology, processes and equipment of waste PET bottles. This has accelerated improving the research and development (R & D) and production of recycled PET spinning complete equipment in China. The Pacific Mechatronic Group and China Textile Machinery Group, two leading chemical fiber machinery enterprises in China, have also joined the R & D of special complete equipment of staple PET from bottle flakes. The recycled system of PET bottles has become the most complete recycled one for China's wastes [8-15].

2. Methods of the precision co-extrusion processes for PET recycling

2.1. Traditional technological process

At present, the PET recycling is mainly based on low-end fiber materials. In recent years, with the development of science and technology and people's increasing demand for high-quality PET precision recycled products, the R & D of relevant complete equipment for precision extrusion spinning has become a new subject.

The method of the traditional process is as follows (Refer to Fig.1):

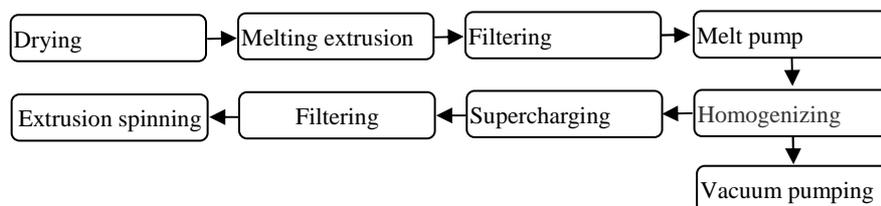


Fig.1 Method of the traditional process

The principle for the method of the traditional process is: After secondly filtering, the solid impurities can be effectively removed from the PET melts, the gaseous impurities can be separated through the vacuum pumping, and the PET melts can be homogenized in a vacuum state. Thus the problems of uneven recycled PET molecular weight, discrete intrinsic viscosity, and difficulty of implementing large-scale production can be solved. So the PET recycling industry can produce pre-oriented yarn (POY), fully-drawn yarn (FDY) filaments or 3D hollow staple fibers with general specifications. This has been a great progress in the PET recycling industry for many years.

Even so, there are still some serious defects in the above processes:

- ① The yellowness (B value) of the manufactured melts is higher, with poor lustrousness;
- ② The viscosity of the manufactured melts is still unstable, so more precise and high-quality products cannot be manufactured;
- ③ The continuity of production is not good, and large-scaled production is restrained.

The major causes for the above defects are as follows:

- ① There are various kinds of impurities in the recycled PET, and lots of gasified impurities will be generated after their melting. So the vacuum pipes and vacuum pumps may be clogged. As a result, the operation of the vacuum system becomes unstable, which causes the dispersion of its intrinsic viscosity further increasing. The production cannot be carried out when it is serious;
- ② Due to the high temperature, the recycled PET is likely to be oxidized in the processing process. The oxidation process is irreversible and may do greater damage to the quality of PET;
- ③ In the extrusion process, a long residence time may lead to thermal degradation of the recycled PET, and the yellowness of PET increases. This is irreversible once it occurs;
- ④ The insufficient drying may cause hydrolysis;
- ⑤ Due to the unstable quality of the recycled PET materials, it is difficult to control the process and guarantee the quality of the products.

2.2. Principle of the co-extrusion technology

The process of the recycled PET precision co-extrusion technology is illustrated in Fig. 2. According to Fig. 2, based

on the full drying of materials, the oxidization and pyrolyzation of recycled PET melts are reduced to minimum degree in the extruder via low-temperature rapid melt co-extrusion. The formulated additives, whose major components are ethylene glycol, are injected by using the quantitative feeding components. A controllable, appropriate alcoholysis is carried out on the bigger molecules of the recycled PET melts, the liquidity of which is improved, and the yellowing is prevented. And then they are re-polymerized by the principle that alcoholysis is a reversible reaction. The controllable velocity, temperature and high vacuum are created in the reaction kettle to promote the intrinsic viscosity of PET melts. Thus the oligomers and small molecular impurities are separated, and then solid impurities are filtered through the melt filter. Finally, recycled PET melts with even intrinsic viscosity, high whiteness and low ash content are obtained.

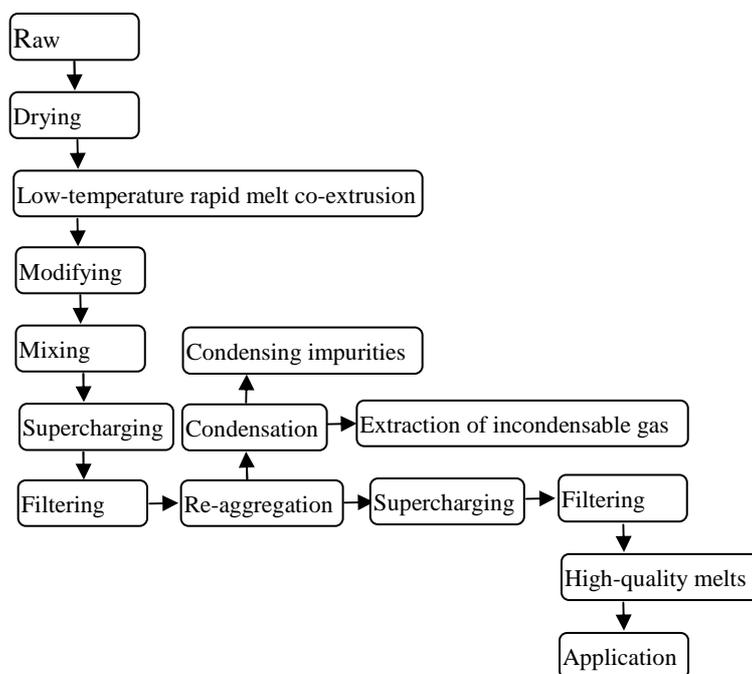


Fig. 2 Process of the recycled PET precision co-extrusion technology

3. Design of the co-extrusion device

In view of the co-extrusion process, the following problems will be met in the practical production. In order to overcome the thermal degradation problems and to meet the requirements of large-scale, continuous industrial production, PET must be extruded efficiently. In case of low-temperature rapid extrusion, as the temperature is low, such phenomena as inadequacy melt, reverse flow, unstable pressure may occur, even no feeding. And to meet the requirements of high-quality, precise products, it must be ensure that the PET based on rapid extrusion can meet the requirements of full melting and homogenization of the temperature for melt plasticization. The strict requirement is a key scientific problem to realize of PET high-quality precision recycling.

By the traditional method, the efficient melt extrusion is realized through using large-diameter screws, but the problems caused by large-diameter screws are that the overdue retention of the melts do damage to the quality of PET, and may cause inadequacy melt. Obviously, it has been unable to meet the requirements of production of high-quality, precise, large-scale and efficient recycled PET. This work uses medium-sized extruders to overcome this problem, and the problem of insufficient extrusion is solved by two extruders. The co-extrusion device is as shown in Fig 3.

As shown in Fig 3, the co-extrusion technology is realized by connecting two extruders with the co-extrusion nozzle. With the co-extrusion technology, the traditional large-diameter screw is replaced by two smaller-diameter screws. It reduces the requirements on the quality of materials of the bottle flakes. Compared with the traditional large-diameter screws, the width and depth of spiral groove of the co-extrusion screws are smaller, while the heating area is bigger. It effectively avoids the insufficient melting and reduces the requirements for temperature control. In addition, the screws are designed with a larger ratio of length to diameter, which can ensure full melting and homogenization of plasticization temperature for the melts. The loss of flow caused by the reduction of the cross-sectional area of spiral grooves can be solved by double screws co-extrusion.

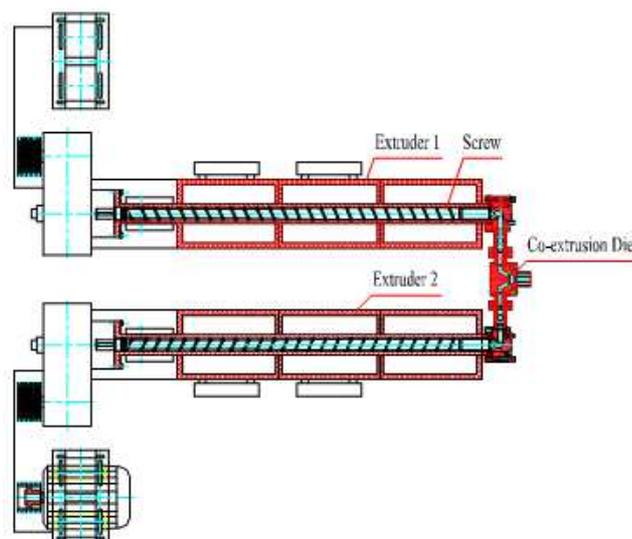


Fig. 3 Co-extrusion device

4. Experimental verification

4.1. Experimental conditions

The experimental equipment: Extruder manufactured by the Zhoushan Dinghai Hisense Machinery Co., Ltd, the model number is JS120-110325;

Screw diameter: 120mm, the ratio of length to diameter: 27;

Material of the screw and barrel: 38CrMoAlA;

Motor power: 75KW;

Heating power: 45KW;

Raw material: Recycled PET;

Screw speed: 48rpm.

4.2. Sampling process

About 5 minutes after the extruder was powered on and the speed of screw was stable, some of PET powder fragments are taken out from the feeding opening of the extruder. As the PET powder fragments are dried, they are immediately sealed in a barrel. In the meantime, open the exhaust vent of the filter, some PET melts will flow out, take about 200 grams of PET melts out with an aluminum plate and then seal them in a container after cooling.

4.3. Experimental results

The indexes of the PET powder fragments and PET melts are as shown in Table 1.

Table 1 Experimental result of PET powder fragments and PET melts

Item	Unit	PET powder fragments	PET melts
Intrinsic viscosity (I.V.)	dL/g	0.715	0.633
Acetaldehyde content (A.A.)	PPM	1.2	1.2
Melting point	°C	254	253
Color value B		1.4	2.9
Power content	PPM	120	0

It is seen from Table 1, the intrinsic viscosity of PET melts is decrease, and the powder content of PPM drops from 120 to 0. In addition, in the experimental process, the pressure at the extruder nozzles are normal (11 MPa), and the fluctuation of the pressure is stable. There are not phenomena of insufficient melt in the experimental process. It shows that the extrusion quantity can meet the technological requirements.

CONCLUSION

The PET precision co-extrusion process was proposed based on the traditional technological process. The co-extrusion technology is realized by connecting two medium-sized extruders together through the design of the co-extrusion die. It ensures the rapid extrusion of recycled PET melts and also overcomes the problem of raw materials of the traditional large extruders. The screw design with bigger ratio of length to diameter can effectively promote the full melting and the homogenization of the plasticization temperature. The experiment result shows the

device can meet the requirements of high-output extrusion and high-quality process, which can effectively avoid quality loss of PET due to over duration of the melts in the melting process of extrusion.

Acknowledgments

This research work was supported by Program of Education Department of Zhejiang Province (Y201225123), International S&T Cooperation Projects of China (2010DFR50860), National Natural Science Foundation of China (41106077), Program of Science and Technology Department of Zhejiang Province (2012C01014-2, 2012C02001-2), and Program of Science and Technology Department of Zhoushan (22011C12014, 2012C23031, 2013C41003). The supports are gratefully acknowledged.

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