Performance Evaluation of Polypropylene Resin for Capacitor Film

SONG Sainan\textsuperscript{1,\textast}, WANG Xia\textsuperscript{1,\text asteroid}, MU Ruijuan\textsuperscript{1,\textasteriskcentered}, XING Zhaoliang\textsuperscript{2,\textasteriskcentered}, Dai Xiying\textsuperscript{2,\textasteriskcentered}

\textsuperscript{1}Lanzhou Chemical Research Center, Petrochemical Research Institute, PetroChina, Lanzhou 730060, China
\textsuperscript{2}State Key Laboratory of Advanced Power Transmission Technology (Global Energy Interconnection Research Institute co., Ltd.), Beijing 102209, China
\textsuperscript{\textasteriskcentered}email: songsainan@petrochina.com.cn, \textsuperscript{\text asteroid}email: wangxia2@petrochina.com.cn, \textsuperscript{\textasteriskcentered}email: musuijuan@petrochina.com.cn, \textsuperscript{\textasteriskcentered}email: 342874263@qq.com

Abstract: The molecular structure and mechanical properties of 3 kinds of imported polypropylene particles for capacitor film were analyzed by Gel Permeation Chromatograph (GPC), differential scanning calorimeter (DSC) and electronic tensile machine. The results showed that the melt index of imported polypropylene for capacitor film was about 3.0g/10min, the ash content was about 20ppm, the isotacticity index was higher than 98.5\%, the crystallinity was higher than 45\%, and the molecular weight distribution was wider than 6.0. The data showed these three kinds of imported polypropylene for capacitor film were all low-ash and higher isotactic polypropylene with high crystallinity and good mechanical tensile properties.

1. Introduction
Biaxially oriented polypropylene (BOPP) film has high mechanical and electrical properties, which is an important dielectric material in capacitor, accounting for 70\% of the cost of capacitor \cite{1}. Although the total supply of BOPP film in China has exceeded the demand, the high-technology capacitance film is still restricted by its basic raw material polypropylene particles. At present, China's demand for electrical grade polypropylene is about 100000 tons / year, most of which depend on imports \cite{2}. The most recognized electrical grade polypropylene in China is Nordic chemical products, such as HC300BF, whose market price is about 15000 yuan / ton, followed by Korean oil chemical company and Singapore TPC products, such as 5014L and FS3030 respectively.

In this paper, three kinds of imported polypropylene for capacitor film, HC300BF, 5014L and FS3030 were analyzed. The structure and performance characteristics of polypropylene for capacitor film were put forward, which will provide reference for the development of high-performance polypropylene special material for capacitor film to meet the domestic demand.

2. Experimental
2.1. Materials
HC300BF, Nordic chemical company. 5014L, Korea Petrochemical Company. FS3030, The Polyolefin Company (Singapore) Pte.,Ltd. N-heptane and 1,2,4-trichlorobenzene, were all of A.R. grade,
2.2. Instruments
Melt index instrument, 6542, Ceast, Italy. GPC, GPCIR, PolymerChar. Differential Scanning Calorimeter, Q2000, TA INSTRUMENTS, USA. Colorimeter, ColorFlex, HunterLab, USA. Photoelectric Haze Meter, WGW, Shanghai Optical Instrument Factory. Injection machine, UN-100, Leistritz, Germany. Electronic Tensile Machine, Instron 5566, Instron Company, USA.

2.3. Performance tests
Melt Index was tested according to GB / T 3682-2000. Ash content was tested according to GB / T 9345-1988. Isotactic index was tested according to GB / T 2412-1980. Haze was tested according to GB / T2410-1980. Yellow index was tested according to GB / T 2409-1980. Tensile strength properties were tested according to GB / T 1040-2008. Oxidation induction time was tested according to GB / T 19466.6-2009.

The method of thermal performance test was as follows. About 10mg polypropylene was weighed, heated to 220 °C at the rate of 30 °C / min under the protection of nitrogen for 5min, then cooled to 30 °C at the rate of 10 °C / min, the crystallization curve was recorded during the cooling process. After kept at 30 °C for 2min, then heated to 210 °C at the rate of 10 °C / min, the melting curve of the sample was recorded during the heating process, and finally dropped to room temperature at the rate of 30 °C / min. The samples were heated from 20 °C to 200 °C at a rate of 20 °C / min, after 5 min of constant temperature, nitrogen was switched to oxygen. The flow rates of N₂ and O₂ were 50 ml / min. When the DSC signal of exothermic peak exceeded the set threshold of 1.000 MW / g, the test was stopped. Oxidation induction time was obtained after 3 min.

3. Results and discussion
3.1. Physical properties
The physical properties of three kinds of imported polypropylene particles for capacitor film were summarized in Table 1. The melt index of polypropylene used for BOPP film production is generally between 2 ~ 4g / 10min, and the melt index of three kinds of imported polypropylene was about 3.0 g / 10min. Ash content is the most important factor that affects the dielectric strength and dielectric loss of polypropylene. Polypropylene which has lower ash content has higher dielectric strength and lower dielectric loss. The capacitor film prepared with low ash polypropylene particles has better electrical properties. Therefore, the ash content of polypropylene for capacitor film is very strict, which should be controlled lower than 50ppm. According to Table 1, the ash content of these three polypropylene was about 20ppm, among them HC300BF had the lowest ash content which is 14.1ppm. Isotactic index is another important index affecting the performance of polypropylene capacitor film. Polypropylene with higher isotactic index has stronger crystallization capacity, which is conducive to reducing the thermal shrinkage of the film, improving the heat resistance and breakdown field strength, improving the aging resistance and prolonging the service life of the capacitor. Consequently, polypropylene capacitor film requires high isotactic index. Isotactivity index of the three kinds of imported polypropylene was higher than 98.5%, and the xylene soluble content was lower than 2%, which indicated that the molecular arrangement regularity of imported polypropylene was high.

The yellow index of samples can be used to evaluate the aging properties of polypropylene products. Table 1 show the yellow index of the three imported polypropylene was negative, indicating that the color of the materials was blue. The haze of polypropylene was related to the crystallinity and crystal size of raw materials. The haze of these imported polypropylene was equivalent, about 53%, showing that the imported material had high crystallinity.
### Table 1 The physical properties of imported polypropylene for capacitor film

| Sample     | MI/g/10min | Ash content/ppm | Isotactic index/% | Xylene soluble content/% | Yellow index/% | Haze/ % |
|------------|------------|-----------------|-------------------|--------------------------|--------------|--------|
| HC300BF    | 3.0        | 14.1            | 99.1              | 1.5                      | -2.36        | 53.5   |
| 5014L      | 3.1        | 19.5            | 98.9              | 1.8                      | -2.90        | 53.6   |
| FS3030     | 3.0        | 21.8            | 99.0              | 1.7                      | -1.51        | 53.9   |

#### 3.2. Thermal properties

### Table 2 The thermal properties of imported polypropylene for capacitor film

| Sample     | Tm/℃   | Tc/℃ | Crystallinity/% | OIT/min |
|------------|--------|------|-----------------|---------|
| HC300BF    | 168.2  | 106.5| 45.55           | 36.9    |
| 5014L      | 170.0  | 106.0| 46.08           | 42.5    |
| FS3030     | 168.7  | 108.6| 45.76           | 37.6    |

The thermal property of polypropylene is one of the important factors affecting the processing and application of products, which is an important way to investigate the temperature resistance of electrical grade polypropylene. The thermal performance data of three kinds of imported polypropylene are shown in Table 2, and the DSC curves are shown in Figure 1. For three imported materials, the melting point was higher than 168 ℃ and the crystallinity was higher than 45%. Polypropylene with high crystallinity will have high melting point and heat resistance, which is helpful to increase the maximum service temperature of polypropylene film for capacitors. From the melting curves, it can be seen that HC300BF and FS3030 had similar melting peak shapes, which were slightly different from 5014L. A small melting peak appeared near 150 ℃ in the low temperature region of the main melting peak, which may be due to α Crystallographic orientation β Crystal transformation during the heating process. Oxidation induction time is an evaluation of the material stabilization level [6]. If the oxidation induction time is too short, the product is easy to be oxidized in the process of processing and easy to adhere to mold which will influence production. The oxidation induction time of the three imported materials was over 35 min, indicating that these materials had good heat resistance and oxygen degradation ability.

![Fig.1 Melting curves of imported polypropylene for capacitor film](image)
3.3. Relative molecular weight and distribution

The resin with wide relative molecular weight distribution has better processability [7]. Within a certain range, appropriately widening the relative molecular weight distribution can improve the fluidity of the melt, and appropriately widening the process conditions can improve the film-forming property. The GPC results of three kinds of imported polypropylene are shown in Table 3, and the molecular weight distribution curves are shown in Figure 2. 5014L had the largest weight average molecular weight and the smallest number average molecular weight, thus it had the widest molecular weight distribution. HC300BF had the narrower molecular weight distribution, MW / Mn was 6.3. According to Fig.2, the content of high molecular weight components of HC300BF was higher than that of the other two imported materials.

![Molecular weight distribution curves of imported polypropylene for capacitor film](image)

Table 3 GPC results of imported polypropylene for capacitor film

| Sample   | Mw    | Mn   | Mw/Mn |
|----------|-------|------|-------|
| HC300BF  | 287300| 45800| 6.3   |
| 5014L    | 297500| 34100| 8.7   |
| FS3030   | 280700| 36400| 7.7   |

3.4. Mechanical properties

The tensile properties of three kinds of imported polypropylene particles were tested, and the results are shown in Table 4. The tensile yield stress of the three imported materials was about 35MPa, which had high tensile modulus of elasticity. The tensile modulus of elasticity of HC300BF and 5014L was higher than 1700 MPa, which indicated that the imported polypropylene had excellent tensile properties.

Table 4 Mechanical properties of imported polypropylene for capacitor film

| Sample   | Tensile yield stress /Mpa | Fracture elongation/% | Tensile modulus /MPa |
|----------|---------------------------|-----------------------|----------------------|
| HC300BF  | 35.0                      | 421.8                 | 1703                 |
| 5014L    | 35.2                      | 364.7                 | 1736                 |
| FS3030   | 34.9                      | 483.0                 | 1624                 |

4. Conclusions

In recent years, with the development of national UHV flexible DC power grid, the construction of
high-speed railway and the promotion of new energy electric vehicles, the demand for metallized film capacitors with good heat resistance is growing rapidly. However, there was still a gap between domestic and foreign products. In this paper, the properties of imported polypropylene for capacitor film were studied. The imported polypropylene for capacitor film were low ash and high regularity, which had high crystallinity, wide molecular weight distribution, good mechanical and tensile properties which is the direction of further optimization of domestic polypropylene for capacitor film.

Acknowledgments
This paper is one of the phased achievements of the science and technology project (5500-201958321a-0-0-00) of the headquarters of State Grid Corporation of China.

References
[1] Zhang Pisheng, Sun Fuguo, Xu Hui, et al. (2021) Production status of PP for capacitor films. China Synthetic Resin And Plastics, 38(3): 59-63.
[2] Duan Guangwei. (2020) Present situation and development of polypropylene for capacitor film. Modern Chemical Research, (14): 8-10.
[3] Wang Lixin. (2001) The production status of polypropylene electrical film and suggestions on developing raw materials in China. New Chemical Materials, 8: 40-42.
[4] Chu Songchao, Chang Qingyang, Wu Jianzhang, et al. (2018) Research and Development on biaxially oriented polypropylene rough-surface film with high field strength. Power Capacitor & Reactive Power Compensation, 39(1): 65-68.
[5] Yao Liding. (2003) Discussion on BOPP capacitor film with improved heat resistance. Power capacitor, 24(2): 46-48.
[6] Wang Fang, Huang He. (2019) Comparative study on thermal and mechanical property of three kinds of polypropylene random copolymer. Synthetic Materials Aging and Application, 48(6): 42-44.
[7] Feng Song, Xu Xianfen. (2012) Industrial trial production of special polypropylene resin for electrical films. China Synthetic Resin And Plastics, 29(3): 38-40.