10294 Session 2022
Study Committee B1
PS1 HVDC Systems and their Applications

Research on Large-length 500KV XLPE Insulation AC Submarine Cable

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SUMMARY

The single length of the world's first 500 kV cross-linked polyethylene (XLPE) insulated AC submarine cable is more than 10 km. The insulation thickness of 500 kV XLPE insulated submarine cable of 1800 mm^2 conductor shall be 31.0 mm. The insulation extrusion and degassing effects of such thick insulation shall directly affect the quality of the product in operating, so its insulation extrusion control and degassing method should be studied further more. In this paper, a new "thermal convection" type degassing method is proposed for this project. Meanwhile, submarine cable by-products content in the insulation layer during different degassing periods was measured and analyzed to confirm degassing effect by thermogravimetric analysis method (TGA). Research results show that: 1) The insulation cleanness and extrusion of XLPE insulated cable core are the key technologies to ensure the quality of 500kV AC cable. 2) The "thermal convection" degassing method ensures that the degassing temperature and degassing speed between insulated cores are basically uniform and constant. Heat air flow through the gap between cables and by-products released from the insulation core to ensure the degassing effect stable. 3) The new degassing technique can significantly promote degassing efficiency of thick insulated submarine cables of large length. Degassing effect of 10 km submarine cable had been determined by TGA test results to be reliable. The research can provide reference for the control of large-length and high voltage XLPE insulation extrusion and degassing process.

KEYWORDS

500kV AC submarine cable; large length; XLPE; degassing; TGA;

0 Introduction

The AC submarine cable project invested by Zhejiang Electric Power Company of State Grid, China, starting from Zhenhai Submarine Cable terminal station and ending at Zhoushan Submarine Cable terminal station, is the world's first 500 kV XLPE insulated AC submarine cable. In the production process of such large-length EHV XLPE insulated AC submarine cable, the removal of gas in the insulating wire core is an important control process [1-2]. The length of degassing time has a certain impact on the structural composition and electrical properties of XLPE insulation material [3]. As dicumyl peroxide (DCP) is generally used as a common crosslinking agent for medium and high voltage XLPE cables [4-5], it will be decomposed and produce crosslinking by-products such as methane and acyl alcohol in the insulation interior through vulcanized pipelines. If the degassing is not sufficient, it is likely to cause gas exhaust at the terminal during the operation, and even produce gas free discharge, which may lead to cable breakdown. Moreover, excessive gas residue will also lead to negative effects such as sheath deformation, which will have a great influence on the electrical performance and long-term stability of the submarine cable [6-7].
According to the above project, a new "degassing" process is adopted in this paper. We have done the research on XLPE insulation extrusion and degassing technology of long-length EHV AC cable and degassing process to provide reference and guiding significance for the future research on XLPE insulation extrusion and degassing technology of long-length EHV AC cable.

1 Basic parameters of 500 kV XLPE insulated AC submarine cable

The single-core 500 kV XLPE insulation, lead sheath, insulated PE sheath, round copper wire armored AC submarine cable used in Zhoushan 500 kV network power transmission and transformation project. The product model is HYJQ71-F 290/500 1×1800+24B1. The schematic structure diagram is shown inFig.1 and the electric power system parameters are shown in Tab.1.

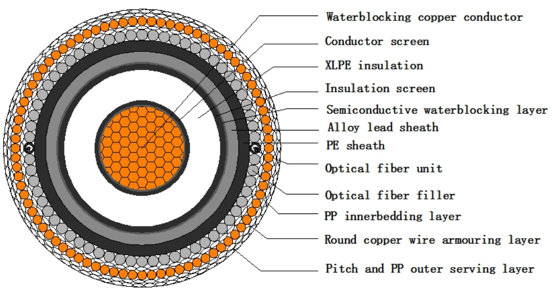


Fig.1 500 kV XLPE insulated submarine cable

Tab.1 Main parameters of submarine cable

Item	Parameter
Nominal voltage of system	500kV
Maximum operating voltage	550kV
System frequency	50Hz
System grounding	Neutral point solidly grounded
Maximum rated operation current	1411A
Single- phase short-circuit current (kA)	55.5
Duration of single-phase short circuit	1s
Copper conductor cross section area	1800mm^2
Nominal thickness of insulation	31.0mm

2 Research on extrusion of XLPE insulation

2.1 Key process control

(1) Adopting an extrusion production line with a large amount of insulation extrusion (φ200 extruder is used for main insulation) and comparing the melting temperature, screw speed and extrusion quantity at different temperatures. Finally the optimum extrusion temperature is obtained. The screw speed is reasonably controlled within 20 rpm/min, and the screw cooling water temperature is within 96~98 to reduce the insulation extrusion temperature to make sure that the extrusion temperature of insulating material is reduced. The melting temperature of material is controlled within 135℃, and the melting temperature of shielding material is within 125℃.

(2) Reasonable design the diameter of the die sleeve to make the diameter of the sizing area of the die sleeve is equal to the thermal outer diameter of the cable, which can not only greatly reduce the risk of the accumulation of outer shielding material at the mold mouth, but also can reduce the extrusion pressure.
(3) Using Nordic Chemical LS4201 EHV ultra-clean and ultra-high voltage anti-scorching insulation material, the appropriate insulation filter and the best temperature design to ensure that no pressure change of 10 km cable in the first production and 18 km cable in the second production.
(4) Special TROESTER Cure Calculation (TCC) software: optimize the production line speed of the crosslinking calculation software and conductor pre and post preheating temperature to avoid the abnormal quality of cross-linking, insulation or shielding caused by higher or lower temperature, production speed and cooling, and control the surface temperature of the cable not to exceed 270°C.
Fig.2 shows the relationship between the material pressure and the continuous running time. It can be seen that conductor shielding, insulation shielding pressure and XLPE insulation extrusion pressure hardly increase with the increase of time; Fig.3 shows the relationship between melting temperature and continuous running time. With the increase of production time, the melting temperature of insulating material and shielding material does not increase significantly. The two figures reflect the excellent performance of 500 kV ultra-smooth shielding material and ultra-clean insulation material, indicating the consistency of our process control and the stability of equipment.
After production, the filter screen and the XLPE insulation material adhered to the filter screen were put into silicon oil for high-temperature oil bath test, and no visible burning phenomenon occurred in the insulation material. Moreover, no impurity micro-holes and protrusions were detected in the insulation slice of tail cable after production, and the interface between insulation and shielding was smooth without any protrusions.
In conclusion, the process method is suitable for the continuous production of large length EHV cable. As for the new type of high voltage insulation material suitable for continuous extrusion of large length and long time, the author is paying attention to its application in degassing and engineering.

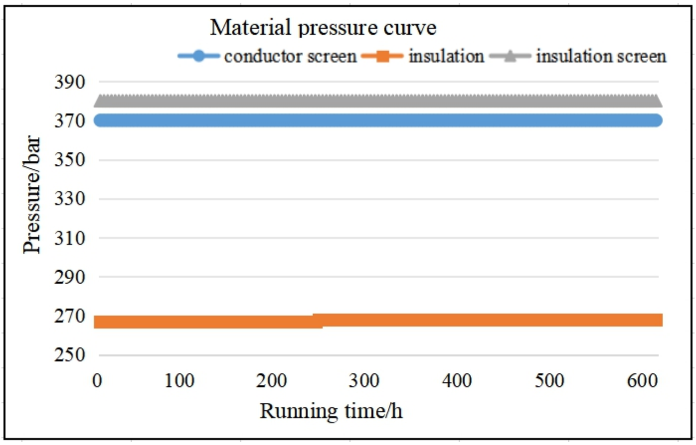


Fig.2 relation curve between the sizing material pressure and the continuous running time

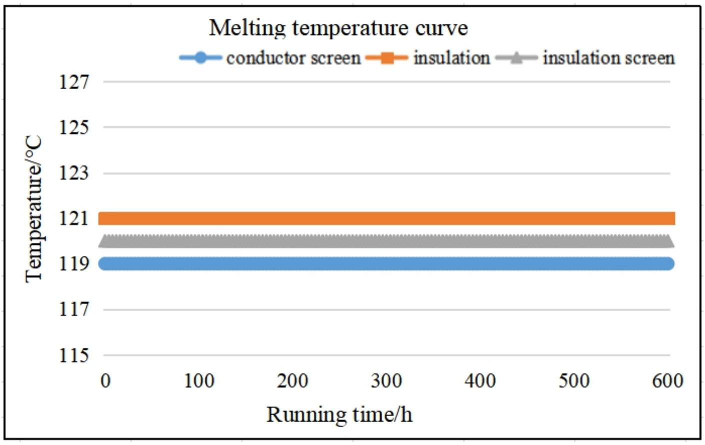


Fig.3 relation curve between melting temperature and continuous running time

3 Improvement of degassing process for crosslinking wire cores

3.1 Improvement of degassing process

Based on the heat release of cross-linking by-products, some experimental studies have been conducted by related scholars[8-9]. Traditional degassing of XLPE insulation wire core generally uses electric heating which heats the air to the target temperature, then fans the hot air into the degassing chamber [10-11]. The disadvantage of this degassing method is that when insulation is thick and many layers of cores are stacked, heat transfer is slow and local temperature is too high, which leads to low degassing effect. Due to the large insulation thickness (31.0 mm) and long length (more than 10 km) of the 500 kV cable, the above method no longer meet requirements. In order to solve this problem, a new type of "heat convection" turntable degassing device is designed as shown in Fig.4. The system is a fully enclosed structure, of which the outer cylinder, cover plate and bottom plate are covered with thermal insulation material. The upper, middle and lower temperature multi-point control and high temperature alarm system are also adopted in this device. At the bottom of this system, some special air passages are set up. Heating equipment and outer air passages are also installed to conduct hot-air circulation between upper and lower cable cores in order to form convective permeation. Besides, layered cushions are used to increase gaps between each cable layer, which helps to fastly and evenly transfer heat to the cable surface. Finally, it will accelerate volatilization and discharge of insulation by-products. The temperature of the upper, middle and lower parts of the whole cable core is even, with the deviation less than 1 as shown in Fig.5.

In practical application, taking the 220 kV 500 mm^2 (thickness of insulation is 27 mm)25 km cross-linked core as an example, the traditional degassing time is about 60 days. After improving the degassing process, the degassing time is reduced to 30 days under the condition of constant degassing temperature, and the degassing efficiency can be increased by about 50%.

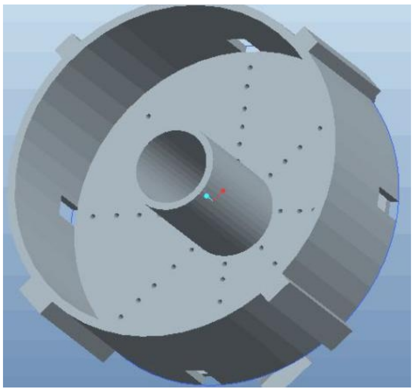


Fig.4 Thermal convection degassing system

Fig.5 Insulation core temperature monitoring values during degassing process

It can be seen from Fig.5 that in the degassing process of 500 kV submarine cable core, the overall heating temperature range in the turntable is 68.00~70.00°C (341.15 K~343.15 K), which is not much different from the set heating temperature of the air inlet, and the temperature difference between the cable cores is small. Through the subsequent degassing effect, it is verified that the "heat convection" type turntable can keep the temperature of the insulated cable core and heat evenly between the cable cores. Air can pass through the gap between the cable cores and take away the gas by-products inside the insulated cable cores under constant pressure, ensuring the stability of degassing effect.

4 Validation study on degassing effect of large length cross-linked wire core

4.1 Thermogravimetric analysis tests（TGA）

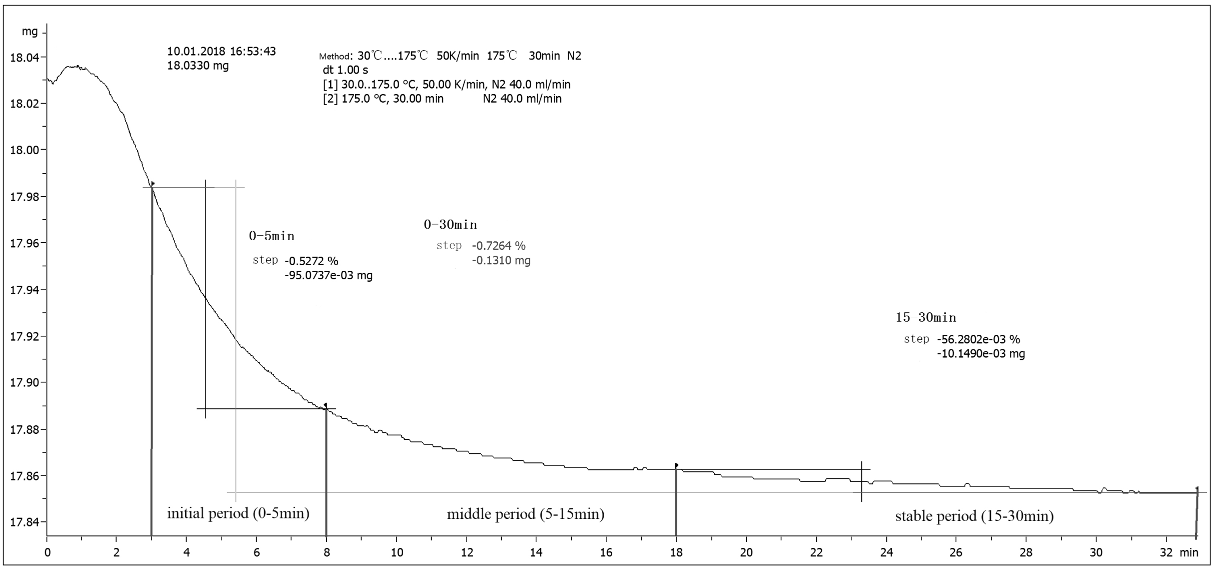
In order to verify the reliability of the effect of the above new degassing method, this paper adopts the TGA test to study the degassing effect of 500kV XLPE insulated core. The test method refers to the standard GB/T 2951.32-2008[12], GB/T 27761-2011[13]. Five sample slices are taken from inside to outside along radial direction of insulation layer, and the average test value is taken as final evaluation basis. Each sample is a cubic structure with the weight of (20±5) mg. At the beginning of the test, the TGAequipment was stabilized at 30℃, and heated up at a heating rate of 50 /min, and then maintained for 30 min under (175±3)℃. During the test, the weight loss rate and change rate for each sample recorded during test.

4.2 Test results analysis

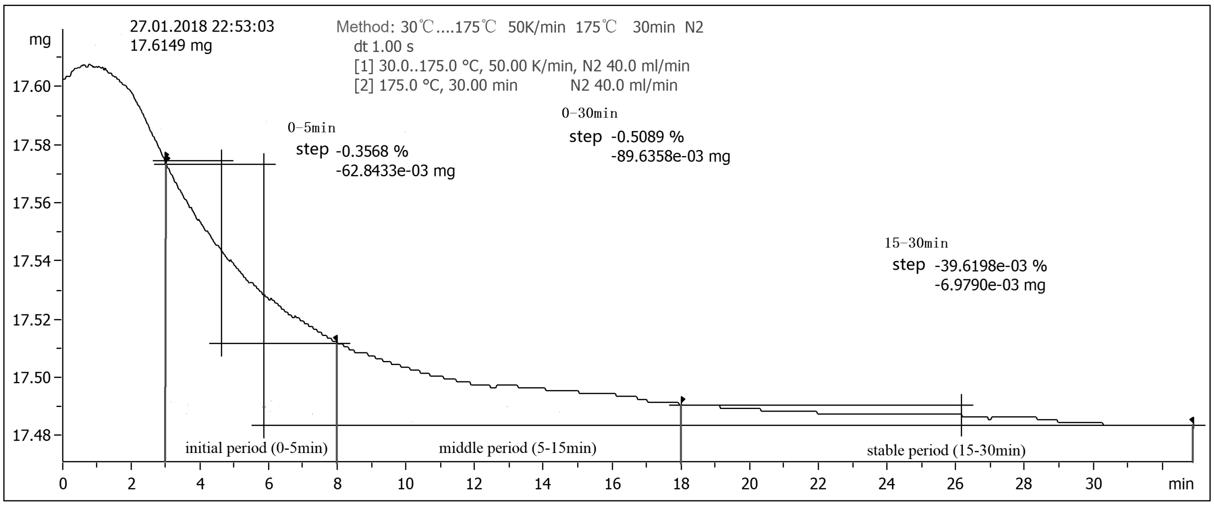
At present, there is no clear determination standard for XLPE insulation degassing effect, but according to the test standard proposed by experts, it can be considered that the detection of insulation cross-linking by-products has passed if the following three conditions are met, that is, the discharge of by-products meets the following requirements.
1) 0-5 min: Weight loss change rate is less than 0.18 per/min.
2) 15-30 min: Weight loss change rate is less than 0.015 per/min.
3) 0-30 min: Total weight loss rate is less than 1.6 percent.
Two different length insulated cores were tested and studied respectively. Tab.2 shows the thermal weightlessness test results of two insulating wires with different degassing time. It can be seen from the table that, with the increase of degassing time, the total thermal weightlessness percentage of insulating wires decreases gradually. Meanwhile, by comparing the results of the two cables after 40 days of degassing, the thermal weightlessness change rates of the two cross-linked wires were 0.077% and 0.067% respectively at the temperature of 175℃, and the thermal weightlessness change rates of the last 15 minutes were 0.00098% and 0.00144% respectively. The final weight loss percentage was 0.49% and 0.48% respectively. The results were similar and all met the requirements of the above indicators.

Tab.2 Thermal weightlessness test results of two crosslinked wire cores

Cable section	Degassing time (days)	Total weight loss rate (%)			Average weight loss change rate (%/min)	
		0~5min	15~30min	0~30min	0~5min	15~30min
Test standard	/	/	/	< 1.6	< 0.18	< 0.015
Cable 1 (9.7km)	40	0.384	0.0146	0.49	0.077	0.00098
	60	0.249	0.0227	0.35	0.050	0.00151
Cable 2 (8.6km)	20	0.350	0.0365	0.51	0.070	0.00244
	40	0.334	0.0217	0.48	0.067	0.00144
	60	0.322	0.0206	0.39	0.054	0.00371



1) Cable 1



2) Cable 2

Fig.6 TGA test curve(40 days)

As can be seen from the fig.6, the variation trend of thermal weightlessness curves of the two cables is relatively close, and the curve variation process can be divided into the initial period (0-5 min), middle segment (5-10 min), and stable segment (15-30 min) under the heating condition of 175°C. The weight loss is relatively large in the initial stage, then decreases gradually in the middle stage, and tends to be stable finally in the stable stage. The above results indicate that the degassing effect of submarine cables with similar length is similar, and the degassing has been basically completed after 40 days.

For the second cable core, the degassing effect of the same insulating wire core at different positions of the insulation layer was studied. Fig.7 and Fig.8 respectively show the curves of thermal weightless change rates at different positions of the insulation layer with the change of degassing time.

According to Fig.7, the thermal weightless rate of each layer decreases with the increase of degassing time under the heating condition of 0-5min. The curve tends to be linear and inversely proportional, and gas emission of the insulating layer decreases significantly. According to the data in Tab.2, after 60 days of degassing, the average thermal weightless change rate of 0-5 min decreases to 0.054%/min, which is far less than the detection standard requirement of 0.18%/min. In the same degassing stage, the thermal weightless change rate gradually increases with the increase of insulation depth, indicating that the degassing effect of outer layer is better than that of inner layer, which is consistent with the actual cognition.

Fig.8 shows that under the heating condition of 15-30 min, the thermal weightless rate of each layer of the sample generally decreases with the degassing time. After 40 days, the average thermal weightless rate is only 0.00144%/min, far less than the standard requirement of 0.015%. It can be considered that at this stage, the output of by-products such as gases inside the insulation is very small, and the sample is in the degassing equilibrium state.

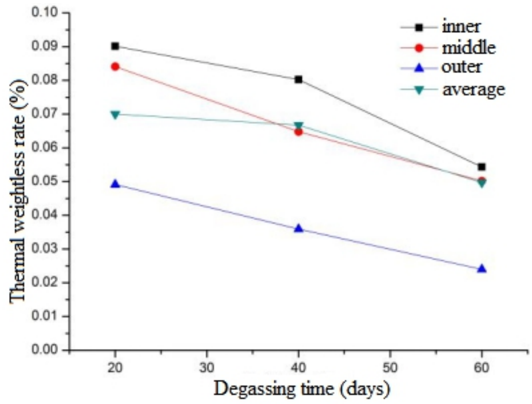


Fig.7 0-5min thermal weightlessness change rate and degassing time curve

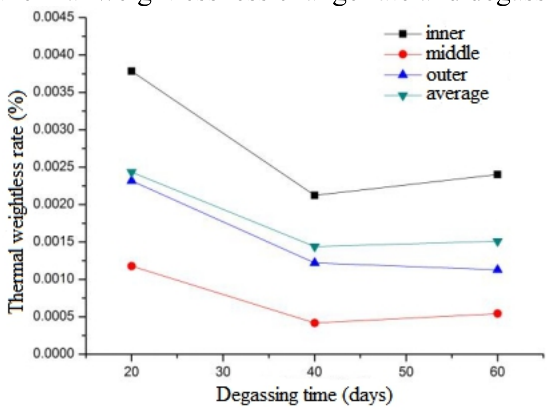


Fig.8 15-30min thermal weightlessness change rate and degassing time curve

By comparing Fig.7 and Fig.8, it can also be found that the change rate of thermal weightlessness in the first 5 minutes was much higher than that in the last 15 minutes, so the test results in the first 5 minutes of thermal weightlessness analysis have certain reference significance. Fig.9 shows the total thermal weightlessness loss percentage within 0-30 minutes, and the curve trend is the same as that in Fig.7. After 40 days, the average thermal weightlessness loss percentage is 0.48%, which meets the by-product discharge standard. Combined with the above results, TGA test method has certain reference value for verifying the degassing effect of 500 kV large-length XLPE insulated wire core.

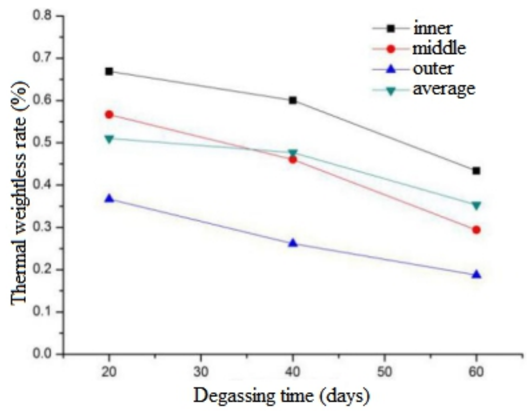


Fig.9 Total thermal weightlessness percentage and degassing time curve

5. Conclusion

Based on 500 kV XLPE AC submarine cable project in Zhoushan, China, this paper adopts a new "thermal convection" degassing method to improve degassing effect of EHV large-length XLPE insulated cable. Combined with simulation analysis and test results, the following conclusions can be drawn:
1) Through process verification, the serial insulation cleanliness and extrusion process control method of large-length EHV XLPE insulated wire core have been formed, which has accumulated experience for the design and manufacture of future large-length EHV submarine cable.
2) Through the TGA test and the calculation results of degassing model, the degassing time of 10km submarine cable has been determined, which verifies the reliability of TGA test.
Large length and large capacity EHV submarine cables will become the development trends of ocean power transmission in the future. It is expected that the research can provide some experience for the manufacturing technology of large length submarine cables.

BIBLIOGRAPHY

[1] ZHAO You-lin, ZHANG Jian-min, MA Zhi-jin, et al. *Design and Manufacturing of 220 kV Three-Core Submarine Fiber Optic Composite Power Cable for Xiangshui Offshore Windfarm* [J]. Electric Wire & Cable, 2016(5): 19-21.
[2] XU Qifa, SHI Chunjing, YE Lihua. *EHV XLPE Insulated Cable By-Products Analysis* [C]. Ninth National Power Cable Operation Experience Exchange Conference, 2012.
[3] LI Zhiwei, JIN Haiyun, ZHANG Tao, et al. *Effect of Degassing Time on Aggregation Structure and Chain Structure of XLPE Cable Insulation Material* [J]. Journal of Xi'an Jiaotong University, 2018, 52(4): 15-23.
[4] Ouyang Benhong, Zhao Jiankang, Li Huan. *Influence of Crosslinking By-products on Dielectric and Mechanical Properties of XLPE Cable Insulation* [J]. Insulation Material, 2015(5):31-34.
[5] WANG Weidong, DUAN Guoquan. *Principle and Application of Cable Technology* [M], Machinery Industry Press, 2016.
[6] WANG Zhisheng, YANG Kaijun, XIE Weibin. *Analysis of Degassing Process on Medium and High Voltage XLPE Power Cables* [J]. Chemical Industry Management, 2013(10): 232-233.
[7] PENG Siyuan. *Effects of the Antioxidant and Degassing in Melt Condition on the Space Charge and Conductivity of LDPE* [D]. Harbin University of Science and Technology, 2014.
[8] REN Hongguang, WU Yongjian. *Research of High Voltage XLPE Cable's Byproducts Release by Thermal Weightlessness Method* [J]. Machinery, 2017, 44(3): 10-13.
[9] Andrews T, Hampton R N, Smedberg A, et al. *The Role of Degassing in XLPE Power Cable Manufacture* [J]. IEEE Electrical Insulation Magazine, 2006, 22(6): 5-16.
[10] MAO Aimin, XU Yumin, ZHANG Jin. *Study on Degassing Time of EHV Cross-linked Cable Insulation*[J]. Proceedings of 2009 Annual Conference of Electric Wire and Cable Special committee of China Electrotechnial Society. Jiamusi.
[11] Wang Zhihui. *Constant Temperature and Energy Saving System for Heat Pump Degassing Chamber Applied to Cross-Linked Cable* [J]. Automation & Information Engineering, 2017, 38(3): 6-11.
[12] GB/T 2951.32-2008 *General test method of insulation and sheath materials for cables and optical cables Part 32: Special Test Method for Polyvinyl Chloride Mixtures: Weightless Test, Thermal Stability Test*[S].
[13]GB/T 27761-2011 *Test Method for Weightlessness and Residual of TGA*[S].