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Preparation and Modification of Flexible Polyurethane Foam for Effective Flame Resistance and Sound Absorption

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***Abstract**: Polyurethane foam as an important sound absorption material is limited by the poor flame resistances in building field, but the modifications of flame resistances tend to have adverse effects on the sound absorption performance. Herein, dibutyltin dilaurate and triethylenediamine are used simultaneously as catalysts, and four new types of flame retardant polyether polyols (FPMPO) are synthesized and combined with modified expanded graphite (PEG) to prepare the flame resistance flexible polyurethane foam (FFPUF) by one-step method. The results show that the combination of the two catalysts can control the cell structure of FFPUF availably for sound absorption. The FPMPO have little negative influence on the cell morphology and the sound absorption performance of FFPUF, but the increase of flame resistances is finite due to the limited amount of FPMPO. In order to improve the flame retardant properties further, the FPMPO and the PEG are combined in the modification. Benefitting by the effective control structure and the modification with composite flame retardant, the FFPUF shows excellent sound absorption and flame retardant properties. The LOI value of FFPUF is 33.4 and the vertical burning level reaches V-0, and the average sound absorption coefficient maintains 0.68 in the 800-6300 Hz range.*

***Keywords:** Flexible polyurethane foam, Catalysts, Flame retardant polyether polyols, Composite flame retardants, Sound absorption*

1.Introduction

Noise pollution problem, as a major pollution problem in the world, affects our daily lives all the time and causes a series of detriments to human health [1, 2]. Reducing the noise from the source is a good way to solve the noise pollution problem, but it is difficult to realize in many conditions. Therefore, using sound absorption materials to absorb sound waves in the process of sound transmission is considered an efficient method. There are many kinds of sound absorption materials such as resonant materials, porous materials, special structure materials and so on [3-5]. Due to the low density, the porous materials were used alone or combined with other materials to prepare sound absorption materials in many researches [6]. Because of the high volume of open-cell structure, polyurethane foam has good sound absorption performance and it is paid many attentions [7-9]. The sound waves could enter into the polyurethane foam through the open-cell structure more easily, after travelling to the surface of polyurethane foam. The sound transmission inside polyurethane foam could cause the vibration of air and polyurethane itself, and then the sound energy could be consumed by transforming to heat energy in virtue of the friction and the viscous resistance.

At present, there are three main ways to prepare polyurethane foam. The prepolymer method is usually used to prepare the polyurethane, but the prepolymer produced by this method has a large viscosity which makes it difficult to operate during the foaming process [10]. The quasi-prepolymer method could adjust the viscosity of the material and the strength of the foam gel more effectively [11]. This method is mostly used to make semi-rigid polyurethane foam, but rarely used the preparation of flexible polyurethane foam which has better sound absorption performance. One-step method is an appropriate manufacturing process of flexible polyurethane foam, and this method has many advantages

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such as simple technology, less investment in equipment and easy operation.

In order to prepare the polyurethane foam with excellent sound absorption performance, the control of the cell structure is most important and scholars have made a variety of related attempts. Choe [12] used chemically treated wood fibers to increase the open cell ratio of polyurethane foam, which allowed the acoustic wave to experience various collisions through the open porous flow path. Sung [13] chose magnesium hydroxide as filler to improve the acoustic property, because the filler enhanced damping motion and increased the proportion of partially open-cell. Gwon [14] studied the effect of catalyst ratio between triethylenediamine and 2-dimethylaminoethyl on the distribution of cavity size, and obtained the best ratio to improve the acoustic property of polyurethane foam. Jiang [15, 16] used two kinds of polyurethane foams with different cell diameters to prepare nitrile butadiene rubber-polyurethane foam composites with alternating multilayered structures, and the acoustic property at low frequency improved significantly. However, few studies were conducted on the use of both tin and amine catalysts to control the cell structure of polyurethane foam.

Although polyurethane foam shows great sound absorption performance, it encounters difficulty in application process of building field, transportation field and so on. Polyurethane foam is highly flammable due to its porosity, and furthermore the combustion of polyurethane foam will produce large quantities of toxic and harmful gases such as hydrogen cyanide and carbon monoxide [17-20]. Various modification methods of polyurethane foams have been studied to improve the flame retardant performances [21]. Chan [22] studied the synergistic effect between expandable graphite and a phosphorus-based flame retardant. The combination of the two flame retardants showed excellent flame retardant performance, so it was expected to enhance the flame resistance of polyurethane foam. Rao [23] synthesized a novel polyester polyol through transesterification, and then prepared inherent flame resistance flexible polyurethane foams which may retain other properties substantially. Carosio [24] prepared a nanoscale coating which could greatly improve the flame retardant performance of polyurethane foam. Chen [25] reported a kind of aerogel which showed strong interactions with the polyurethane foam matrix, and the aerogel was injected into the porous structure of polyurethane foam by the freeze-drying to improve the flame retardant performance. Maddalena [26] synthesized flame resistance polyurethane foam with multilayer structure which contained graphene oxide platelets capable and chitosan using layer-by-layer technique. Actually, the method of adding flame retardant to modify polyurethane foam is more common. However, the plenty of additive flame retardant cannot be uniformly dispersed in the polyurethane foam, resulting in an unbalanced resistance to the gas in all directions during the formation of cells and structural damage [27]. Therefore, the uniformity of the cell size is deteriorated and the semi-open cells decrease, which reduces the sound absorption performance of the material.

In this paper, dibutyltin dilaurate (DBTDL) and triethylenediamine (DABCO) was used simultaneously to prepare the flexible polyurethane foam (FPUF) and control its cell structure by one-step method. And then four new types of flame retardant polyether polyols were synthesized and were used as flame retardants monomer to prepare the flame resistance flexible polyurethane foam (FFPUF) with the adding of expanded graphite (PEG) as additive flame retardant. Benefitting by the structure control and flame retardant modification, the FFPUF with excellent sound absorption and flame retardant properties is obtained.

2. Materials and methods

2.1. Materials

Polyether polyol 360 (OH-value: 25-31 mg KOH/g) was provided by Jining Baichuan Chemical Co., Ltd. modified isocyanate (MDI, polyaryl polymethylene isocyanate) was supplied by Wanhua Chemical Group Co., Ltd. Phenyl phosphate dichloride was provided by Guangdong Wengjiang Chemical Reagent Co., Ltd. Diethanolamine, N-methyldiethanolamine, and N-butyldiethanolamine were all provided by Sinopharm Chemical Reagent Co., Ltd. N,N-Dihydroxyethyl-p-toluidine was provided by Guangdong Wengjiang Chemical Reagent Co., Ltd. Phosphorus oxychloride ($POCl_3$), 1,4-Dioxane and triethylamine were purchased from Sinopharm Chemical Reagent Co., Ltd. Dibutyltin dilaurate (DBTDL) and triethylenediamine (DABCO) were purchased from Jining Hongming Chemical factory. Expanded graphite (EG, 150 mesh, expansion rate of 200 mL/g) was provided by Qingdao Herita factory. Dimethicone was provided by Sinopharm Chemical Reagent Co., Ltd.

2.2. Synthesis of the flame retardant polyether polyols

Four types of alcohols (diethanolamine, N-methyldiethanolamine, N-butyldiethanolamine, N, N-dihydroxyethyl-p-toluidine) and triethylamine with a molar ratio of 6:1 were placed in 1, 4-dioxane, respectively, and the mixture was stirred at 25°C. The mixture was added dropwise in 1, 4-dioxane with stirring at 25°C after phenyl phosphate dichloride (molar ratio to alcoholamine is 1:0.8) was dissolved in 1, 4-dioxane. And then the mixture was heated to 58°C under nitrogen protection and reacted for 6 h. After the product was distilled under reduced pressure to remove the organic solvent, the flame retardant polyether polyols were obtained. And the four types of flame retardant polyether polyols were referred to as FPMPO-1, FPMPO-2, FPMPO-3, and FPMPO-4, respectively (Figure 1).

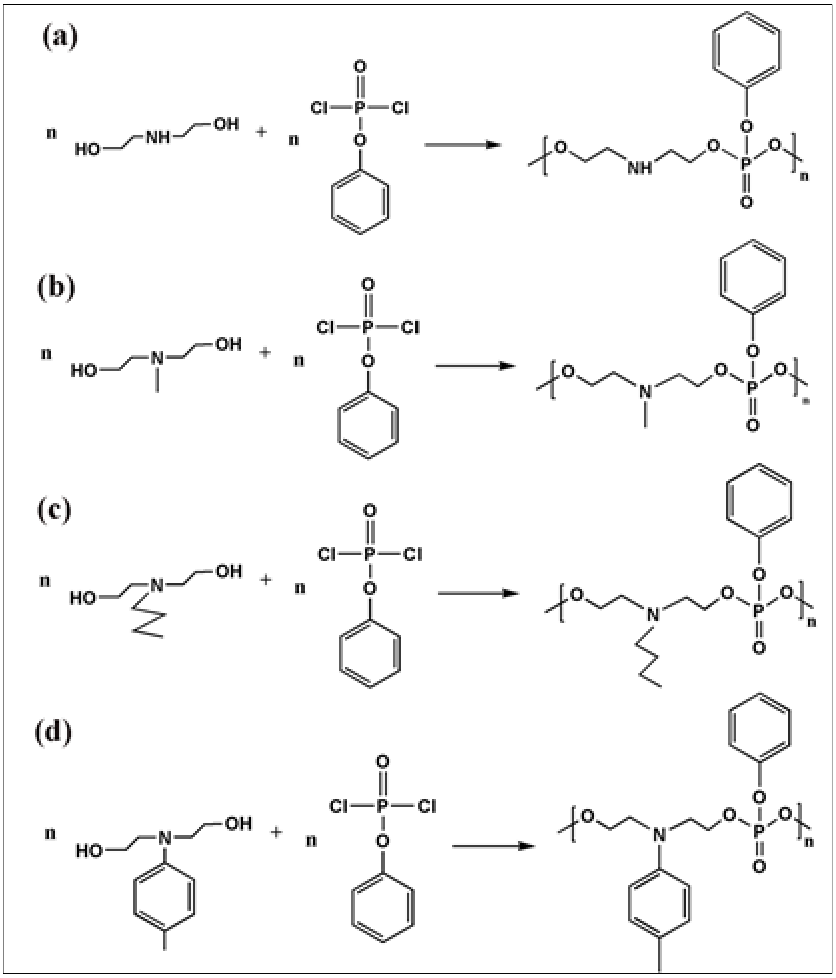

Figure 1. Synthesis of Polyether Polyol: (a) FPMPO-1; (b) FPMPO-3; (c) FPMPO-3; (d) FPMPO-4

2.3 Preparation of FPUF and FFPUF

Polyether polyol 360 with the flame retardant polyether polyols in certain proportions, catalysts (DABCO and DBTDL, various contents), surfactant (silicone oil, 2 phr), and blowing agent (deionized water, 3 phr) were mixed in a 250 mL beaker with mechanical stirring for 10 min. Next, 51.6 phr MDI was added and then the mixture was subsequently decanted into two open tetrafluoroethylene mold (Φ100×20 mm^3 and Φ30×20 mm^3) to realize free-rise foaming. After a treatment in an oven at 50^{o}C for 4 h, the flexible polyurethane foam was obtained.

The preparation method of flame resistance flexible polyurethane foam is same as that of FPUF basically, except that Polyether polyol 360 with the flame retardant polyether polyols in certain proportions was used as the monomer and the flame-retardant modified expanded graphite (PEG) was added before the foaming process. And the PEG was prepared by the method that 6 mL $POCl_3$, 10 g EG and 150 mL 1, 4-dioxane were mixed in a 250 mL three-neck round-bottom flask with distillation apparatus and then were stirred at 60°C for 5 h.

2.4. Characterization

The Fourier transform infrared (FTIR) spectra and the ^1H nuclear magnetic resonance (^1H NMR) spectra of the prepared flame retardant polyether polyols were recorded on the Nicolet 6700 FTIR Spectroscopy (Therma Electron) and the Agilent 400 MR NMR Spectrometer (Agilent Technologies), respectively. The average diameters of interconnection cells were calculated using Image Pro Plus software (Media Cybernetics Inc.). The morphology of the FPUF was investigated with a scanning elevtron microscope (SEM, SU 3500, Hitachi Limited, Japan). The sound absorption property of the composites was examined using the impedance tube devices (BSWA SW 477 and 422, BSWA Technology Co.), and the thickness of the samples was 20 mm thick. The flame resistances were characterized by JF-3 Limiting oxygen index (LOI) apparatus (Beijing Zhonghang Times Instrument Equipment Co. Ltd) and CZF-5 vertical burning instrument. The LOI testing and the vertical burning test were performed according to ASTM D 2863-97 and ASTM D 3801-96, respectively. And the sizes of their samples were $100\times10\times10$ mm^3 and $127\times13\times3$ mm^3, respectively.

3. Results and discussions

3.1. Effects of the catalysts on the FPUF

The sound absorption property of polyurethane foams is great influenced by the cell characteristics. The cell sizes, size distributions and uniformity of cells determine the sound absorption property of polyurethane foams. Therefore, the analysis of the cell characteristics has been considered as the key to improve the sound absorption performance of polyurethane foams. Notably, the catalytic activity of each catalyst and the cooperation between the two catalysts would affect the cell characteristics significantly. As catalysts, DABCO and DBTDL showed different catalytic activity for the urethane formation reaction and urea formation (Table 1).

Table 1. Catalytic activity of DABCO and DBTDL

Catalyst/activity	**urethane formation ($L^2/(g\cdot mol\cdot h)$)**	**urea formation ($L^2/(g\cdot mol\cdot h)$)**
DABCO	109	14.5
DBTDL	144	4.8

Figure 2a-d showed the cell distributions of the foams in different contents of DBTDL at 0.3 phr of DABCO. The cell size of the FPUF at 0.2 phr DBTDL was concentrated in the range of 0.2-0.4 mm (Figure 2a). With the increase of the content of DBTDL, the cell size increased gradually, because DBDTL had high catalytic effect on the gelling reaction between polyether polyol and modified isocyanate. The increase of the gelling reaction rate would keep the gas produced in blowing reaction from escaping, and more gas could be used to form the cells. With the continuous increase of the content of DBTDL, the gelling reaction is much more reactive and most of the small cells had already cured before coalescence, which led to the increase number of small cells. Furthermore, the cells squeezed each other violently, which led to the break of cells and the uneven cell size. In summary, the cell structure of FPUF had suitable size and uniform distribution when the DBTDL content was 0.3 phr.

The sound absorption efficiencies of FPUF with various contents of DBTDL were shown in Figure 2b. All of the samples, except the FPUF with 0.2 phr of DBTDL, had two absorption peaks around 1100 and 4700 Hz which were over 0.75, and their average sound absorption efficiency exceeded 0.61. When the DBTDL content was 0.3 phr, the FPUF showed great sound absorption efficiency and its absorption peak at 1100Hz reached 0.95. However, the sound absorption efficiency decreased with the continued increase of the DBTDL content. It could be concluded that the increase of sound absorption property relied on the increase of the cell size and the cell uniformity.

The FPUF with great cell structure was got at 0.3 phr of DBTDL and 0.3 phr of DABCO in synthetic process, but it's not sure whether the gelling reaction and blowing reaction had reached the optimal balance. Therefore, the cell distributions of the foams in different contents of DABCO at 0.3 phr of DBTDL were observed (Figure 2c). When the content of DABCO was 0.2 phr, the size of cells concentrated in the range of 0.1-0.5 mm. And the gelling reaction was more intense than blowing reaction, so most of small cells had cured before growing up. With the increase of the content of DABCO, the blowing reaction became intense and the formation rate of cells increased. Hence, the small cells squeezed each other and some of the small cells coalesced together, which led to the increase of the cell size. When the content of DABCO was 0.3 phr, the size of cell distributed widely, which might mean the blowing reaction and gelling reaction still had not reached balance. When the content of DABCO increased farther, the cell size showed good uniformity but decreased, due to the too intense squeeze which led to the fracture of cells. Considering synthetically the cell size and the cell uniformity, the blowing reaction and the gelling reaction reached relative balance when the DABCO content was 0.4 phr.

The sound absorption efficiencies of FPUF with various contents of DBTDL were shown in Figure 2d. All of the samples, except the FPUF with 0.2 phr of DBTDL, had two absorption peaks around 1100 and 4700 Hz which were over 0.75, and their average sound absorption efficiency exceeded 0.61. When the DBTDL content was 0.3 phr, the FPUF showed great sound absorption efficiency and its absorption peak at 1100Hz reached 0.95. However, the sound absorption efficiency decreased with the continued increase of the DBTDL content. It could be concluded that the increase of sound absorption property relied on the increase of the cell size and the cell uniformity.

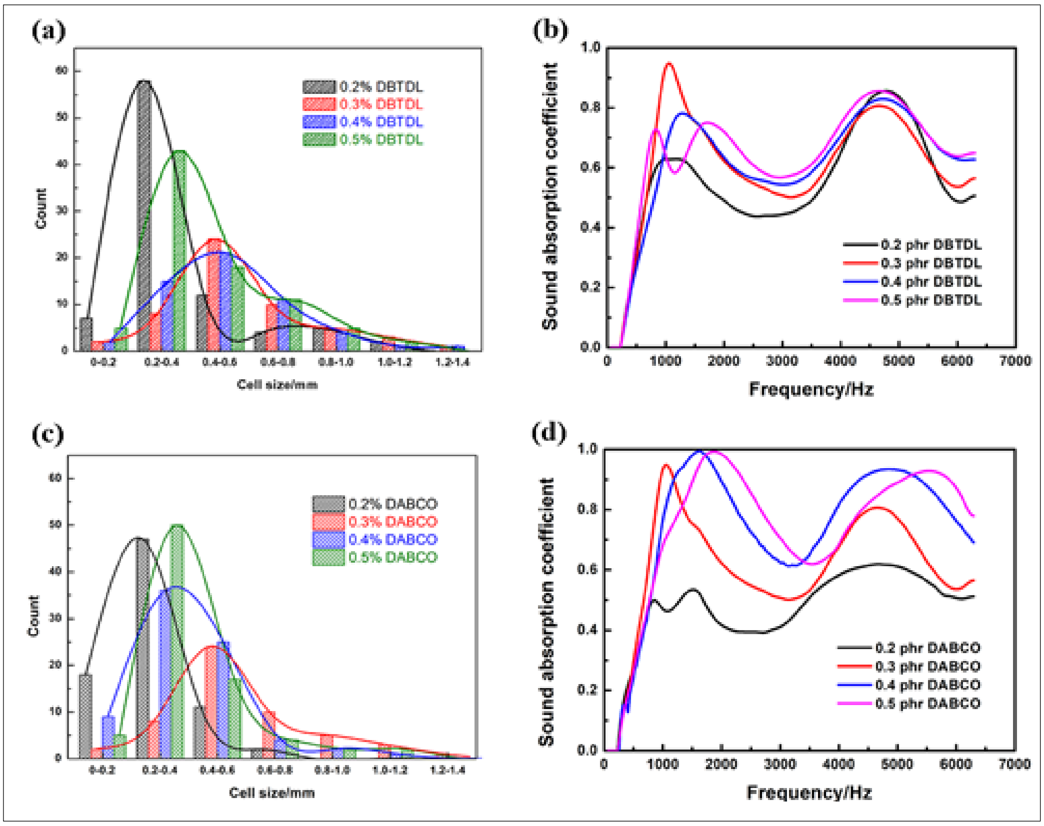

Figure 2. Cell distributions (a) and Sound absorption efficiencies; (b) of FPUF with various contents of DBTDL. Cell distributions (c) and Sound absorption efficiencies; (d) of FPUF with various contents of DABCO

3.2. FFPUF with flame retardant polyether polyols

The infrared spectra of the prepared flame retardant polyether polyols were shown in Figure 3. The four low molecular weight alcohols were all dihydric alcohols with similar structures, and then the nitrogen atoms were connected by hydrogen bonds, methyl groups, butyl groups and aromatic heterocycles, respectively. The absorption peak of the monomer appeared at 3390 cm^{-1}, which was attributed to the stretching vibration of OH. The band observed at 2966 cm^{-1} was assigned to the H vibration of the benzene ring in the monomer. The peak at 1278cm^{-1} was attributed to the stretching vibration of C-N. The characteristic peak at 1211 cm^{-1} was assigned to the vibration of the P-O bond. The absorption peaks at 1076 and 959 cm^{-1} were corresponded to the vibrations of P-O-C and P-O-ph, respectively. These results indicated that the designed flame retardant polyether polyols were successfully synthesized.

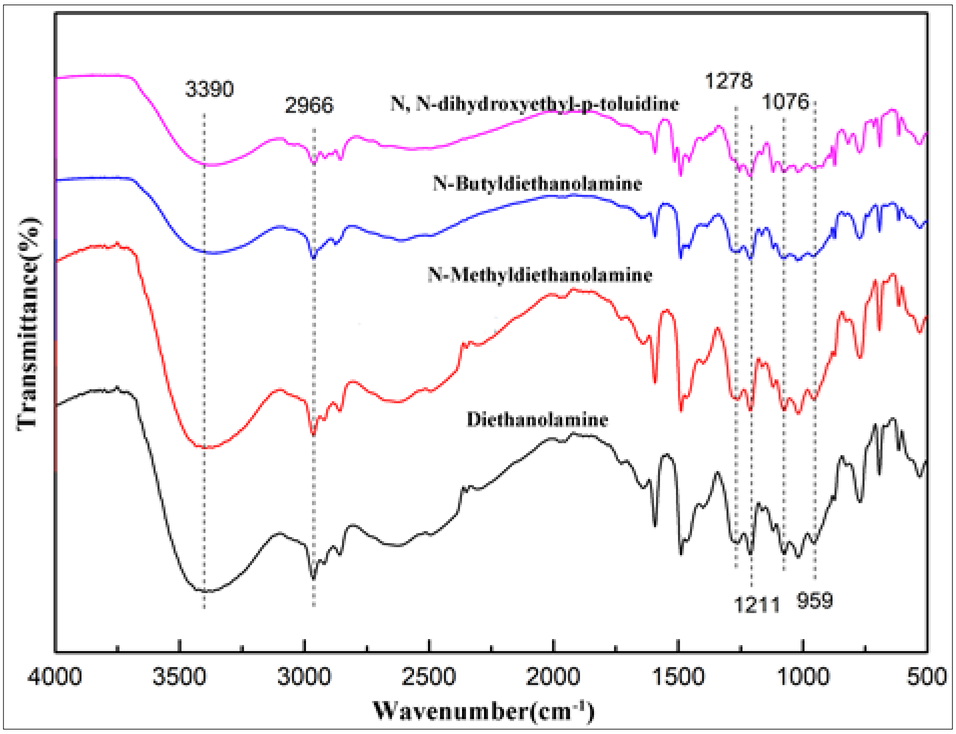

Figure 3. FTIR spectra of flame retardant polyether polyols prepared from four types of alcohols

The hydrogen NMR spectra of the prepared four flame-retardant polyether polyols could be observed in Figure 4a-d. In Figure 4a, 4.22, 3.64 and 4.35 were corresponded to the chemical shifts of the methylene groups at a, c, and e on the monomer, respectively. Since the chemical shift activity of the hydrogen on the N-H bond at b was high and susceptible to various factors, it was difficult to observe. Besides, the chemical shift of the hydrogen on the benzene ring at d at 7.34 in the hydrogen spectrum. 3.90 was corresponded to the chemical shift of the hydrogen on the hydroxyl group at f on the monomer. Meanwhile, the chemical shift at 2.48 was assigned to the hydrogen in the deuterated reagent DMSO-d6. The chemical shifts of panels b, c and d were basically the same as those of panel a, but the chemical shift of the methyl group attached to the N element was observed at 2.22. Therefore, ^{1}HNMR spectra further implied that the designed flame retardant polyether polyols were successfully synthesized.

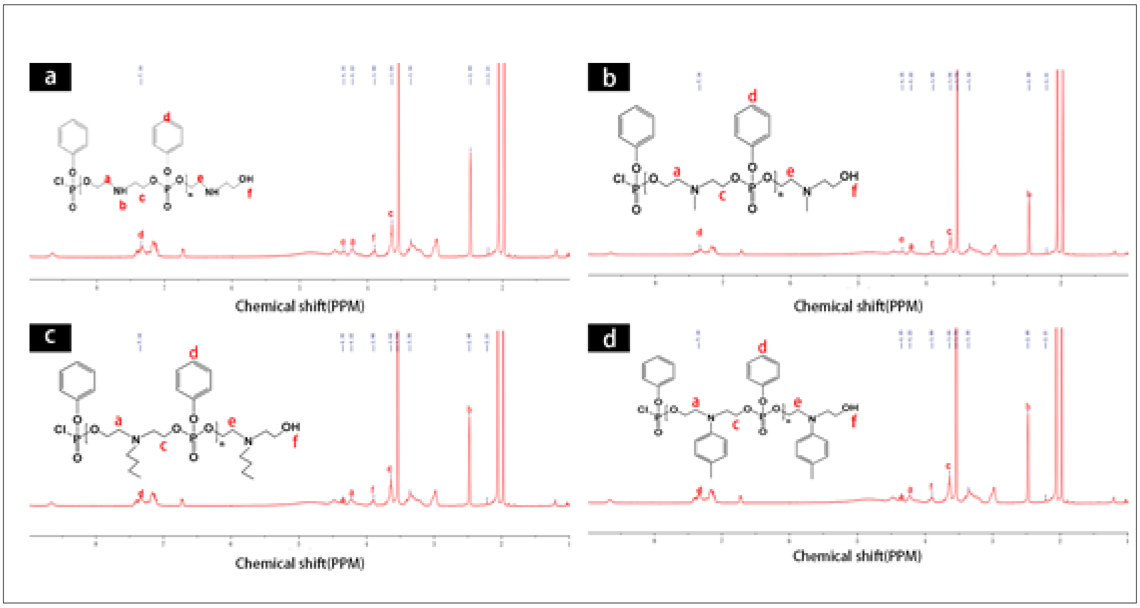

Figure 4. ^{1}H NMR spectra of four types of polyether polyol: (a) FPMPO-1, (b) FPMPO-2, (c) FPMPO-3, (d) FPMPO-4

The effects of different flame retardant polyether polyols on the foam morphologies and the cell distributions of FFPUF were shown in Figure 5. The cell diameters of FFPUF-1 and FFPUF-2 prepared from polyether polyols which were synthesized from diethanolamine and methyldiethanolamine were concentrated in 1-1.5 mm. However, the cell sizes of FFPUF-3 and FFPUF-4 prepared from polyether polyols which were synthesized from butyldiethanolamine and N,N-dihydroxyethyl-p-toluidine were not uniform, which was distributed in 0.6-2 mm. At the same time, the number of semi-open cells gradually decreased and the number of closed cells gradually increased from FFPUF-1 to FFPUF-4. Due to the increase in the polarity of the polyether polyol branch, the flexibility of the polymer segment gradually decreased. As the soft end of FPUF, polyether polyol was participated in the cross-linking reaction during the reaction. Therefore, with the decrease of the crosslinking reaction rate, the cells of FPUF gradually became uneven, and the number of semi-open cells decreased.

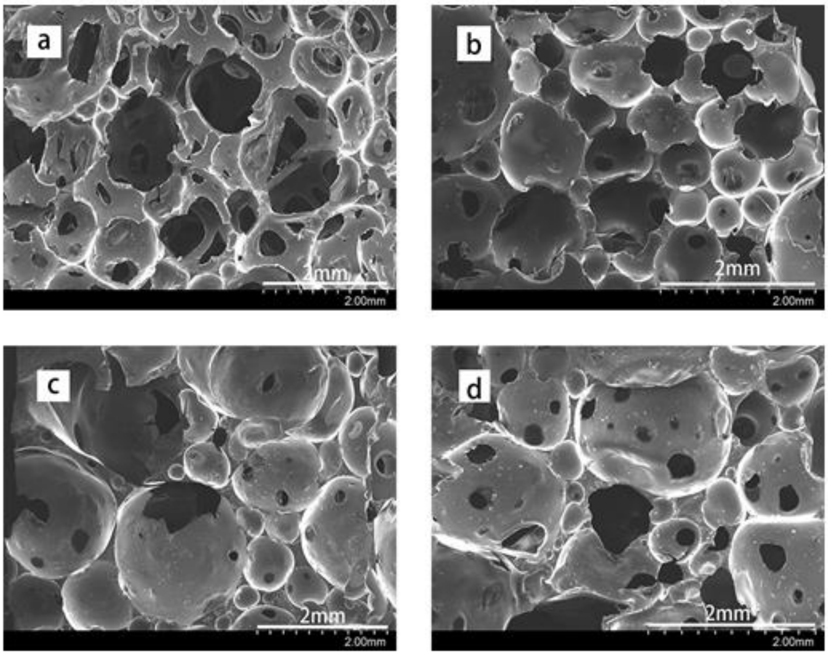

Figure 5. SEM images of polyurethane foam prepared by different flame retardant polyether polyols: (a) FPMPO-1, (b) FPMPO-2, (c) FPMPO-3, (d) FPMPO-4

The flame resistance comparison of polyurethane foams modified by four flame retardant polyether polyols was shown in Figure 6 and Table 2. The LOI value of FPUF without FPMPO was only 18, which was easy to ignite in the air. When the amount of the flame retardant polyether polyols reached 20%, the LOI value of FFPUF-1 reached 23.6 and the LOI value of the other three FFPUF also increased to about 22. Besides, the vertical burning tests show that the FFPUF with a small amount of the flame retardant polyether polyols have poor flame resistance due to the insufficient flame retardant elements. When the addition amount increased to 20%, the flame retardant elements in FFPUF-1 and FFPUF-2 can produce a certain flame retardant effect during combustion, and their vertical combustion grade reached V-2 level. The results indicated that the flame retardant properties of FFPUF improved with the increase of the flame retardant polyether polyols. However, an excess of flame retardant polyether polyols are not favorable to the flexibility of the polymer segment and will mar the smooth running of the foaming process. Therefore, the amount of flame retardant polyether polyols is unfit to increase further, though the flame retardant properties of FFPUF don't meet actual requirements.

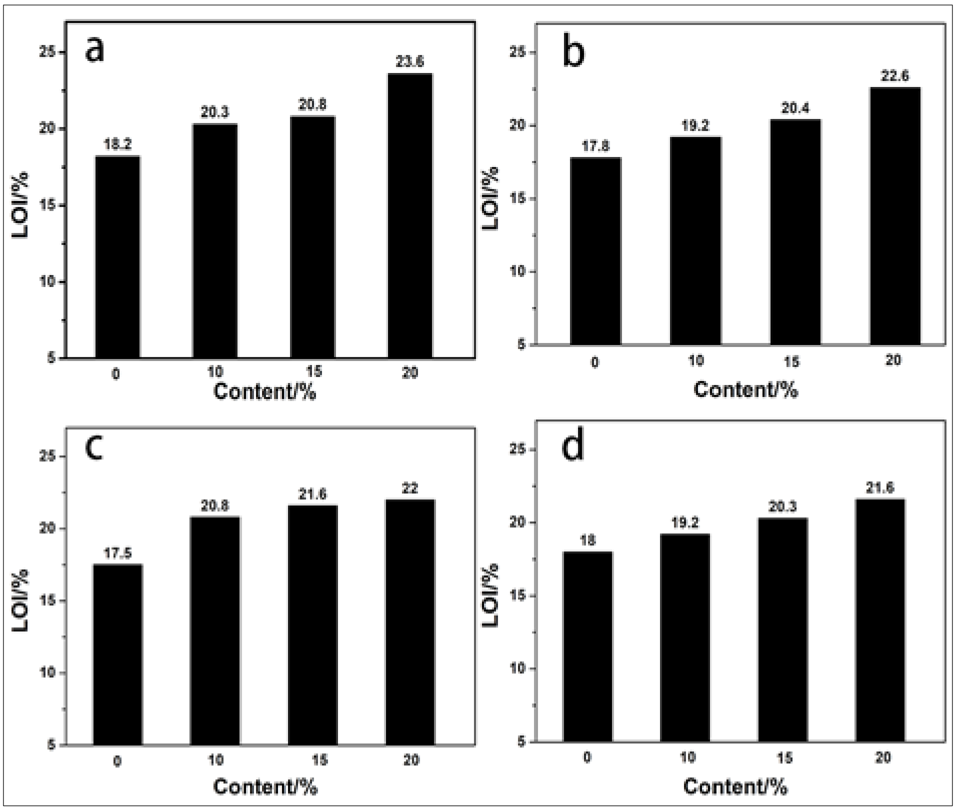

Figure 6. LOI values of FFPUF: a) FFPUF-1, b) FFPUF-2, c) FFPUF-3, d) FFPUF-4

Table 2. Vertical burning level of FFPUF with the different amounts of the flame retardant polyether polyols

Samples	0%	10%	15%	20%
FFPUF-1	No rating	No rating	No rating	V-2
FFPUF-2	No rating	No rating	No rating	V-2
FFPUF-3	No rating	No rating	No rating	No rating
FFPUF-4	No rating	No rating	No rating	No rating

The sound absorption coefficient curve of FFPUF with different flame retardant polyether polyol addition amounts could be observed in Figure 7. When 10% FPMPO-1 was used to replace polyether polyol 360 with the same molecular weight, the sound absorption performance of FFPUF-1 in medium and high frequency was excellent, and the average sound absorption coefficient reached 0.8 (Figure 7a). With the increase of monomer substitution, the overall sound absorption coefficient of FFPUF decreased, and the average sound absorption coefficient decreased to 0.64. Because the reaction rate of flame retardant polyether polyol and isocyanate was slower than that of common polyether polyol and isocyanate, the rate of foaming reaction and cross-linking reaction was more balanced when 10% FPMPO-1 was added. Besides, the rate of cell generation and the rate of cross-linking and curing of cell walls were relatively balanced, resulting in more semi-open cells with uniform pore size. Therefore, with the increase of FPMPO-1 content, the speed of the crosslinking reaction decreased, and then the equilibrium of the reaction was disturbed. Then, the cell uniformity decreased, and the number of half-open cells decreased, which reduced the sound absorption effect. The sound absorption effect of FFPUF-2 was similar to FFPUF-1 (Figure 7b). When the monomer addition amount was 10%, the sound absorption effect of FFPUF-2 was the best, and the average sound absorption coefficient was 0.73, which was slightly lower than that of FFPUF-1. As shown in Figure 7c, d, the sound absorption effects of FFPUF added with flame retardants monomer were lower than that of FPUF. The sound absorption effect of the two flame retardant polyurethanes was better when the monomer content was 20%, and their average sound absorption coefficients were 0.68 and 0.66, respectively. Because the flexibility of polyether polyol decreased, leading to the decrease of the reactivity between polyether polyol and isocyanate, the foaming reaction and cross-linking reaction failed to reach a relative balance. The cell size of the prepared FFPUF gradually became relative uneven, and the number of semi-open cells decreased and the number of closed cells increased. Although the sound absorption performance of the samples decreased, the decrease was not significant. Therefore, the addition of flame retardant polyether polyols not only improved the flame retardant performance of FFPUF, but also had little negative influence on the cell morphology and the sound absorption performance of FFPUF.

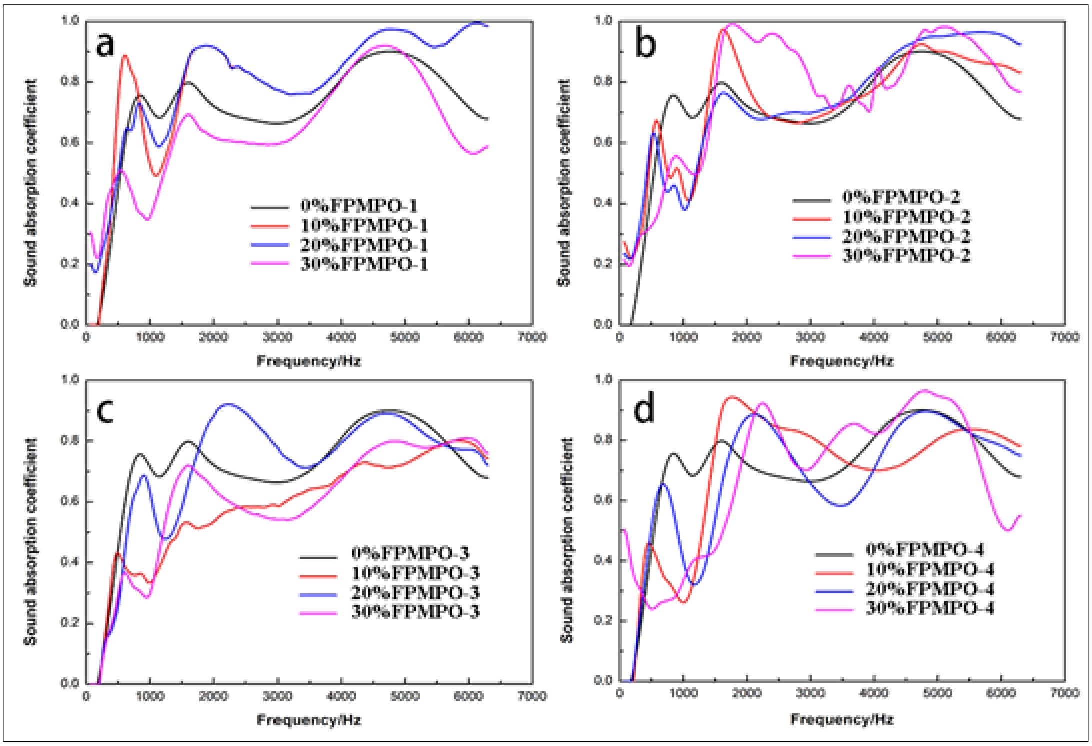

Figure 7. Sound absorption efficiencies of the polyurethane foams synthesized by different types of additive flame retardant

3.3. FFPUF with composite flame retardants

In order to improve the flame retardant properties of FFPUF with the addition of flame retardant polyether polyols further, the PEG as additive flame retardant was added, and its amount was limited to prevent the adverse effects on the sound absorption performance of FFPUF. The micromorphology of polyurethane foam modified by composite flame retardants was shown in Figure 8. The cells display spherical morphology while the shape is regular and the cells are mostly semi-open, and the cell size was basically concentrated at 1 mm, when the amount of FPMPO-1 was 20% and the amount of PEG was 10 phr. Compared with the flat cells of FFPUF with the abundant additive flame retardant (as in Figure S1), the cells with uniform spherical shape and uniform pore size of FFPUF with the composite flame retardants are beneficial for the effective sound absorption.

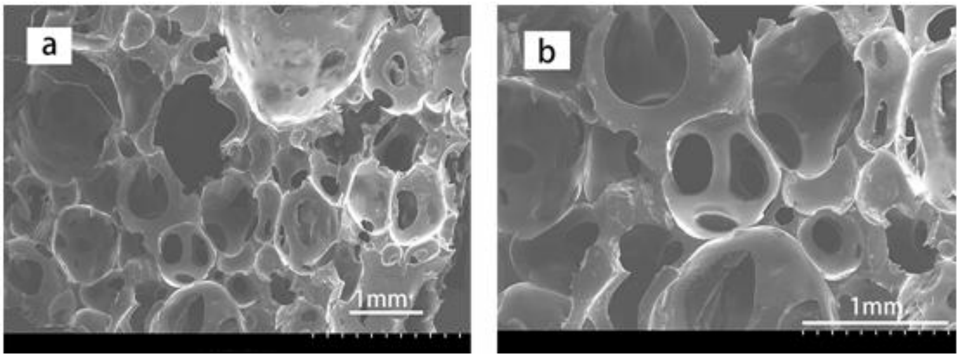

Figure 8. SEM images of FFPUF with composite flame retardants (20% FMPPO-1 and 10 phr PEG)

Figure 9a-d and Table 3 showed the vertical combustion grades of FFPUF modified by composite flame retardants. When the amount of FPMPO-1 reached 20%, the FFPUF do not ignite in the first 5s, and it was still not ignited after removing the flame and heating it again for 5s. These results implied that the modified FFPUF achieved vertical combustion at the V-0 level. The LOI values of FFPUF modified by the composite flame retardant were shown in Figure 9e. The LOI of FFPUF with only 10 phr PEG added remained at 23.6, and the limiting oxygen index of FFPUF increased to 27.6 with the addition of 10% FPMPO-1, which reached the flame retardant material range. With the continuous increase of FPMPO content, the LOI of FFPUF finally reached 33.4, and the flame retardant effect was excellent. Remarkably, the combination of additive flame retardant and reactive flame retardant could significantly improve the flame retardant performance of the materials.

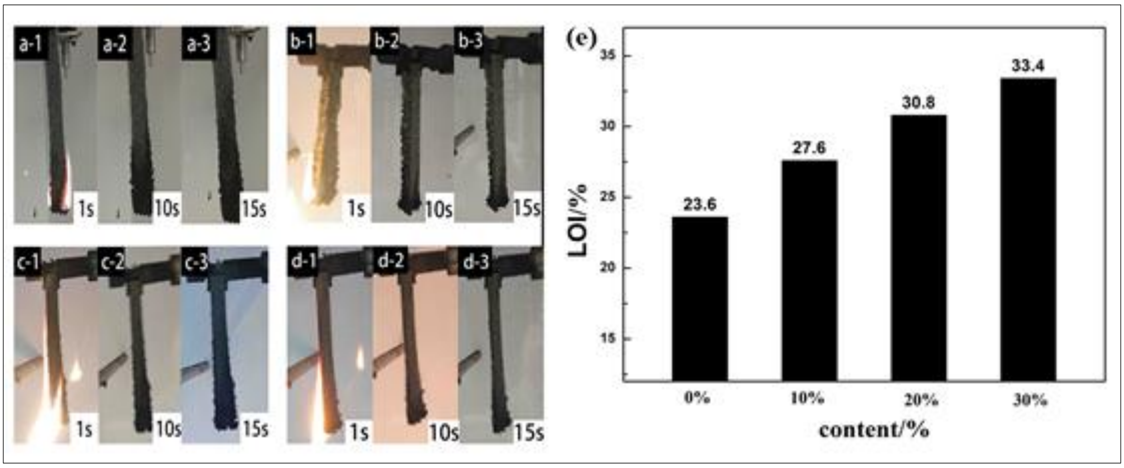

Figure 9a-d. The vertical burning level of FFPUF modified by composite flame retardants that the amount of FPMPO-1 is 10%, 20%, 30%, and 40%, respectively. (e) LOI values of FFPUF with composite flame retardants.

Table 3. Vertical burning level of FFPUF with composite flame retardants

Samples	0%	10%	20%	30%
Vertical burning level	V-2	V-1	V-0	V-0

The sound absorption coefficients of FFPUF modified by composite flame retardants were shown in Figure 10. When only 10% PEG was added into FFPUF without FPMPO-1 monomer, the average sound absorption coefficient exceeds 0.7 in the 800-6300 Hz range. With the addition of FPMPO-1, the absorption peak of the material at 800 Hz shifted to the low frequency direction, but the sound absorption coefficient decreased to 0.5. When the content of FPMPO-1 was 10%, the absorption peak at 800 Hz moved to 500 Hz. The absorption effects of other frequency bands were basically unchanged, and the average sound absorption coefficient was 0.65. Moreover, when the monomer content was 20%, the low-frequency absorption effect of the material was basically unchanged, but the peak value of the absorption peak at 1600 Hz was significantly increased. The peak value reached 0.93, and the average sound absorption coefficient reached 0.68. With the addition of 30% FPMPO-1, the sound absorption effect of the material decreased, and then the average sound absorption coefficient decreased to 0.65. Due to the use of mixed flame retardants, not only the flame retardant properties of the foam were improved, but also its own cell structure was not changed. Satisfyingly, FFPUF which was prepared by mixing a variety of flame retardants were provided with both flame retardant properties and relatively good sound absorption properties.

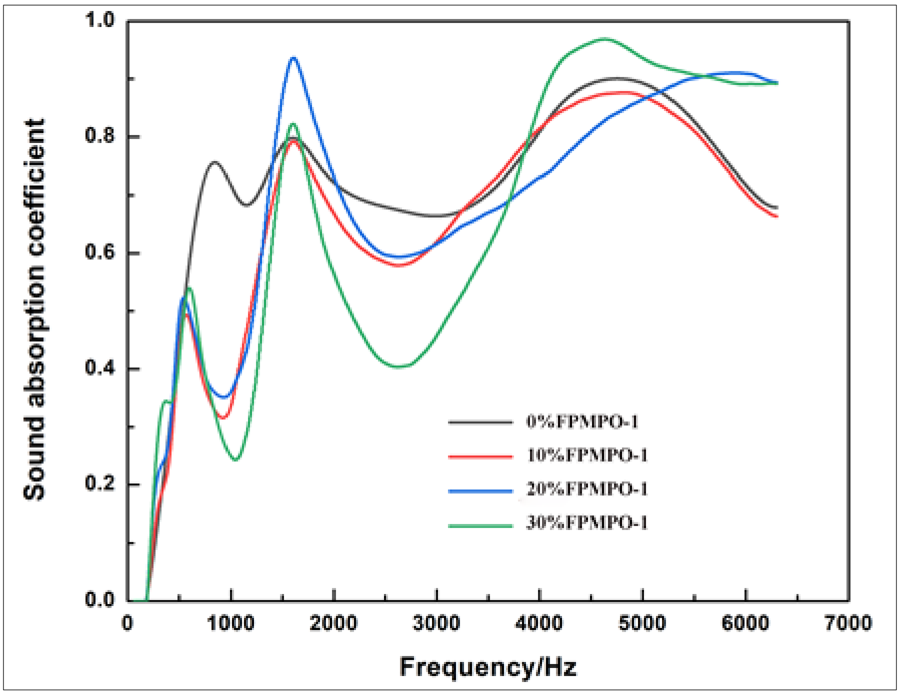

Figure 10. Sound absorption efficiencies of FFPUF with composite flame retardants

4. Conclusions

In summary, the four FPMPO are synthesized and combined with PEG to prepare the FFPUF by one-step method using dibutyltin dilaurate and triethylenediamine as catalysts simultaneously. The results show that the combination of the two catalysts can increase the cell size and the cell uniformity of FFPUF, and the cell structure control is beneficial to sound absorption. The FPMPO have little negative influence on the cell morphology and the sound absorption performance of FFPUF, and the flame resistances of FFPUF improve with the increase of the flame retardant polyether polyols. However, the increase of flame resistances is finite, because an excess of flame retardant polyether polyols are not favorable to the flexibility of the polymer segment and will mar the smooth running of the foaming process. In order to improve the flame retardant properties further, the flame retardant polyether polyols and the PEG are combined to use as the composite flame retardants for the modification of FFPUF. Benefitting by the effective control structure and the modification with composite flame retardant, the FFPUF shows excellent sound absorption and flame retardant properties.

The LOI value of FFPUF is 33.4 and the vertical burning level reaches V-0. And the average sound absorption coefficient of FFPUF maintains 0.68 over the range from 800 to 6300 Hz. The flame resistance flexible polyurethane foam presented in this work is promising for efficient sound absorption in the application of building, transportation, and other fields, stimulating broad interest in constructing competitive candidate for noise pollution treatment.

Supplementary materials

The following supporting information can be downloaded online: Figure S1. SEM images of FFPUF with (a) no flame retardant, (b) PEG, (c) $Al\ (OH)_3$, (d) Sb_2O_3.

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