CHAPTER-1

General Introduction

This chapter of the thesis describes literature survey on synthesis, characterization and applications of bisphenols and their derivatives.

1.1 General Introduction of bisphenols

Bisphenols are a group of chemical compounds with two hydroxyphenyl functionalities. They are also defined as compounds consisting of two phenol nuclei linked by a hydrocarbon bridge. Most of them are based on diphenylmethane. Bisphenol A is the most popular representative of this group, often simply called "bisphenol."

\[
\begin{align*}
\text{R} & \text{ represents hydrogen or various substituents attached to phenol group} \\
\text{X} & \text{ represents bridging atoms or substituents linking two phenol groups}
\end{align*}
\]

Structures of some common bisphenols

![Bisphenol A](image1)

![Bisphenol S](image2)

![Bisphenol B](image3)

![Bisphenol F](image4)
1.2 History

The importance of bisphenols has increased continually with the growth of the plastic industry from about the end of the 1930s. 2,2’-Bis(4-hydroxyphenol)propane (bisphenol A), first described in 1891 by A. Dianin, is by far the most important compound in this series. It has been produced industrially from acetone and phenol to be used as a starting material for epoxy resins since about 1945. The development of polycarbonates, the most important thermoplastic based on bisphenols A, began in the 1950s.

1.3 Physical and chemical properties of bisphenols

Bisphenols are colorless, odorless substances and most of them are solid at room temperature. The melting points of the most important bisphenols are between 100 and 200°C. Bisphenols are virtually insoluble in water. Their solubility in organic solvents is determined by their substituents. The alkaline salts of bisphenols are water-soluble. However, their solubility decreases drastically with increasing substitution. The boiling points of bisphenols are very high because of the size of the molecule and its polarity. For this reason and because of the decomposition frequently observed during boiling, bisphenols are rarely distilled. The chemical properties of the bisphenols are determined by the phenolic OH group, the aromatic rings, and the alkyl bridge. They therefore undergo the same reaction as the corresponding substituted monophenols (esterification and etherification at OH group, substitution and hydrogenation on the aromatic ring). They are suitable as building blocks for high molecular mass linear polyester and polyethers because of their bifunctionally. Bisphenols which alkylated ortho to the OH group readily trap radicals and therefore suitable as stabilizers [1].

1.4 Literature survey on bisphenols and their derivatives

Bisphenols are the important constituents of plastics, epoxy resins, lacquers, etc [2-3]. They are useful in manufacturing thermally stable polymers and polyester resins [4]. Various bisphenols have been found to be effective fungicides, antibacterial and are also used as insecticides as well as miticides [5-7]. The polycondensation product of phenol with cyclic hydroaromatic ketones are known as cardo monomer. The monomer containing cardo groups are useful in synthesis of polymer with very specific properties such as enhanced thermal stability together with excellent solubility and film forming properties due to the back bone structure [8]. Bisphenols are useful for the preparation of polycarbonates that are generally used for the production of medical equipments, bottles for feeding infants and kitchen dishes, also used as binder for the charge transport molecules and photogenerating pigments incorporated, for example, into layered photoconductive imaging member [9-11]. Bisphenols like 1,1′-bis(4-hydroxyphenyl)cyclohexane and 1,1,1′-tris(4-hydroxyphenyl) ethane are used as hardeners for epoxy resins and as branching agents in air craft window for flame resistance [12]. Diallyl bisphenols are important precursors for many thermoset polymer formulations. They are known to react with maleimides, particularly bismaleimides to form tough network polymers with good mechanical properties and thermo mechanical profile [13]. These compounds have received a tremendous amount of attention from research scientists, government panels, and the popular press due the potential health risks.


Farbenind [14,15] has reported the condensation of phenols and ketones in the presence of acetic acid, hydrochloric acid at 50°C and also reported the melting points of 1,1'-bis(4-hydroxyphenyl)cyclohexane (186°C), 1,1'-bis(4-hydroxyphenyl)-4-methylcyclohexane (179°C). The products are useful as intermediate for dyes and drugs.

Rothrock [16] has reported condensation of β-napthanone with PhOH or other mononuclear monohydric phenol by heating at 30-60°C in the presence of HCl. The product is useful for the preparation of synthetic resin with formaldehyde.


McGreal et al. [17] have reported the condensation of ketones (0.5 mole) and phenols (1.0 mole) in acetic acid. The solutions were saturated with dry HCl for 3-4 h and kept the reaction mixture for varying periods up to 4 weeks until the mass crystallized. The yields with aliphatic and aromatic ketones were 10-25% and with cyclic ketones 50-80%.

They have also proposed the following mechanism.

1. The addition of phenol to ketone
   \[
   \text{PhOH} + \text{R}_2\text{CO} \rightarrow \text{R}_2\text{C(OH)}\text{C}_6\text{H}_4\text{OH}
   \]

2. \[
   \text{R}_2\text{C(OH)}\text{C}_6\text{H}_4\text{OH} + \text{PhOH} \rightarrow \text{R}_2\text{C(C}_6\text{H}_4\text{OH)}_2 + \text{H}_2\text{O}
   \]

Johnson and Musell [18,19] have reported synthesis of 1,1’-bis(4-hydroxyphenyl)cyclohexane using 5 moles of phenol, 1 mole of a cyclohexanone, H$_2$S or BuSH below 40°C with 0.1-0.3 mole dry HCl gave (I) m.p. 186-187°C; 2-Me-I, 236-240°C; 4-Me-I, 178°C; 1,1’-bis(4-hydroxy-3-methylphenyl)cyclohexane, m.p. 187°C and 1,1’-bis(4-hydroxy-3-isopropylphenyl)cyclohexane, m.p. 109-111.5°C.

Mash containing small quantities of bisphenol (I) protect chickens from coccidiosis better than does a sulfaguanidine.

Bender et al. [20] have reported have reported preparation of various bisphenols by reacting phenol, NaOH and acetone. The mixture was refluxed for 16 h and acidified to pH 2-3 with 6N HCl. The yield was 47.5%.

Dietzler [21] has reported bromination of bisphenol in methanol-water system. Thus, bisphenol was treated with bromine at 42°C with stirring (4h). The mixture was kept for 2h at 40°C yielded 94.4% 4, 4’-isopropylidene-bis(2,6-dibromophenol) (181-182°C), 4, 4’-cyclohexyldiene-bis(2,6-dibromophenol) (m.p. 190°C).

Maeda et al. [22] have reported that polyurethane can be stabilized by 4,4’-thiobis(6-tert-butyl-3-methylphenyl) with 1,1’-bis(4-hydroxyphenyl)cyclohexane thermally and against UV light by adding a mixture of 4,4’-thio-bis(6-tert-butyl-3-methylphenyl) with 1, 1’-bis (4-hydroxyphenyl)cyclohexane or 1,1’-bis(3-methyl-4-hydroxyphenyl)cyclohexane.

Farbenfabriken [23] has reported the preparation of 4, 4’-dihydroxydiphenyl cyclohexane (m.p. 186°C) using cyclohexanone (78 kg) and excess phenol (400 kg) in the presence of 38% HCl as a catalyst at room temperature for 6 days.

Farnham et al. [24] have reported condensation of ketone with a methyl group in α-position to the CO group such as acetone, PhCOMe or cyclohexanone with an excess of phenol like phenol, o-cresol and o-chlorophenol (ratio 1.3-2.0) with a free para position at 40-100°C in the presence of an insoluble anhydrous sulfonated cation exchange resin.

Freudewald et al. [25] have reported the condensation of phenol (94 g) with cyclohexanone (98 g) in the presence of 2.0 g EtSH and anhydrous HCl (4.7 g) and heating at 70°C in closed system for 3h to give 97% 1,1’-bis(4-hydroxy phenyl) cyclohexane.

Islam *et al.* [26] have reported the synthesis of tetra halogenated 4,4’-dihydroxydiphenylalkanes. The condensation of PhOH with MeCOMe, cyclohexanone, cyclopentanone and AcPh gave respective bisphenols in 66-80% yields. The condensation of o and m-cresol with ketones gave 70, 68 and 60% yields of respective bisphenols. They have also reported bromination of bisphenols by Br-AcOH in 61-70% yields. Chlorination of bisphenols by HCl in presence of H$_2$O$_2$ gave the respective tetrachlorobisphenol derivatives in 67-87% yields. The condensation of bisphenols with ClCH$_2$COOH in aqueous NaOH gave dioxyacetic acid derivatives of bisphenols in 61-75% yields.

Rao *et al.* [27] have reported a convenient method for the preparation of bisphenols. Cyclohexanone was treated with PhOH at 40°C and with o-cresol at room temperature in the presence of HCl and AcOH to give 1,1’-bis(4-hydroxyphenyl)cyclohexane and 1,1’-bis(3-methyl-4-hydroxyphenyl)cyclohexane, respectively.

Alexandru [28] has reported the preparation of bisphenols by reaction of a ketone (cyclohexanone) with phenol, BuSH, ClCH$_2$CH$_2$Cl and Me$_3$SiCl. The mixture was stirred and heated to 50-55°C and finally at 65°C to give bisphenol-Z.

Subramaniam *et al.* [29] have reported the synthesis of 4,4’-isopropylidene bisphenyl dicinnamate, 4,4’-cyclohexylidene bisphenyl dicinnamate, 4,4’-isopropylidene bisphenyl disalicylate, 4,4’-cyclohexylidene bisphenyl disalicylate, dioxyacetic acid and dimethyl ether of bisphenol-A and bisphenol-C. They have tested the compounds for their activity against a fungus *Fusarium oxysporum* by filter paper disc method and reported that dimethyl ether and the dioxyacetic acid are inactive even at the highest concentration level used, whereas both the esters are active even at the minimum concentration level used.

![Synthesis of bisphenol-A & bisphenol-C derivatives](image)
Arnold-Stanton et al. [30] have studied that bisphenol A reacted as its disodium salt with tetrafluoroethylene and carbon dioxide followed by dimethyl sulfate to give in high yield a symmetrical dimethyl ester assembled from seven structural elements. This diester was transformed into the corresponding diol, diamide, diamine, disiocyanate, and bis(methylcarbamate). Analogous diesters were prepared by using bisphenol A and chlorotrifluoroethylene as well as hexafluoro bisphenol A and tetrafluoroethylene. Both of these esters were transformed into other bifunctional derivatives. Catalytic hydrogenation of the diol derived from bisphenol A and tetrafluoroethylene was accompanied by hydrogenolysis of the aryl-oxygen bonds.

Fluorinated bifunctional derivative of bisphenol-A

Garchar et al. [31, 32] have studied optimization reaction conditions for the synthesis of 1,1’-bis(R,R’-4-hydroxyphenyl)cyclohexane by condensing cyclohexanone (0.05 mole) and phenol, o-cresol and 2, 6-dimethylphenol (0.1 mole) in the presence of varying mixture of hydrochloric acid and acetic acid (2:1 v/v) at four different temperatures 40, 50, 60 and 70°C. They have reported optimum catalyst concentration (10-15 ml), time (30-90 min) and temperature (55-70°C) for obtaining yields greater than 80%. They have also synthesized chloro, bromo and nitro derivatives and screened for their potential antimicrobial and antifungal activities against microbes. Some of these compounds are significantly found active against B. subtilis, S. pyogens and A. niger. The nitro compounds are found to be the most active as antifungal agents.


Sumoto et al. [33] have prepared regioselective new diphenylmethane-type 2, 2’-dihydroxybisphenols in good yields and evaluated antiviral activity of some bisphenol derivatives synthesized by the plaque reduction assay. Most of the compounds showed significant antiviral activity and the 4, 4’-dihydroxybisphenol derivative showed higher activity than 2,2’-bisphenol derivatives. This compound had EC$_{50}$ value of 1.8m $\mu$g/mL.

![Chemical structure](image)

1a : $R^1R^2 = -OCH_2O$
1b : $R^1R^2 = H$

2 : $R = -CH_3$
3 : $R = -CH_2CH(CH_3)_2$
4 : $R = -CH_2CH_2Ph$
5a : $R^1R^2 = -OCH_2O$, $R = -CH_3$
5b : $R^1R^2 = -OCH_2O$, $R = -CH_2CH(CH_3)_2$
5c : $R^1R^2 = -OCH_2O$, $R = -CH_2CH_2Ph$
5d : $R^1 = R^2 = H$, $R = -CH_2CH_2Ph$


Amorati et al. [34] have studied a kinetic and thermodynamic investigation on the antioxidant activity of 2,2′-methylenebis(6-tert-butyl-4-methylphenol) (2), 2,2′-ethylidenebis(4,6-di-tert-butylphenol) (3), and 4,4′-methylenebis(2,6-di-tert-butylphenol) (4). EPR studies of the equilibration between 3 or 4 and a reference phenol, and the corresponding phenoxy radicals, allowed to determine the O-H bond dissociation enthalpy (BDE) of the O-H bond as 81.2 and 81.1 kcal/mol in 3 and 4, respectively. Despite this similarity, the absolute rate constants for the reaction with peroxy radicals, determined by autoxidation studies under controlled conditions, indicated that the o-bisphenols 2 and 3 behave as excellent antioxidants while the p-bisphenol 4 is less effective by a factor of 64 and 22, respectively. FT-IR spectroscopy and product studies suggested that the very good antioxidant activity of the o-bisphenols largely arose from both the reduced steric crowding about the hydroxyl group and the stabilization of the aroxyl radical due to the formation of an intramolecular hydrogen bond between the residual OH and the oxygen radical center.

XU Jing-zhe et al. [35] have reported synthesis of bisphenols containing long chain aliphatic hydrocarbon side chains by condensing phenol and aldehyde or ketone in the presence of heteropolyacid. Their structures were charactreized by IR, ¹H NMR and ¹³C NMR analysis. The experimental results showed that when heteropolyacid was used as a catalyst, these bisphenols were obtained in high selectively and high yields.

Massah et al. [36] have reported efficient etherification of phenols using dimethyl- and diethylsulfates and benzyl in the presence of a suitable solid base, NaHCO$_3$ or K$_2$CO$_3$, under solvent-free conditions. The reaction proceeded rapidly at low temperature, and the corresponding ethers were obtained with high purity and excellent yield. Selective etherification of electron-poor phenols in the presence of electron-rich ones and also selective mono-etherification of bisphenols are the noteworthy advantages of this method. This method is environmentally friendly.

**Etherification of phenols**

Maezawa et al. [37] have reported synthesis of bisphenol A derivatives possessing a fluorescent dye and a photo-reactive group. The inhibitory activity of the derivatives was evaluated against hypoxic response. The synthesized derivatives were found to inhibit the hypoxic expression of erythropoietin in Hep3B cells as well as bisphenol A.

Ogawa et al. [38,39] have reported synthesis of a series of \textit{m}-carborane derivatives, which were prepared on the basis of the structures of antiestrogenic drug. The activities were evaluated by estrogen receptor alpha (ER\(\alpha\)) binding assay and transactivation assay using human breast cancer cell line, MCF-7 cells. The \textit{m}-carborane bisphenol exhibited about a thousand times more potent ER agonistic activity than the \textit{o}-carborane bisphenol. The \textit{m}-carborane bisphenol structure appears to be a favourable hydrophobic pharmacophore for the development of novel selective estrogen receptor modulators (SERMs). Also studied \textit{p}-carborane bisphenols and their derivatives, which were prepared and evaluated for binding affinity to estrogen receptor \(\alpha\). Their estrogenic activity was evaluated by means of transcriptional assay and cell proliferation assay using MCF-7 cell lines. 1,12-Bis(4-hydroxyphenyl)-1,12-dicarba-closo-dodecaborane (4a) showed potent estrogenic activity, approaching that
of 17β-estradiol, in transactivation assay. The activity of isomers 1-(3-hydroxyphenyl)-12-(4-hydroxyphenyl)-1,12-dicarba-closo-dodecaborane (5a) and 1-(2-hydroxyphenyl)-12-(4-hydroxyphenyl)-1,12-dicarba-closo-dodecaborane (6a) was drastically affected by the change in the position of one of the hydroxyl groups; 6a (ortho-OH in one ring) was about 1000 times less potent than 4a. Modification of this hydroxyl group with alkyl groups decreased the estrogenic activity in all isomers. Compound 4a also showed potent MCF-7 cell proliferation-enhancing activity.

**Synthesis of m-carborane derivatives**


Zhou et al. [40] have been studied the aggregation of Aβ a crucial step in the etiology of Alzheimer’s disease. Previous work showed that Aβ undergoes α-helix/β-sheet intermediate structures during the conformational transition, and an Aβ aggregation inhibitor (1) was discovered by targeting the intermediates. Structure optimization toward compound 1 was performed and 34 novel derivatives were designed and synthesized. Nine compounds showed more effective inhibitory activity than the hit compound 1 in ThT fluorescence assay. Among them, compound 3,3’-(4,4’-(propane-2,2-diyl)bis(2,6-dibromo-4,1-phenylene))-bis(oxy)bis(1-(3,5-dimethyl piperidin-1-yl)propan-2-ol) (43) demonstrated more excellent inhibitory potency which not only can suppress the aggregation of Aβ but also can dissolve the preformed fibrils as shown by CD spectroscopy, PICUP and AFM assays. Cellular assay indicated that 43 has no toxicity to neuronal cells, moreover, can effectively inhibit Aβ1-42 induced neurotoxicity and increase the cell viability. Together, on the basis of these positive results, these novel chemical structures may provide a
promising potential for therapeutic applications in AD and other types of neurodegenerative disorders.

Chemical structure of inhibitor (1) (DC-AB1)

Synthesis of substituted bisphenols derivatives as β-amyloid peptide aggregation inhibitors
Bhadja and Parsania [41,42] have reported synthesis of R,R’,4,4’-cyclohexylidene diphenyloxy acetic acids (R, R’= H, CH₃ and Cl) by dissolving 0.1 mole bisphenols in 0.4 mole NaOH with drop wise addition of 0.2 mole chloroacetic acid. The reaction mixture refluxed for 4h at 60⁰C. Phenoxy acids have been confirmed by IR and NMR spectral characterization. The acids are also characterized by their antimicrobial and antifungal activities. The activities have been interpreted in light of bisphenol structures and the nature of substituent(s). The wide scale uses of bisphenol bioactive agents have brought many advantages to the agricultural industries. Also studied polyphosphate of 1,1’-bis(R,R’-4-hydroxyphenyl)cyclohexane (R, R’ = H, CH₃ and Cl) are synthesized by refluxing bisphenol-C derivatives with phosphorous oxytrichloride in pyridine at 95⁰C for 4h and then at 240⁰C for 6h. Polyphosphates have been ascertained by IR and NMR spectral data. Polyphosphates are also characterized by their antibacterial and antifungal activities. The activity is interpreted in light of bisphenol structure and the nature of substituent(s).
Shinde et al. [43] have reported an efficient synthesis of bisphenols by condensation of substituted phenols with corresponding cyclic ketones in presence of cetyltrimethylammonium chloride and 3-mercaptopropionic acid as catalysts in extremely high purity and yields.

**Synthesis of bisphenol derivatives**

![Synthesis of bisphenol derivatives](image)

**Reaction Condition (i) Cetyltrimethylammonium chloride, 3-mercaptopropionic acid, dry HCl, 40-45 °C, 4h, 60-94%**


Sawaryn et al. [44] have reported synthesis of polymerizable non-ionic benzoxazine surfactants. Different target structures with varying hydrophobichydrophilic balance (HLB) values were synthesized and successfully tested for the miniemulsification of two N-aliphatic and N-aromatic benzoxazine resins. As a model system, the difunctional benzoxazine surfactant bis(3,4-dihydro-2H-3-(poly propyleneoxide-block-polyethyleneoxide-1,3-benzoxazinyl)isopropane (B2000) was analyzed in detail via FT-IR, \(^1\)H NMR, surface tension measurements, and thermal analysis such as DSC and TGA. Additional to the colloidal stability of the benzoxazine miniemulsions, investigations focused on the surfactant copolymerization behaviour and compatibility with other resins. It was found that despite the observed slow homopolymerization the described surfactants easily undergo copolymerization with the model benzoxazine resins.

![Synthesis of thermally polymerizable benzoxazine non-ionic gemini surfactant](image)

Karakus et al. [45] have reported synthesis of \textit{tetrakis} derivatives of bisphenol-A containing azo groups. Bisphenol-A, coupled with diazonium salts derived from 4-phenylazoaniline and 5-(4-aminophenylazo)-25,26,27-tribenzoyloxy-28-hydroxy-calix[4]areane. It has been observed that the coupling reaction of diazonium salt obtained from 4-phenylazoaniline with bisphenol-A gave \textit{tetrakis}-while those derived from 5-(4-aminophenylazo)-25,26,27-tribenzoyloxy-28-hydroxycalix[4]areane gave partially substituted bisphenol-A analogues. The newly prepared \textit{tetrakis-azo} substituted bisphenol-A compounds are characterized by using UV-vis, FT-IR, \(^1\)H-NMR spectroscopic methods as well as elemental analysis techniques. These azo compounds gave rise to bathochromic shifts in the absorptions spectra, which can even be detected by “naked eye”.

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Karmishina et al. [46] have reported synthesis of new fungicidal and antimicrobial siloxane oligomers using γ-aminopropyltriethoxysilane and a series of bisphenols. Chemical immobilization of these oligomers on the surface of various fabrics was studied with the aim to develop textile materials resistant to microbiological degradation.

Verma et al. [47] have reported polyethylene glycol-bound potassium tribromide \([\{\text{K}^+\text{PEG}\}\cdot \text{Br}_3^-]\) as an efficient brominating agent for the bromination of bisphenol A to tetrabromobisphenol A of a very high purity and in excellent yield. The brominating agent was easily prepared by reacting the PEG\(_{400}\) with KBr\(_3\) using the host-guest chemistry concept. The effect of various reaction parameters such as solvent, temperature, and concentration of brominating agent on the yield and purity of tetrabromobisphenol A was studied. The key advantages of the developed method are the use of inexpensive, non-volatile poly(ethylene)glycol, facile regeneration, and inbuilt recycling of generated HBr waste.

![Bromination of bisphenol A](image)

De and Baruah et al. [48] have reported a studied series of potentially active quinoline based bisphenols. The compounds have been synthesized by simple and efficient synthetic protocol. The quinoline based bisphenol, \(4-(4\text{-hydroxyphenyl})\) (quinolin-4-yl)methyl)phenol formed from quinoline-4-carbaldehyde and phenol in acetic acid medium followed by reaction with various substituted methyl groups. The newly synthesized bisphenols has an aromatic amine part, which is fluorescence active and also can act as a binding site.


The quinoline based bisphenols act as chemosensor, when on addition of indium ion(+3), the curve is shifted towards the longer wavelength as well as the intensity of fluorescence emission spectra has been increased. The structure of the final analogues has been confirmed on the basis of $^1$H NMR, IR and Mass analysis.

Schutyser et al. [49] have reported 2, 3-pentanedione (2,3-PD), a bio-based chemical derived from lactic acid, as a the potential precursor for the synthesis of novel bisphenols. They developed a solvent-free catalytic strategy for the condensation of phenol with 2,3-PD by using acid catalysts at temperatures ranging from 323 to 373 K. Various soluble and solid acids exhibit high activity, while a high chemoselectivity to bisphenol requires a high phenol to 2,3-PD molar ratio. Bisphenol yields as high as 84% are for instance reported in an excess of phenol in the presence of Nafion NR50. Recycling of the Nafion catalyst after washing with ethanol at room temperature is demonstrated. The regioselectivity in the bisphenol fraction is influenced by the acid strength. A clear trend is presented in which the regioselectivity towards the desired $p,p'$-isomers increases with increasing acid strength, showing $p,p'/o,p'$-isomer ratios as high as 100. A tentative mechanism is discussed based on the ionic versus non-ionic pathway. The purified 2,3-PD-derived $p,p'$-bisphenols are assessed as plasticizers for polyethylene terephthalate (PET), showing promising properties similar to that of the reference bisphenol A, but with a broader processing window due to the lower melting point and higher thermal stability under an inert atmosphere.
Reinel et al. [50] have reported thiol–ene photopolymerizations, which gained a growing interest in academic research. Coatings and dental restoratives are interesting applications for thiol–ene photopolymerizations due to their unique features. In most studies the relative flexible and hydrophilic ester derivative, namely pentaerythritoltetra(3-mercaptopropionate) (PETMP), is investigated as the thiol component. They investigated the performance of more hydrophobic ester-free thiol-modified bis- and trisphenol derivatives in thiol–ene photopolymerizations. For this, six different thiol-modified bis- and trisphenol derivatives exhibiting four to six thiol groups were synthesized via the radical addition of thioacetic acid to suitable allyl-modified precursors and subsequent hydrolysis. Compared to PETMP better flexural
strength and modulus of elasticity were achieved in thiol–ene photopolymerizations employing 1,3,5-triallyl-1,3,5-triazine-2,4,6-trione (TATATO) as the ene derivative. Especially, after storage in water, the flexural strength and modulus of elasticity were twice as high compared to the PETMP reference system.

![Synthesis of thio-functionalized bisphenols](image)

