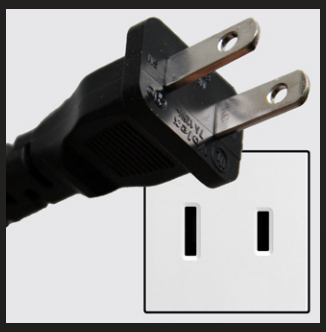
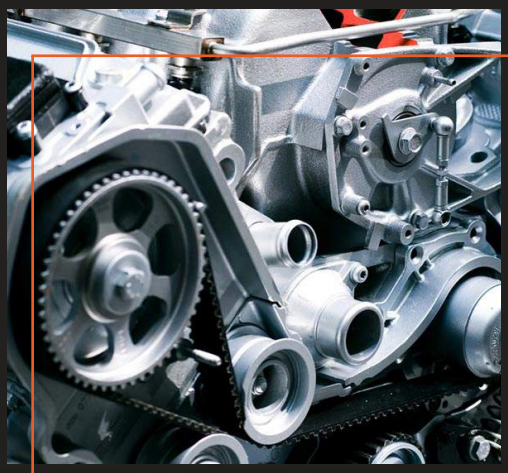
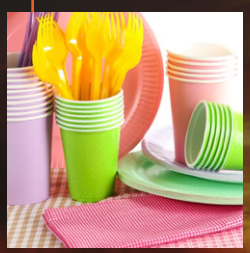
Toxics Link
for a toxics-free world

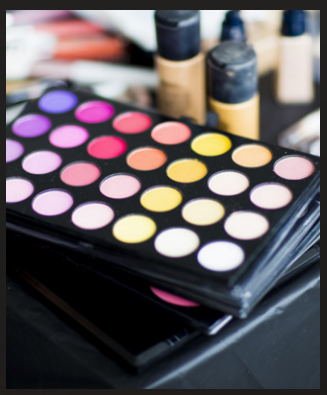
PHENOLIC COMPOUNDS






Lesser-known Emerging Contaminants



DECEMBER 2021.

About Toxics Link

Set up in 1996, Toxics Link is an Indian environmental research and advocacy organization engaged in disseminating information to help strengthen the campaign against toxics pollution, provide cleaner alternatives and bring together groups and people affected by the problem. Toxics Link's Mission Statement is: "Working together for environmental justice and freedom from toxics."

We have taken it upon ourselves to collect and share both information about the sources and the dangers of toxins in our environment and bodies, and information about clean and sustainable alternatives for India and the rest of the world. The unique expertise of the organization lies in the areas of hazardous, medical, and municipal waste, international waste trade, and the emerging issues of pesticides, Persistent Organic Pollutants (POPs), hazardous heavy metal contamination, etc. from the environment and public health point of view. We have successfully implemented various best practices and have brought in policy changes in the aforementioned areas apart from creating awareness among several stakeholder groups.

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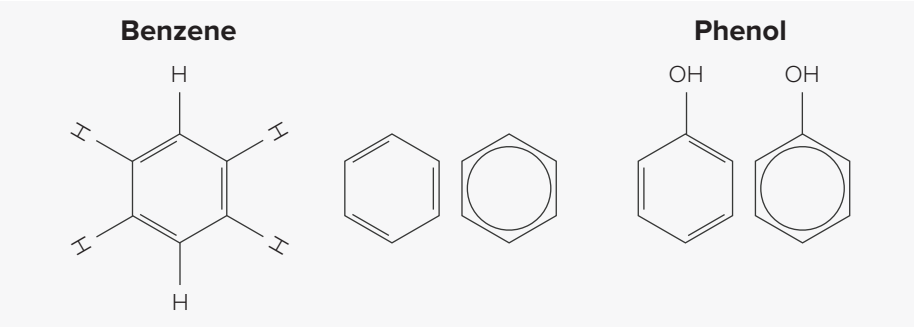
01

Introduction

Phenolic compounds or phenolics are a family of organic compounds characterized by a hydroxyl (-OH) group attached to a benzene (aromatic) ring. Several phenolic compounds pose a major environmental concern as they tend to persist in the environment for a long period and are toxic even at low concentrations.[1]

Fig. 1 Structure of Benzene and Phenol



Phenol is the most utilized chemical with a production of about 3-billion pounds annually in the United States.

Global phenol demand amounted to about 11 million metric tons in 2019, which resulted in a 2.6% average annual increase over the last five years.

The largest consumption of phenol is for the production of **Bisphenol A (BPA), which was nearly 50% of the global phenol consumption in 2019**. BPA is mainly used to make polycarbonate and epoxy resins. The second-largest end-use for phenol remains phenol-formaldehyde resins. Global phenol demand is led by Asia, accounting for more than half of total consumption.

Phenol is the simplest member of the phenolic group having the chemical formula C_6H_5OH (Fig. 1). The primary use of phenol is in the production of phenolic resins. Other applications for phenol include the manufacture of polyphenols, as a disinfectant, in medicinal products, etc.

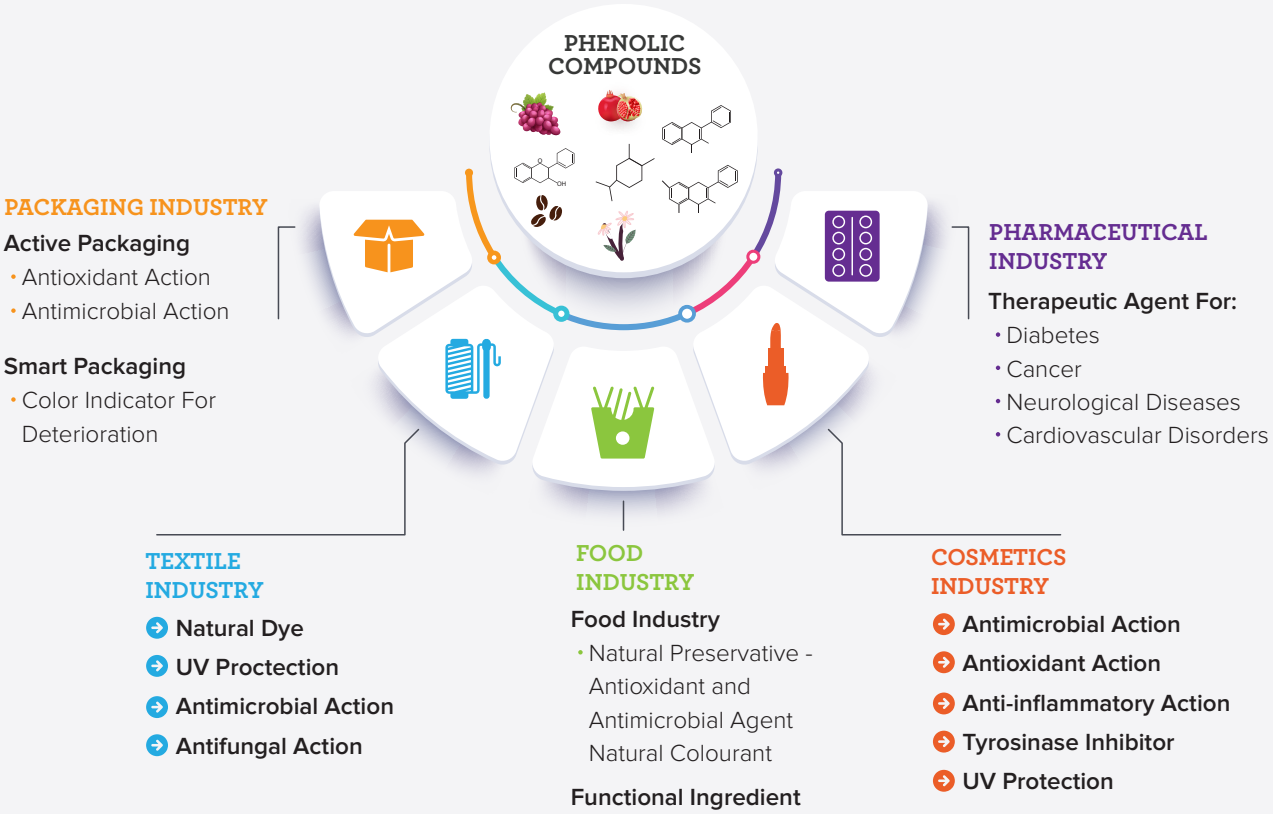
Phenol is the most utilized chemical with a production of about 3-billion pounds annually in the United States. Global phenol demand amounted to about 11 million metric tons in 2019, which resulted in a 2.6% average annual increase over the last five years. The largest consumption of phenol is for the production of Bisphenol A (BPA), which was nearly 50% of the global phenol consumption in 2019. BPA is mainly used to make polycarbonate and epoxy resins. The second-largest end-use for phenol remains phenol-formaldehyde resins. Global phenol demand is led by Asia, accounting for more than half of total consumption.[2]

Phenolic compounds can be classified into various groups based on their physical and chemical properties. The most studied phenolic groups are chlorophenols, nitrophenols, methyl phenols, alkylphenols, and bisphenols.[3] These compounds are used or formed mainly in the chemical, polymer, textile, pharmaceutical, pulp and paper, and wood industries. Other applications or sources of these compounds include plasticizers, pesticide manufacturing, detergent applications, and metallurgic industries. As phenolic compounds are widely used in several products, they are discharged into the environment along with the effluents from industries such as textiles, woolen mills, dye and dye intermediate industries, coke ovens, pulp, and paper industries, iron and steel plants, petrochemicals, paint Industries, pharmaceuticals, etc.

Many phenolic compounds are known to be toxic and inflict both severe and long lasting effects on both humans and animals. Some phenolic compounds are even known to be endocrine-disrupting chemicals (EDCs), which impact the endocrine system. Upon entry into the environment, these chemicals tend to transform into other compounds that can be more harmful than the original compounds.[4] Therefore considering the health and environmental challenges, increasing attention has been paid to phenolic compounds and several countries have taken active steps towards regulating or even banning toxic phenolic compounds.

However, the issues surrounding the phenolic compounds are not widely discussed in India. Therefore, it is necessary to initiate, sustain and facilitate discussion on these emerging contaminants to raise awareness among researchers, and policymakers, and to influence priorities for action. Moreover, enhanced efforts must be taken to gather and exchange information on toxic phenolic compounds for a transition to safer alternatives.

Applications of phenolic compounds



02

Major types of phenolic compounds

World Health Organization and the International Agency for Research on Cancer have characterized several chlorophenols as potential human carcinogens.

Phenolic compounds represent a diverse range of compounds from simple phenolic molecules to complex polymerized compounds. Some of the major types of phenolic compounds are described below:

2.1 Chlorophenols

The chlorophenols is a group of 19 related compounds (known as congeners in chemical terms) consisting of mono-, di-, tri-, tetra-, and pentachlorophenol (PCP) and are the most widespread and the largest group of phenols. Chlorophenols and their derivatives are known to be highly toxic to living beings because of their bioaccumulative, carcinogenic, mutagenic, and cytotoxic properties.

Pentachlorophenol (PCP) is the most commonly used chlorophenol. PCP and its derivatives sodium pentachlorophenate (NaPCP) and pentachlorophenyl laurate (PCPL) have been used worldwide as herbicides, biocides, pesticides, and wood preservatives since the 1930s. PCP can undergo degradation into several metabolites depending on the environmental conditions. Examples of degradation products include **tetrachlorophenols (TecP), trichlorophenols (TCP), and dichlorophenol (DCP).** Some of these degradation products are highly toxic.

DCP and TCP are mainly used to manufacture herbicides. However, TCP is no longer intentionally manufactured and may be produced as by-products during the manufacture of other chlorinated aromatic compounds.

2.2 Nitrophenols

Nitrophenols are synthetic chemicals used in the synthesis of many industrial products such as pesticides, herbicides, petrochemicals, explosives, pharmaceuticals, synthetic dyes, and the leather processing.[5] Nitrophenols are also formed during the degradation of pesticides such as parathion and nitrofen.[6] Therefore, **nitroaromatics (nitrophenols are one type of nitroaromatics) have been blacklisted by the US EPA as high-priority toxic pollutants in 2008.**[7]

2.3 Alkylphenols

Alkylphenols are phenols consisting of alkyl (-CH_3) groups. **Alkylphenols have a wide range of applications, including the production of lubricating oil additives, laundry and dish detergents, emulsifiers, and solubilizers.**[8] These phenolic compounds are added to pesticide formulations as inert ingredients to enhance performance. **Alkylphenols have attracted increased attention due to their prevalence in the environment and their potential roles as endocrine disruptors and xenoestrogens.**

Methyl phenols (alkylphenols with a single methyl group; also known as cresols) are commonly used as solvents, in disinfectants and deodorizers, and the manufacture of other chemical compounds.

The most commercially important alkylphenols are nonylphenols and octylphenols. Alkylphenols are used to make alkylphenol ethoxylates such as nonylphenol ethoxylates and octylphenol ethoxylates.

It is to be noted that, out of all the alkylphenol ethoxylates manufactured globally, 80% are nonylphenol ethoxylates (NPEs) because of their wide range of applications. NPEs are highly cost-effective surfactants and are widely used in industrial, institutional, commercial, and household applications such as detergents, emulsifiers, wetting and dispersing agents, antistatic agents, demulsifiers, and solubilizers. When NPEs are released into the environment, they ultimately degrade to nonylphenols (NPs), which can enter different environmental matrices such as water, soil, etc.[9]

United Nations Environment Programme has identified nonylphenol as a chemical of global concern in its region-based Assessment of Persistent Toxic Substances.

United Nations Environment Programme has identified NP as a chemical of global concern in its region-based Assessment of Persistent Toxic Substances.

2.4 Bisphenols

Bisphenols are a group of chemicals used to manufacture plastics, epoxy resins, and other products since the 1960s. **Bisphenol A (BPA) is the most widely used and studied of the bisphenols**.[10] They are widely used in different products of daily life, including CDs and DVDs, electronic equipment, automobiles, construction glazing, sports safety equipment, medical devices (e.g. dental sealants), tableware, reusable bottles (e.g., baby bottles), and food storage containers. Children's toys may also contain BPA.

It is also used in the manufacturing of specialty resins and flame retardants, such as tetrabromobisphenol A. Bisphenols, also known as 'Everywhere Chemicals', are industrial chemicals often used in receipts and tickets

BPA is one of the chemicals that has been classified as an EDC. Moreover, BPA is lipophilic and has been detected in adipose tissue, brain, liver, and breast milk in humans.[11] BPA has the potential to leach in small amounts into food and beverages stored in materials containing these substances, which can cause harm to human health.

Although other bisphenols such as Bisphenol S, Bisphenol B, etc. have not been studied as closely as BPA, they have similar chemical characteristics and are suspected of having similarly damaging effects.

Bisphenols, also known as 'Everywhere Chemicals', are industrial chemicals often used in receipts and tickets

BPA Based Products


Plastic Bottles


Disc

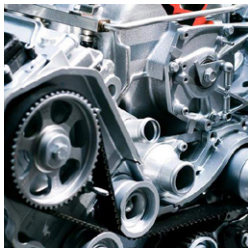

Food Packaging

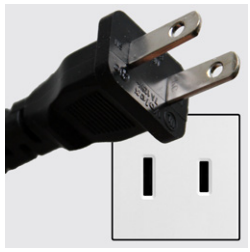
Sports Safety Equipments

Children's Toys


Medical Devices


Tableware


Automobile Parts


Electrical

2.5 Aminophenols

Aminophenols exist in three isomeric forms; namely, 2-aminophenol, 3-aminophenol, and 4-aminophenol. Aminophenols and their derivatives are of commercial importance in the photographic, pharmaceutical, and chemical dye industries. Aminophenols are also used in the preparation of azo dyes used in textile industries.

2.6 Buthylhydroxytoluene and Buthylhydroxyanisole

Butylated hydroxytoluene (BHT) and butylated hydroxyanisole (BHA) are phenolic compounds that have been extensively used for several years as antioxidants to preserve and stabilize the freshness, nutritive value, flavour, and colour of foods and animal feed products.[12] They are also used as preservatives in cosmetics such as lipsticks and moisturizers. These chemicals are associated with several health concerns, including endocrine disruption and organ-system toxicity.[13] **The International Agency for Research on Cancer (IARC) classifies BHA as a possible human carcinogen.**

2.7 Triclosan

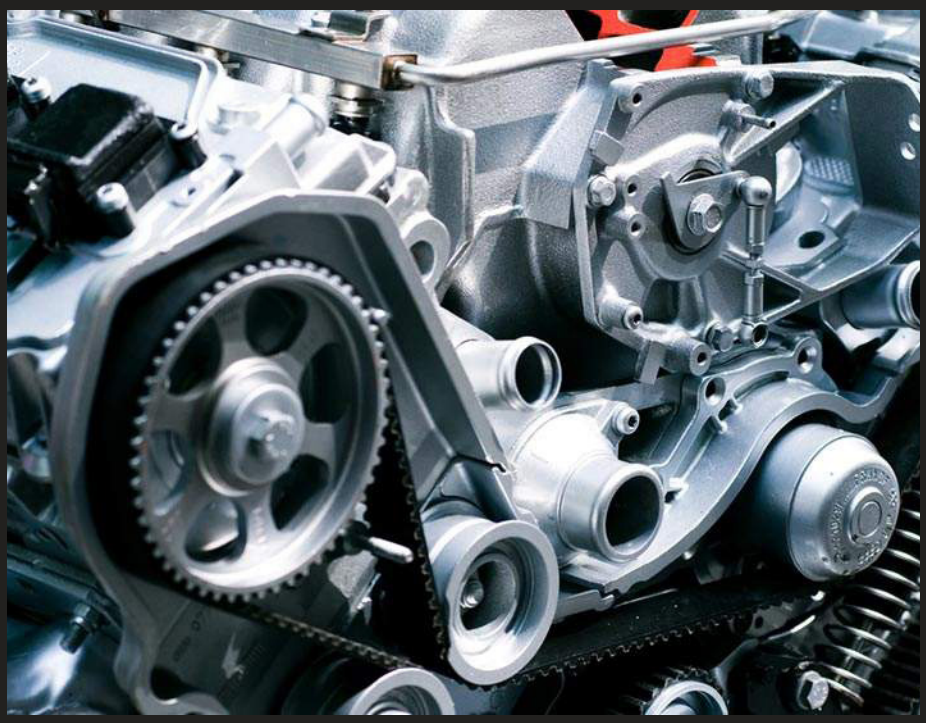
Triclosan (5-chloro-2-(2,4-dichloro phenoxy) phenol) is one such compound having antimicrobial and antifungal properties. Due to these properties, it is used as a preservative and antibacterial agent in personal care products, soaps, veterinary, industrial, and household products. Because of its structure, triclosan is related to many other toxic compounds such as polychlorinated biphenyls (PCBs), polybrominated diphenyl ethers, BPA, and dioxins.[14] Triclosan is frequently being detected in the wastewater treatment plants, lakes, rivers, and seawater in various countries.

Triclosan is lipophilic and bioaccumulates in the fatty tissues. It tends to interfere with hormone function, so has been categorized as an EDC.

Status of phenolic compounds in India

In the year 2020, the production volume of phenol across India was around 58 thousand metric tons. India was the sixth largest producer of chemicals in the world and the third-largest in Asia. The demand for phenol increased at a growth rate of 7.9% over the period of 2016–21. The demand for phenol is primarily fuelled by the growth in phenol-formaldehyde resin manufacture. The manufacture of agrochemicals, alkylphenols, and their uses in the pharmaceutical industry is notable growth drivers of phenol in the domestic market.[15] The two major manufacturers of phenols are Hindustan Organics and SI Group. India like Japan, South Korea, and Taiwan are witnessing an increase in the use of phenol derivatives in the production of electronic goods and automobiles.

The value of phenol exports from India totaled $284 million in 2020, i.e., 0.1% of total Indian exports. The top export destinations included the USA, China, and Germany. The value of phenol imports to India totaled $472 million in 2020, i.e., 0.13% of total imports. The top importers of phenols to India are China, the USA, Japan, and Korea. The top export commodities were polyphenols and monophenols; while top import commodities were phenol and its salts and monophenols.[16] As per the DGFT website, 1,511.27 × 10^3 bisphenol A, diphenylolpropane, and its salts were exported; while 61,544.05 × 10^3 were imported in 2020. This implies that BPA is one of the biggest drivers of phenolic compounds in India.



03

Phenolic compounds and toxicity

Many studies have shown phenolic compounds to be common pollutants in surface water, soil/sediments, and ambient air. The occurrence of phenolic compounds in the environment poses a danger as far as human health and wildlife are concerned. Therefore, many phenolic compounds have been enlisted by the United States Environmental Protection Agency (US EPA)[17], and the European Union (EU)[18], as pollutants of priority concern. Further, the World Health Organisation (WHO) has also designated the phenolic compounds as chemicals of concern.

EXPOSURE TO PHENOLIC COMPOUNDS

The exposure to the phenolic compounds can be through all environmental matrices such as air, water, soil, groundwater, and biota. The major source of exposure to phenolic compounds is from manufacturing and hazardous waste sites. Therefore, people living near landfills, hazardous waste sites, or plants manufacturing phenol and phenolic compounds are the most likely to get exposed. Other possible direct routes of exposure are through the use of consumer products containing phenolic compounds, such as disinfectants, ointments, antiseptic lotions, pesticides, detergents, plastics, etc.

Phenolic compounds have been found in drinking water, indoor air, and certain foods. Compounds such as parabens, bisphenol A, and triclosan, are ubiquitous in indoor environments because of their use in packaging, plastics, personal care products, and as anti-microbials. Women and children tend to be more highly exposed than men, given the types of products in which these chemicals are used. Phenolic compounds are readily absorbed by the inhalation, oral, and dermal routes.

Health and Environmental impacts of phenolic compounds

Most of the phenolic compounds can penetrate the human body and exert toxic effects on humans.[19] Chlorophenols, aminophenols, chlorocatechols, nitrophenols, methyl phenols, and other phenolic compounds all have been shown to exert toxic influence on humans. Long-term exposure to phenolic compounds can lead to irregular breathing,

muscle weakness, and respiratory arrest in humans. Also, chronic exposure to phenolic compounds leads to irritation in the gastrointestinal and central nervous systems, growth retardation, and abnormal development in the offspring of animals.

BPA and some alkylphenols have been identified as endocrine disruptors and alter the development of mammary glands in exposed animals.[20] Studies have found that BPA can interact with a number of body systems including those regulated by the female hormone, estrogen, and thyroid hormones. Pregnant women and children are the most vulnerable to BPA exposure. **BPA can cause harm to the fetus developing inside the mother's womb, thus impacting the developing brain and subsequent behavior of the child.**

Alkylphenols such as NP and OP are potent EDCs and pose potential harm to immune and reproductive systems. They have been shown to affect the male reproductive system, leading to testicular damage, decreased testicular size, and decreased sperm quality.[21] NP is also a potential neurotoxin and found to be highly irritating and corrosive to the skin and eye.

PCP is extremely toxic to humans from acute (short-term) ingestion and inhalation exposure. Short-term exposure to large amounts of PCP can cause harmful effects on the liver, kidneys, blood, lungs, nervous system, immune system, and gastrointestinal tract. Long-term exposure to low PCP levels can cause damage to the liver, kidneys, blood, and nervous system. There is evidence that PCP may have the potential to cause cancer. **US EPA has classified PCP as a Group B2, a probable human carcinogen.**

Skin application of products containing a high concentration of phenolic compounds causes blisters and burns on the skin. Moreover, exposure to high phenolic levels may lead to damage to the heart, kidneys, and liver.[22] Triclosan, widely used in personal care products, can lead to developmental and reproductive effects and also potential cancer risks. The studies on the toxic effects of phenolic compounds are provided in detail in **Annexure II**.

Phenolic compounds have a far-reaching impact on the environment as well. These chemicals can cause the death of fish and other aquatic species and destroy natural ecosystems. They can act as phytotoxins; therefore, their presence in the soil can inhibit seed germination and the growth of local plants. PCP is strongly toxic to plants because of its defoliant and desiccant properties.

Phenolic compounds and their halogenated derivatives can lead to the production of dioxin compounds during the incineration of waste containing phenolic compounds. Dioxins are known persistent organic pollutants and pose well-known health hazards.

04

Global Regulations on phenol and phenolic compounds

Phenolic compounds such as pentachlorophenol and nonylphenol are on the list of chemicals appearing in "Toxic Chemicals Subject to Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986".

Many studies suggest that phenolic compounds such as chlorophenols, bisphenols, alkylphenols, etc. can cause potential harm to human health. Therefore, countries across the globe have come up with regulations to either restrict or phase the use of toxic phenolic compounds.

4.1 Regulations in the United States

Phenol is regulated by the Clean Water Effluent Guidelines for various industrial point sources in the US Code of Federal Regulations.[23] US EPA regulates phenol under the Clean Water Act and the Clean Air Act and has designated it as a hazardous substance and a hazardous air pollutant.

Eleven phenolic compounds are listed as priority pollutants by the US EPA. Phenols listed as priority pollutants include phenol, 2-chlorophenol, 2,4-dichlorophenol, 2,4,6-trichlorophenol, PCP, 4-chloro-3-methyl phenol, 2,4-dimethylphenol, 2-nitrophenol, 4-nitrophenol, 2,4-dinitrophenol, and 2-methyl-4,6-dinitrophenol.

Phenolic compounds such as PCP and NP are on the list of chemicals appearing in "Toxic Chemicals Subject to Section 313 of the Emergency Planning and Community Right-to-Know Act of 1986". This Act requires certain facilities manufacturing, processing, or otherwise using listed toxic chemicals to report the annual quantity of such chemicals entering each environmental medium.

The US FDA deauthorized the use of BPA for baby bottles and sippy cups in 2012 and epoxy resin packaging for infant formulas in 2013. Additionally, around 15 US states also have their laws restricting the use of BPA, mainly in food contact materials intended for children.

In December 2020, the US EPA included five persistent, bioaccumulative and toxic (PBT) chemicals under the Toxic Substances Control Act (TSCA), three of which are phenolic compounds.[24] These phenolic compounds are,

- **2,4,6-Tris(tert-butyl)phenol (2,4,6-TTBP):** An antioxidant in fuel additives and fuel injector cleaners as well as an additive in oil and lubricants.
- **Phenol, isopropylated phosphate (3:1) (PIP 3:1):** A flame retardant in plastics and as a functional fluid in aircraft and industrial machinery.
- **Pentachlorothiophenol (PCTP):** A substance with applications in the rubber industry.

TSCA required EPA to take expedited action on specific PBT chemicals to address risk and reduce exposures to the extent practicable.

In 2021, US EPA has proposed canceling the registration of PCP as a wood preservative.[25]

In 2016, the US Food and Drug Administration (FDA)

Issued a regulation that over-the-counter (OTC) consumer antiseptic wash products containing phenolic compound, triclosan and certain other active ingredients can no longer be marketed.

US EPA has also recommended standards for certain chlorophenols in drinking water such as 1 µg/L for PCP, a maximum of 0.04 ppm for 2-chlorophenol, and a maximum of 0.02 ppm for 2,4-dichlorophenol.[26]

4.2 Regulations in the European Union

Many phenolic compounds such as NPs, 2-(2H-benzotriazol-2-yl)-4,6-ditertpentylphenol (UV-328), 2,4-di-tert-butyl-6-(5-chlorobenzotriazol-2-yl) phenol (UV-327), 4,4'-(1-methylpropylidene) bisphenol, etc. have been classified as **Substances of Very High Concern (SVHC)** under the EU **Registration, Evaluation, Authorisation, and Restriction of Chemicals (REACH)** regulation. The manufacturers and importers of articles containing any SVHC above 0.1% are required to notify their customers and provide instructions on the safe use of the product.

Since 1986, the use of nonylphenol ethoxylate (NPE) has been banned or voluntarily restricted in Europe. For example, Germany has prohibited the use of alkylphenol ethoxylate (APE) in detergents since 1998. The use of NP and NPE in concentrations equal to or higher than 0.1% has been restricted within the EU since 2005 in chemical products under REACH.[27] Since February 2021, a more restrictive regulation applies to NPEs present in textile articles, wherein a maximum concentration of NPE is restricted to 0.01% by the weight of an article (or each part of a textile article).[28] NPs are also prohibited in cosmetics in the EU in 2009.

The EU has put stringent regulations for Triclosan in cosmetics and also banned some products effective from Jan 2017. As per the EU cosmetic directives, the limit for triclosan has been restricted to 0.2% in mouthwashes, and 0.3% in other cosmetic products such as toothpaste, hand soaps, and face powders.

PCP and its salts and esters are banned in the EU. However, they are allowed as unintentional contaminants in substances, mixtures, and articles up to 5 mg/kg

BPA is restricted by several EU regulations and directives such as:

REACH

- BPA has been listed as SVHC due to its toxicity for reproduction and endocrine-disrupting properties that may cause adverse effects on people's health and the environment.
- Starting from 2020, REACH mandates an additional restriction on the use of BPA for thermal paper, with BPA not equal to or greater than 0.02% by weight in such products.

Toy Safety Directive

- The directive requires that the migration limit for BPA in chewable toys by children under the age of 3 years old should be less than 0.04 mg/l (migration limit)

Plastic Food Contact Materials Regulation

- This regulation stipulates that the specific migration limit of BPA from varnishes or coatings on food contact materials should not exceed 0.05 mg/kg
- There is a ban on the use of BPA in plastic bottles and packaging containing food intended to be used by infants and children younger than 3 years old

PCP and its salts and esters are banned in the EU. However, they are allowed as unintentional contaminants in substances, mixtures, and articles up to 5 mg/kg.[29]

PCP, OPs, and NPs are on the list of priority substances of the EU Water Framework Directive and Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) list of dangerous substances.[30,31]

4.3 Regulations of phenolic compounds in other countries

Many other countries have also started taking action to restrict or ban the use of phenolic compounds. BPA is a commonly known EDC and has been phased out in baby feeding bottles and other children products in many countries. The use of BPA in baby feeding bottles has been restricted in China, Malaysia, Brazil, South Africa, and many other countries.

Canada is the first country to recognize BPA as a toxic chemical and put restrictions on the use of BPA for various products. It was the first country, which imposed a ban on the use of BPA in baby feeding bottles and infant feeding cups.

There are also restrictions in place on the environmental release of other phenolic compounds as well as on their use in products. NP and NPE have been added to the list of toxic substances under Schedule 1 of the Canadian Environmental Protection Act, 1999. Under this Act, preventive or control actions will be taken for managing the substance and thereby reduce or eliminate its release into the environment. In China, NP and NPE have been included in the first list of priority chemicals.[32] Further other phenolic compounds such as 2,4,6-tri-tert-butylphenol and pentachlorophenol and its salts and their esters were included in the second list of priority chemicals.[33] NP has been restricted for use in food-to-contact materials by the Chinese National Health and Family Planning Commission in 2017.

In Japan, NP is designated as one of the parameters in the environmental quality standards for water pollution. The US and Canada[34] have also come up with the water quality criteria for phenolic compounds in freshwater.

Australia has set a maximum triclosan permissible limit of 0.3% in cosmetics. Japan has also set a maximum allowable triclosan concentration of 0.1% in cosmetic products.[35]

Many countries have fixed the limit of the Tolerable Daily Intake (TDI) of BPA. The European Food Safety Authority, US FDA, Chinese food safety Authority and Korean Food Safety Authority have issued strict TDI for BPA intake.

4.4 Regulations in India

Despite the global developments to restrict or phase out the use of toxic phenolic compounds, these compounds are not well regulated in India. Like some of the advanced countries, the Indian Food Safety Authority has not established any standard for TDI for BPA.

Currently, India has no regulatory framework for BPA, apart from Bureau of Indian Standards (BIS) standards for baby feeding bottles. In 2015, BIS had banned the use of polycarbonates or any material where BPA is used for manufacturing feeding bottles while observing that an infant's health is at risk due to BPA leaching.

BIS has prohibited the use of NP in cosmetics. Moreover, according to the BIS standard, for cosmetics raw materials and adjuncts, triclosan has been allowed to be used as preservatives at a Maximum Authorized Concentration of 0.3%.

Pentachlorophenol has been banned for manufacture, import, and use in agriculture. However, it is allowed to be used as a wood preservative.

The BIS has set standards for phenols (phenolic compounds expressed as phenols) in drinking water (0.001 mg/L) and surface water (5 mg/L). However, there are no standards for specific phenolic compounds such as chlorophenols, nonylphenols, etc. in drinking water and surface water or regulations on their use in surfactants and other consumer products. The regulatory environmental standards for the effluents discharged from different types of industries for phenolic compounds under Environmental (Protection) Rules, 1986[36] are given in **Annexure III**.

BIS has prohibited the use of nonylphenol in cosmetics. Moreover, according to the BIS standard, for cosmetics raw materials and adjuncts, triclosan has been allowed to be used as preservatives at a Maximum Authorized Concentration of 0.3%.

4.5 Other global developments on phenolic compounds

WHO has given guidance values for certain phenolic compounds in drinking water.[37] For example, a guidance value of 0.009 mg/L for PCP, a health-based value of 1 mg/L for 2-phenyl phenol and its sodium salt, a guidance value of 0.2 mg/L for 2,4,6-trichlorophenol. WHO has also published guideline values for phenoxy herbicides that are sources of phenolic compounds in drinking water, such as 0.03 mg/L for 2,4-D (2,4-dichlorophenoxyacetic acid, 0.09 mg/L for 2,4-DB (2,4-dichlorophenoxybutyric acid) and 0.009 mg/L for 2,4,5-T (2,4,5-trichlorophenoxyacetic acid).

Pentachlorophenol and its salts and esters are included under Annex- A of the Stockholm Convention on Persistent Organic Pollutants with specific exemptions for use in utility poles and cross-arms.

The global organic textile standards (GOTS) prohibit the use of phenolic compounds; namely, chlorophenols (including their salts and esters), complexing agents and surfactants (all APs and APEOs), and plasticizers (BPA) for environmental and/or toxicological reasons in all processing stages of GOTS goods. This standard covers the processing, manufacturing, packaging, labeling, trading, and distribution of all textiles made from at least 70% certified organic natural fibres. Even if the textiles are produced in compliance with this standard, they may carry trace residues due to unavoidable circumstances. The following table lists the corresponding limit values for phenolic compounds in GOTS goods.[38]

Parameters	Criteria (mg/kg)
Alkylphenol (ethoxylates)	
Sum of NP, OP, NPEO, OPEO	<20
Sum of NP, OP	<10
Chlorophenols	
Pentachlorophenol (PCP)	<0.01
Tetrachlorophenol (TeCP)	<0.01
Trichlorophenol (TrCP)	<0.2
Dichlorophenol (DCP)	<0.5
Monochlorophenol (MCP)	<0.5
O-Phenyl phenol (OPP)	<1

- Environmental, Health and Safety (EHS) Guidelines issued by International Finance Cooperation (IFC) for Tanning and Leather Finishing industries include phenol at 0.5 mg/L.
- APEOs and chlorophenols are two of the 11 priority chemicals that have been listed to be phased out by ZDHC in their roadmap ZDHC 2020

05

Conclusions

Several phenolic compounds pose significant risks to human and environmental health; therefore, it is necessary to identify and reduce environmental impacts through the prevention of pollution by phenolic compounds. Concerted actions have been initiated globally to restrict the use of these compounds in products and other environmental matrices to minimize their adverse impacts.

However, considering the development in the countries like the US and EU countries, the level of information and interventions to restrict the use of phenolic compounds in India is very limited . For example, the EU countries have taken decisive action to restrict nonylphenols but there are no regulations on these compounds in India, except in cosmetics. There are no standards for specific phenolic compounds such as chlorophenols, nonylphenols, etc. in drinking water. Moreover, there is a hardly any research studies are being conducted on the impact of the environment and human health from the phenolic compunds in India.

Therfore there is a need more data on the use of these compounds and their impact on human and environmental health. The government should also encourage and support research projects on phenolic compounds in the country. Further considering the significant adverse impact of phenolic compunds on the environment, a road map is required to phase out or restrict some of the toxic phenolic compounds in the country.

For example, the EU countries have taken decisive action to restrict nonylphenols but there are no regulations on these compounds in India, except in cosmetics.

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Annexure I: Studies on phenolic compounds in water and sediments

Location/Country	Findings	Reference
Weihe River, Northwest China	• 11 phenolic compounds; namely, phenol, 2-chlorophenol, 4-chloro-m-cresol, 2,4-dichlorophenol, 2,4,6-trichlorophenol, pentachlorophenol (PCP), 4-nitrophenol, 3-methylphenol, 2,4-dinitrophenol, 2-nitrophenol, 2,4-dimethyl phenol were analysed • Total phenolic concentration ranged from 0.06 to 14.12 µg/L with an average of 5.22 µg/L in water • PCP concentration (2.65 µg/L) was the highest among all the compounds • Concentration ranged from 0.92 to 34,885 µg/g in suspended particulate matter, and 3.54 to 34.09 µg/g in sediment	Chen et al.[39]
Jiangsu province, China	• 4 compounds; namely, Bisphenol A (BPA), octylphenol (OP), nonylphenol (NP), and diethylstilbestrol (DES), were tested in 32 samples from two drinking waterworks • DES was present in all the samples, with concentrations ranging from 1.46 to 12.0 ng/L • BPA, OP and NP concentrations ranged from ND to 17.73 ng/L, ND to 0.49 ng/L, and ND to 3.27 ng/L, respectively	Lv et al.[40]
Cuautla River, State of Morelos, Mexico	• BPA, 4-NP and 4-t-OP, were determined in the River during the dry season • The most abundant compound was BPA (22.46 ng/L), followed by 4-t-OP (11.24 ng/L) and 4-NP (7.53 ng/L)	Calderón-Moreno et al.[41]
Minas Gerais, Brazil	• Seventeen phenolic compounds were monitored in the surface/untreated water (RW) and drinking/treated water (TW), taking the EPA priority compounds list as a reference • The compounds detected at high frequency in the raw surface water were 2,3,4–trichlorophenol (2,3,4-TCP), 2,4–dimethylphenol (2,4-DMP), and 4–nitrophenol (4-NP) • The compounds detected at high frequency in the treated water were 4-NP and BPA	Ramos et al.[42]
Korea and other 7 South-east Asian countries (Laos, Cambodia, Vietnam, China, Indonesia, Thailand, and Malaysia)	• Range of average concentrations of NP, OP and BPA during the subsequent years of 2007 and 2008 in 7 South-east Asian countries are: NP (BDL to 2.1 µg/L), OP (BDL to 15.1 ng/L) and BPA (BDL 10 133 ng/L) • Average concentrations of NP, OP and BPA during the years 2005 to 2007 in Korea are: NP (123.5 ng/L), OP (0.1 ng/L) and BPA (3.2 ng/L) • NP concentrations in these 8 countries were higher compared to those reported in the European countries, America and Japan	Duong et al.[43]
Buffalo River of Eastern Cape, South Africa	• 11 phenolic derivatives were measured in Buffalo River in two seasons, summer and autumn • Total phenolic concentrations were remarkably higher than the regulatory standard (USEPA) of 500 ng/L in all the sites during summer and in sites BRE and MSN during autumn	Yahaya et al.[44]

Location/Country	Findings	Reference
Swedish Rivers	• 10 phenolic compounds; namely, 4-octylphenol (4-OP), 4-tertoctylphenol-monoethoxylate (4-OP-EO1), 4-tert-octylphenol-diethoxylate (4-OP-EO2), 4- nonylphenol (4-NP), 4-tert-nonylphenol-monoethoxylate (4-NP-EO1), 4-tert-nonylphenoldiethoxylate (4-NP-EO2), 2,4,6-tribromophenol (TBP), pentachlorophenol (PCP), triclosan (TCS), and bishenol A (BPA) were investigated in 10 Swedish rivers • Dominant phenolic compounds were 4-NP, 4-NP-EO2, and TBP	Ahrens et al.[45]
Rivers in Lagos, Nigeria	• Water samples were collected from River Ogun and River Ibeche in southwestern part of Nigeria and analysed for 4-t-OP, 4-NP and BPA • 4-NP and 4-t-Op were detected in all the water samples with concentrations ranging from 43.9–79.4 ng/L and 57.1–68.6 ng/L, respectively. However, BPA was not detected in any sample	Oketola and Fagbemigun[46]
Lake Maryut, Egypt	• Phenolic compounds were investigated in the sediments of a heavily polluted coastal wetl and • Chlorophenols (25 to 1246 µg/kg) were the major group detected in the lake sediments followed by methylphenols (up to 396 µg/kg) and nitrophenols (up to 163 µg/kg)	Khairy[47]
Select rivers in Japan, Korea, China, and India	• Concentrations of eight bisphenol analogues including BPA, BPS, and BPF were determined in surface water • The highest concentration of BPA was found in Buckingham Canal and Cooum River in Chennai, India • BPF was the major contaminant in rivers in Japan, Korea, and China and the concentrations of this compound were 1 to 2 orders higher than those of BPA present in these samples	Yamazaki et al.[48]
Kaveri, Vellar and Tamiraparani rivers, Tamil Nadu, India	• Concentrations of OP, NP and BPA ranged from ND to 16.3 ng/L, ND to 2200 ng/L, and 2.8 to 136 ng/L, respectively • All three rivers showed a similar distribution pattern of NP >> BPA > OP	Selvaraj et al.[49]
Surface waters, India	• Eight BPs were analyzed in surface waters collected from 12 states and Delhi-National Capital Terriority, India • BPA, BPS, and BPF were prevalent analogues, out of which BPA was the predominant species • The highest BPA concentration was observed in the Yamuna River (14,800 ng/L), followed by the Cooum River (1,420 ng/L)	Lalwani et al.[50]
River Ganga and Suderban wetland, India	• River concentrations of BPA (0.04–4.46 µg/L) were higher than BPA (0.21–2.82 µg/L) in the Suderban wetland	Chakraborty et al.[51]

Annexure II: Toxic effects of phenolic compounds

Phenolic compounds	Toxic effects
Phenol	Irregular breathing, muscle weakness, and tremors, Central Nervous System disorders, Gastrointestinal irritation, cardiac arrhythmias
Chlorophenols	White necrotic lesions in mouth, oesophagus, and stomach, irregular pulse, hypotension, damage to lungs, liver, kidneys, skin, and digestive tract
Nitrophenols	Irritation to eyes, skin, and respiratory tract, Causes cyanosis, confusion, and unconsciousness

Phenolic compounds	Toxic effects
Methyl phenols	burning pain in mouth and throat, abdominal pain, headache, weak irregular pulse, shock, paralysis of the nervous system, coma, and death
Aminophenols	Skin and eye irritation, eczemas, asthma, and anoxia
Buthylhydroxytoluene/buthylhydroxyanisole	Damage to the adrenal gland and increase brain and liver weight
Bisphenols	heart disease, diabetes, and liver abnormalities in adults as well as brain and hormone development problems in fetuses and young children

Annexure III: Regulatory environmental standards for the effluents discharged from different types of industries for phenolic compounds in India

Industry	Parameter	Regulatory Environmental Standards (mg/L)
Cotton textile industry (Composite and Processing)	Phenolic compounds (as C_4H_2OH)	5.0
Composite Woollen Mills	Phenolic compounds (as C_6H_5OH)	5.0
Textile Industries	Phenolic compounds (as C_6H_5OH)	1.0
Dye and Dye Intermediate Industries	Phenolic compounds (as C_6H_5OH)	1.0
Coke Ovens	Phenolic compounds (as C_6H_5OH)	5.0
Petrochemicals (Basic and Intermediate)	Phenol	5.0
Pesticide Manufacturing and Formulation Industry	Phenolic compounds (as C_6H_5OH)	1.0
Paint Industry Wastewater discharge	Phenolic compounds (as C_6H_5OH)	1.0
CETP	A. Primary treatment Phenolic compounds (as C_6H_5OH) B. Treated effluent quality Phenolic compounds as C_6H_5OH)	5.0 1.0 (Inland Surface Water) 5.0 (Marine Coastal Water)
Organic Chemicals Manufacturing Industries	Phenolic compounds as C_6H_5OH)	5.0
Oil drilling and Gas Extraction Industries	Phenolic compounds as C_6H_5OH)	1.2
Pharmaceuticals (Manufacturing and Formulation Industries)	Phenolic compounds as C_6H_5OH)	1.0
Coal Washeries	Phenolic compounds as C_6H_5OH)	1.0

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