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A brief review on Aromatic Volatile Organic Compounds

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Abstract

The review article highlights the major features and the hazardous effects of aromatic volatile organic compounds on environment. The environmental issues are a serious note for today's world and volatile organic compounds are now well known for environmental pollution. The aromatic compounds are a major class of organic chemistry. The aromatic compounds with low boiling points are volatile in nature and they easily contaminate the air. There are many aromatic volatile organic compounds used in our daily commodities from which the compounds enter into the air in vapour form. Most of the aromatic volatile compounds are toxic to biological systems. This review article focuses on the major compounds those are hazardous to the environment.

Keywords: *VOC, aromatic, environment, organic*

1 Introduction

Organic compounds are the covalent compounds of carbon excluding carbonates, carbides and the oxides. Based on different criteria, the compounds are classified into several sub classes. A relatively new class of organic compounds is Volatile Organic Compounds abbreviated as VOCs. Although the compounds belonging to the class were known for long time, they have been come into light because of their impact on the environment [1-3].

Depending upon the physical properties and chemical structures, organic compounds are classified in different subclasses. Volatile organic compounds are the compounds which can easily vaporise under normal temperature and pressure. The compounds have usually low boiling point at standard atmospheric pressure. Depending upon the boiling points, the volatile organic compounds can further be subdivided into three categories [4].

Very volatile organic compounds (Relatively lower boiling point less than 100 ^{0}C)

Volatile Organic compounds (boiling point in between 100 to 250 ^{0}C)

Semi volatile Organic compounds (boiling point in between 250 to 400 ^{0}C)

The classification is arbitrary and was proposed by World Health Organisation in 1989. When we discuss about VOCs, we consider any organic compound that vaporise under normal conditions.

Although several VOCs were known from organic chemistry laboratories, the extensive research has been started not before 1970s when it was revealed that VOCs are primary contributors to ground level ozone contributors. VOCs are responsible for destroying the ozone layer by free radical mechanism and the reactivity is comparable to nitrogen oxides $(NO)_x$. For examples, several halogenated hydrocarbons (low molecular weight to high molecular weight) are used in refrigerator and cooling machines which are very volatile organic compounds. The halogenated hydrocarbons are considered as one of the most ozone layer depletory agents [5,6].

2 **VOCs and their potential sources** [7,8]

The major sources of VOCs are petroleum based fuels used in industries and automobiles. Apart from industrial uses, many organic chemicals have been used as household commodities since long ago. Paints and other building materials, Burnishes, Perfumes, disinfectants, Oil cleaners, air fresheners are the mostly used household commodities containing VOCs. These products constantly release VOCs when they are in use and also when they are stored. When VOC containing products are used inside the home, the emitted VOCs are concentrated in indoor air. The concentration of VOC in indoor air depends on the amount and frequency of the products used and also how quickly fresh outdoor air enters into the house. Many VOCs are toxic and harmful for health and the indoor air quality is affected by the contamination of VOCs. The VOCs can be inhaled easily during respiration and depending upon the chemical structures and chemical natures, some of VOCs are very harmful for a biological system.

The measurement of overall concentrations of the volatile organic compounds in air is called Total

Volatile Organic Compounds (TVOC) which is used for estimation of indoor air quality (IAQ) [9-12]. The measurement highlights the effects of the VOCs in environment and prediction of health issues. Most of the literature reports about the Indoor air quality in non- industrial areas reveal that most of the VOCs are present in less than 1 mg/ m^3 in concentration and very few VOCs exceed 25 mg/ m^3.A list of commonly used household products containing VOCs is given below:

Table 1: Common volatile compounds in our essential commodities

Name of the household commodity	VOCs present
Cosmetics and beauty products: Nail polish remover, hair spray, perfumes	Acetone, ethyl alcohol, isopropyl alcohol, organic esters
Household fuels like kerosene, gasoline and other petroleum distillates	Pentane, hexane,cyclohexane, octane
Paints,burnishes, glue,oil based stains	Benzene, toluene,
Refrigerant in refrigerators, air-conditioner	Freons (chlorofluoro carbons)
Paint stripper, adhesive remover	Methylene chloride, toluene, carbon tetrachloride
Perfumes, Fragrance products, scented materials	Limonene, pinene, isoprenes, ethyl alcohol, linalool, β-phenethyl alcohol, and β-myrcene
Kitchen oil cleaner, degreaser, electronic cleaners, spot removers, dry cleaners, fabric cleaners, commercial solvents	Methylene chloride, toluene, trichloroethylene, xylenes, MTBE, per chloroethylene
New furniture, carpets, press-wood materials	formaldehyde

A long list of volatile organic compounds is known till date. This review focuses on the aromatic VOCs which are known as major environmental pollutant and cause serious health issues. Aromatic compounds are a special class of organic compounds having some special features in their electronic structures and chemical properties [13]. And a considerable list of aromatic compounds contributes to the volatile organic compounds.

3 Aromatic VOCs

3.1 Benzene:

Benzene is the mostly used aromatic compound. It is a component of crude oil. It is a colourless, highly volatile liquid at room temperature with boiling point of 80.1 ^{0}C and the vapour pressure of 12.7 kPa at 25 ^{0}C. The high vapour pressure makes it a very volatile organic compound (VVOC).

Benzene is widely used as solvents, cleaning agent in industries and laboratories and fuels for vehicles and machines and contaminates the outdoor air. The benzene vapours from outdoor air enters into indoor air. In addition to the incoming benzene vapour from outdoor air, the indoor air benzene is caused mainly by human activities. Fuels like kerosene, gasoline and LPGs emit benzene vapours into air. The benzene concentration has been found to be very high in kitchen space. Benzene is a very common solvent in paints, burnishes, adhesives, degreasing agents, paint removers, rubber cements and denatured alcohols which are very common household products [14- 19]

Another very strong source of indoor benzene vapour is tobacco smoke. Mainstream cigarette smoke contains approximately 4400 chemicals. The main components of cigarette smoke are vapours of volatile aromatic compounds like benzene, toluene, styrene, xylenes [16]

In USA, the indoor air of a smoker's house is contaminated with 10.5 µg/ m^3 of benzene and a non-smoker's house the indoor benzene concentration is 7 µg/ m^3. In Canada, the average benzene concentration in indoor air is 7.4 µg/ m^3. In comparison to USA or Europe, the indoor benzene concentration in Asian or Africa countries are considerably large. In India, a house where kerosene stoves are used as fuel source, has benzene concentration in indoor air of 103 µg/ m^3. It has been found that in USA and Canada a human being intakes benzene vapour mostly from indoor air and the intake range range is 180 – 1300 µg/ day. Active smoking adds 400- 1800 µg/ day of benzene inhalation whereas passive smoking (alternatively known as Environmental Tobacco Smoke or ETS) adds 14-50 µg/ day of benzene inhalation to the average benzene intake.

Short exposure to very high levels of benzene in air (10,000-20,000 ppm) can even result in death. Lower levels (700 - 3,000 ppm) of benzene in air can cause several health hazards like drowsiness, dizziness, rapid heart rate, headaches, tremors, confusion, and unconsciousness. Consumption of foods or drinks

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containing high concentration of benzene can cause vomiting, irritation of the stomach, dizziness, sleepiness, convulsions, rapid heart rate, coma, and death. Benzene causes damage to cornea when it comes in direct contact to the eye.

Long exposure of benzene affects the production of blood cells as benzene is accumulated in bone marrow inside the body and effects the formation of blood cells. It causes abrupt decreases in red blood cells in blood and can lead to anaemia. Long term bezene exposure also affects the immune system.

Long term exposure of benzene is responsible for leukaemia which is the state of cancer of blood forming organs and the type of leukemia is called as acute myeloid leukemia (AML).

3.2 Toluene:

Another very commonly used aromatic hydrocarbon is toluene which is methylbenzene. It is also obtained from fractional distillation of crude oil. The physical properties include the boiling point of 110 ^{0}C and vapour pressure of 2.8 kPa at 20 ^{0}C. Now- day's toluene is prepared in large scale as a by-product of gasoline production and production of coke from coal. Toluene is less volatile compared to benzene.

Toluene is largely used as solvent in glues, paints, lacquers, correction fluid, adhesives and nail polish remover, and is used in the printing and leather tanning processes. It is mixed with gasoline as octane booster (it enhances the octane rating of the fuel). Toluene is also a component of some beauty care products like nail polishes. It is used in manufacturing other chemicals like benzene, urethanes, dyes and other pharmaceutical molecules. Cigarette smokes also contain toluene but in less concentration. The largest sources of toluene is the automobiles and the concentration of toluene in urban areas are very high (350 ppb) with respect to remote areas (1.3- 6.6 ppb). The concentration of toluene in the air near a petrol station is excessively very high (2400 ppb) [20, 21]

The health hazards caused by toluene and its vapour depend upon the time of exposure and personal sensitivity. Toluene causes, eye, skin, throat and nose irritation. Toluene is easily absorbed by gastrointestinal tract after ingestion. After being absorbed, toluene mainly deposit in adipose tissues and then in kidneys, liver and brain. Long exposure causes headaches and dizziness. It is also related to affecting the nervous system causing short term memory loss, loss of concentration.

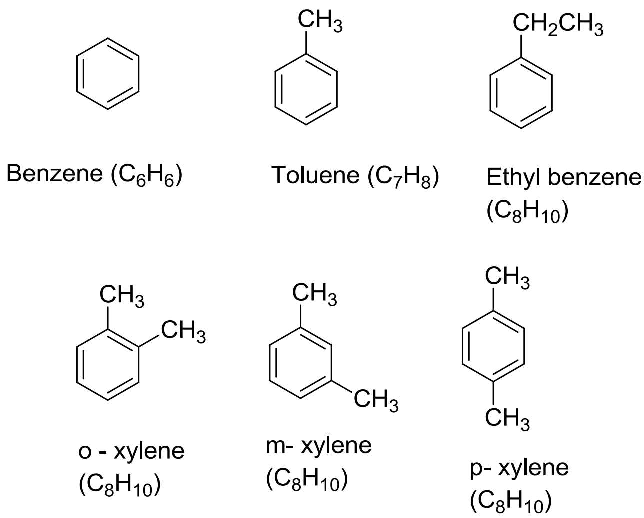

Figure 1: Structures of BTEX (benzene, toluene, ethyl benzene and xylenes)

Four isomers of aromatic hydrocarbon with molecular formulas C_8H_{10} are also known as VOCs. Their molecular structures are formulas have been shown in figure 1. o- Xylene, m- Xylene and p-xylene are collectively known as xylenes. The aromatic hydrocarbons are abbreviated as BTEX (Benezene, Toluene, Ethyl benzene and Xylene) [22-28]. Their physical properties are listed below:

Table 2: Physical characteristics of BTEX

Name of the compound	Physical state and density	Vapour pressure	Boiling point
Ethyl benzene	Colourless liquid 0.8665 g / mL	1.33 kPa at 25 ^{0}C	136 ^{0}C
o- Xylene	Colourless liquid 0.88 g / mL	0.93 kPa at 25 ^{0}C	144.4 ^{0}C
m- Xylene	Colourless Liquid 0.86 g / mL	1.19 kPa at 25 ^{0} C	139 ^{0}C
p- Xylene	Colourless liquid 0.86 g / mL	1.19 kPa at 25 ^{0} C	138.4 ^{0}C

3.3 Ethyl benzene and Xylenes:

Ethyl benzene is found in fuels like gasoline (ethyl benzene is mixed with gasoline as anti- knock agent), permanent marker pens, inks, carpet glues, insecticides paints and tobacco products. Most of the ethyl benzene is used in plastic industries as it is used to make styrene which is the monomer of polystyrene. Polystyrene is widely used polymer. Xylenes are used as solvents in industries and laboratories. P- Xylene is mainly used in making terepthalic acid which is the monomer component of the polymer, polythene terephthalate.

Ethyl benzene and xylenes are absorbed into human body mostly by inhalation. Ethyl benzene is readily absorbed by gastrointestinal tract and causes kidney and liver enlargement at high doses. Long exposure to ethyl benzene causes eye and skin irritation. Exposure to xylene mainly affects the central nervous system causing headaches, dizziness, lack of muscle coordination etc.

The quality of air depends on the concentration ratios of different volatile aromatic hydrocarbons. Benzene and toluene have atmospheric life time of 12.5 and 2 days and they are relatively stable. On the other hand, Xylenes have an average life time of only 7.8 hours and are unstable. The concentration ratio of toluene to benzene (T/B) is particularly important to quantify the quality of an air sample. In industrial areas, the ratio is high. Higher the ratio of T/B, more polluted the air is.

Table 2: Reported values of BTEX in air

Air (μg/m^3)	Benzene	Toluene	Ethyl benzene	Xylenes
Remote rural areas	0.2 – 16	0.5 – 260	0.2 – 1.6	< 0.1 – 0.3
Industrial areas with heavy traffic	upto 349	Upto 1310	upto 360	upto 775

All data of the table have been collected from Agency for Toxic Substances and Disease Registry, 2000, 2007a, 2007b, 2007c and WHO, 2008.

3.4 Exposure of BTEX to environment and biological systems

Petroleum industries and automobiles where hydrocarbons are used as fuels, are the major sources of BTEX. The BTEX emitted from different sources directly enter into the air. The ground water is mainly contaminated by BTEX when petroleum products are directly mixed with water. The intake of BTEX into biological systems is mainly due to inhalation. Exposure of BTEX in human and other animals from ground water contribute to only a very small fraction.

BTEX is collectively referred as Hazardous air pollutants (HPAs) as they mix with air very easily and inhalation of the compounds causes several serious health disorders including cancer, central nervous system diseases, respiratory and nasal problems. Being the hydrocarbons, BTEX are lipophilic in nature and they are accumulated in the body parts containing lipids, like brain, bone marrow, liver, body fat. The lipophilicity of the compounds helps them to cross mucous epithelia of the respiratory tract and the cell membranes in various organs. The biotransformation of the compounds in different body organs mostly in liver, nose mucous epithelium and tracheobronchial tree produce toxic metabolites which inhibit enzymatic actions in the body system.

BTEX compounds are moderately reactive and their toxicity effect is regulated by their chemical reactivity. BTEX compounds in living system undergo biotransformation by enzymatic activities. Among the BTEX, benzene has the highest toxic potential as it has been found that the oxidation of benzene forms epoxide molecule by CYP2E1 action. Benzene during its metabolism in body system is oxidised to benzoquinone which is accumulated in bone marrow and is myelotoxic as well as clastogenic. At low doses, benzene forms toxic metabolites into body systems like benzene epoxide, benzene dihydrol, benzoquinone, catechol etc. At high doses, benzene inhibits hydroquinone from phenol by competing with CYP2E1 and hence benzene is found to be toxic at low doses. The oxidised form benzene (benzoquinone) is responsible for leukemia in bone marrow and livers [18].

Among the BTEX, benzene is classified as the most toxic VOC and is highly carcinogenic (Group A carcinogen) and other compounds like toluene, ethyl benzenes and xylenes are classified as Group D carcinogen (very less or no carcinogenicity).

3.5 Other aromatic VOCs

The chlorinated analogues of benzene, chlorobenzene is another aromatic volatrile organic compounds. The chlorinated aliphatic VOCs are well known for their toxic and polluting nature. Chlorobenzene has vapour pressure of 1.57 kPa at 25 ^{0}C with boiling point of 132 ^{0}C. The colourless, flammable liquid has an almond like odour. In the past, it was mainly used in preparing the pesticide DDT. Now-a –days, it is mainly used in chemical laboratories as solvents and in degreasing parts of automobiles.

An aromatic aldehyde, benzaldehyde is known to be a VOC. It is a colourless liquid with almond like odour. It has the vapour pressure of 0.53 kPa at 25 ^{0}C with a boiling point of 178.1 ^{0}C. It is a very common chemical in perfume and cosmetic industries as a denaturant, a flavoring agent, and as a fragrance. The highest percentage of benzaldehyde in cosmetics was reported to be 0.5%. It is also used in manufacturing several derivatives derivatives that are commonly used in the perfume and flavor industries. In the pharmaceutical industry benzaldehyde is used as an intermediate in the manufacture of chloramphenicol, ephedrine, ampicillin, diphenylhydantoin, and other products.

Breathing benzaldehyde vapours cause irritation to noses and throats. Benzaldehyde may cause mutations. In addition, it causes skin allergy on long exposure.

4 Conclusion

In conclusion, the present review focuses on the chemical characteristics of the major aromatic volatile compounds and their effects on environment and biological systems. The aromatic volatile compounds have their presence in industrial sources as well as in daily life commodities from low to high concentrations. Mostly used aromatic volatile compounds are the hydrocarbons (BTEX). Apart from that some other compounds like aromatic aldehydes, halogenated aromatic compounds are also known which also has adverse effects. The compounds have considerable volaitily which allow them to mix in the environment easily and enter into the biological systems by inhalation. The review also describes the hazardous effect caused by the compounds inside the body.

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