



Naphthalene

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Abstract: Both the ongoing grouping of naphthalene as a potential human cancer-causing agent and its ubiquitous presence motivate this critical review of naphthalene's sources and exposures. We evaluate the environmental literature on naphthalene published since 1990, drawing on nearly 150 studies that report emissions and concentrations in indoor, outdoor and personal air. While naphthalene is both a volatile organic compound and a polycyclic aromatic hydrocarbon, concentrations and exposures are poorly characterized relative to many other pollutants. Most airborne emissions result from combustion, and key sources include industry, open burning, tailpipe emissions, and cigarettes. The second largest source is off-gassing, specifically from naphthalene's use as a deodorizer, repellent and fumigant.

In the U.S., naphthalene's utilization as a moth repellent has been decreased for para-dichlorobenzene, but extensive use continues in mothballs, which seems responsible for some of the highest indoor exposures, along with off-label uses. Among the studies judged to be representative, average concentrations ranged from 0.18 to 1.7 $\mu\text{g m}^{-3}$ in nonsmoker's homes, and from 0.02 to 0.31 $\mu\text{g m}^{-3}$ outdoors in urban areas. Personal exposures have been reported in only three European studies. Indoor sources are the major contributor to (non-occupational) exposure. While its central tendencies fall well below guideline levels relevant to acute health impacts, several studies have reported maximum concentrations exceeding 100 $\mu\text{g m}^{-3}$, far above guideline levels. Using current but draft estimates of cancer risks, naphthalene is a major environmental risk driver, with typical individual risk levels in the 10⁻⁴ range, which is high and notable given that millions of individuals are exposed. Several factors influence indoor and outdoor concentrations, but the literature is inconsistent on their effects. Further investigation is needed to better characterize naphthalene's sources and exposures, especially for indoor and personal measurements.

Keywords: naphthalene; air quality; ambient air; exposure; indoor air; personal exposure; health effect; residences; risk; physical and chemical properties; volatile organic compound.

1 INTRODUCTION

Naphthalene is a harmful air poison generally found in encompassing and indoor air because of outflows from the chemical and primary metals industries, biomass burning, gasoline and oil combustion, tobacco smoking, the use of mothballs, fumigants and deodorizers, and many other sources. Naphthalene is widely used as an intermediate in the production of phthalic anhydride (66,000 metric tons in the U.S. in 2000), surfactants (27,000 tons) and pesticides (14,000 tons). Naphthalene is also called tar camphor, naphthene, naphthalene, naphthalene, mothballs, mothflakes and white tar; trade names include albocarbon, dezodorator and it is rather a special compound in terms of its properties and chemical structure. It is a flammable white solid with the formula C₁₀H₈ and the structure of two fused benzene rings, with melting and boiling points of 80.5 and 218 °C, respectively.

Its odor is fairly distinctive but not unpleasant, and its odor threshold is about 440 $\mu\text{g m}^{-3}$. It is classified as a semi-volatile organic compound (SVOC) due to its vapor pressure of 0.087 mmHg at 25 °C, which is just below the 0.1 mmHg cut-off often used to define volatile organic compounds (VOCs). However, naphthalene sublimates rapidly at room temperatures. Due to its bicyclic aromatic structure, naphthalene is also a polycyclic aromatic hydrocarbon (PAH), and it is the most volatile member of this group. Exposure to naphthalene has been linked to a

number of adverse health effects. The major non-cancer endpoints are hyperplasia and metaplasia in respiratory and olfactory epithelium, respectively, and the cancer endpoint of concern are nasal tumors.

The World Health Organization is considering the development of an indoor air guideline for naphthalene. Meaningful estimates of exposures for the general public can only be developed with appropriate and adequate information on concentrations in the various microenvironments frequented by people. Often, the home residence is considered the most important microenvironment in exposure assessment since this is where people spend most of their time, e.g., 69% in the U.S. and 66% in Canada. Focusing on current exposures is important as these represent the starting point for risk reduction efforts, and since exposures to many pollutants have declined due to actions aimed at controlling pollutant use, emissions, and concentrations.

This paper reviews the more recent naphthalene literature, concentrating on sources and concentrations in private indoor environments and open air. We derive representative estimates of naphthalene concentrations that can be used to estimate background levels and risks, and we discuss determinants of exposure, information intended to inform the development of policies and regulations aimed at improving air quality and reducing exposures. Our scope largely excludes occupational and industrial settings, though we note that many workers may be exposed, estimated that 112,700 workers were potentially exposed to naphthalene. Exposure concentrations from 0.7 to 93.2 $\mu\text{g m}^{-3}$ have been reported in industrial settings in Germany and have exceeded 1,000 $\mu\text{g m}^{-3}$ in aluminum, coke, creosote and iron industries in Europe, much higher than seen in the outdoor, indoor and personal air studies discussed in the body of this paper.

2 NAPHTHALENE

Naphthalene is an organic compound with formula C_{10}H_8 . It is the simplest polycyclic aromatic hydrocarbon, and is a white crystalline solid with a characteristic odor that is detectable at concentrations as low as 0.08 ppm by mass. Naphthalene was first registered as a pesticide in the United States in 1948. and it is made from crude oil or coal tar. It is also produced when things burn, so naphthalene is found in cigarette smoke, car exhaust, and smoke from forest fires. It is used as an insecticide and pest repellent. As an aromatic hydrocarbon, naphthalene's structure consists of a fused pair of benzene rings.

It is best known as the main ingredient of traditional mothballs. Naphthalene works when gas is inhaled, the body breaks it down into other chemicals that react with cells in the body and damage tissues. How naphthalene kills moths are not understood. The odor is thought to be unpleasant enough to drive animals away in repellent products. Naphthalene can be exposed to a pesticide if you breathe it in, get it on your skin, or if you accidentally eat or drink something containing a pesticide. This can happen if you get some on your hands and don't wash them before eating or smoking. People are most likely to be exposed to naphthalene by breathing in the vapors. When you smell mothballs, you are inhaling the pesticide. Small children and pets are at risk of eating mothballs, because they look like candy or other treats.

3 SIGNS AND SYMPTOMS OF NAPHTHALENE

As its stated earlier that naphthalene is known as the main ingredients of traditional mothballs the underneath are the most essentials signs and symptoms of naphthalenes

People have developed headaches, nausea, dizziness, and/or vomiting after being exposed to naphthalene vapors. If someone breathes in enough of the vapor or eats a mothball containing naphthalene, they might develop hemolytic anemia. This is when red blood cells break apart, and no longer carry oxygen the way they should. Small children have also developed diarrhea, fever, abdominal pain, and painful urination with discolored urine after eating naphthalene mothballs. Dogs that have eaten naphthalene mothballs may have lethargy, vomiting, diarrhea, lack of appetite and tremors. Clothing that was stored in mothballs without being washed afterwards has caused anemia in infants who wore the clothing, diapers or blankets.

People with an inherited enzyme deficiency are at much greater risk of anemia than people with normal enzyme levels. When naphthalenes enters to the human body it brings great changes and entirely affects the body of human beings. In humans, naphthalene is broken down to alpha-naphthol, which is linked to the development of hemolytic anemia. Kidney and liver damage may also occur. Alpha-naphthol and other metabolites are excreted in urine. In animals, naphthalene breaks down into other compounds including alpha-naphthol, which may affect the lungs and eyes. Naphthalene was found in the milk of exposed cows, but the residues disappeared quickly after the

cows were no longer exposed. Nearly all the naphthalene was broken down into other compounds and excreted in their urine. Naphthalene not only affect human being but it also has a great effect in the environment and as well, birds, and animals. Most naphthalene in the environment will turn into a gas. Some of it may be bound to soil, where it can be taken up by plants. It can also be deposited on plant leaves from the air.

Naphthalene is broken down by bacteria, fungi, air, and sunlight. Naphthalene has been found in wastewater treatment plant discharge. No information was found on naphthalene and groundwater. The half-life of naphthalene in the environment may range from less than one day in air to over 80 days in soil .Naphthalene affects birds, fish and other wildlife. It was considered moderately toxic to several species of fish, water fleas, and Pacific oysters. It was considered slightly toxic to green algae. Naphthalene was considered practically non-toxic after being fed to bobwhite quail.

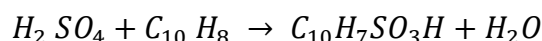
4 PHYSICAL PROPERTIES

A naphthalene molecule can be viewed as the fusion of a pair of benzene rings. (In organic chemistry, rings are *fused* if they share two or more atoms.) As such, naphthalene is classified as a benzenoid polycyclic aromatic hydrocarbon (PAH). The eight carbons that are not shared by the two rings carry one hydrogen atom each. For purpose of the standard IUPAC nomenclature of derived compounds, those eight atoms are numbered 1 through 8 in sequence around the perimeter of the molecule, starting with a carbon adjacent to a shared one. The shared carbons are labeled 4a (between 4 and 5) and 8a (between 8 and 1) The chemical formula for naphthalene is C₁₀H₈, and its molecular weight is 128.19 g/mol. Naphthalene occurs as a white solid or powder that is insoluble in water. (1,8) Naphthalene has a strong, mothball odor, with an odor threshold of 0.44 mg/m³ (0.084 parts per million, ppm). The vapor pressure for naphthalene is 0.087 mm Hg at 25 °C, and its log octanol/water partition coefficient (log Kow) is 3.29.

5 CHEMICAL PROPERTIES

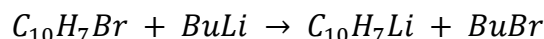
5.1 Reactions with electrophiles

In electrophilic aromatic substitution reactions, naphthalene reacts more readily than benzene. For example, chlorination and bromination of naphthalene proceeds without a catalyst to give 1-chloronaphthalene and 1-bromonaphthalene, respectively. Likewise, whereas both benzene and naphthalene can be alkylated using Friedel–Crafts reactions, naphthalene can also be easily alkylated by reaction with alkenes or alcohols, using sulfuric or phosphoric acid catalysts. In terms of regiochemistry, electrophiles attack at the alpha position. The selectivity for alpha over beta substitution can be rationalized in terms of the resonance structures of the intermediate: for the alpha substitution intermediate, seven resonance structures can be drawn, of which four preserve an aromatic ring. For beta substitution, the intermediate has only six resonance structures, and only two of these are aromatic. Sulfonation gives the "alpha" product naphthalene-1-sulfonic acid as the kinetic product but naphthalene-2-sulfonic acid as the thermodynamic product. The 1-isomer forms predominantly at 25 °C, and the 2-isomer at 160 °C. Sulfonation to give the 1- and 2-sulfonic acid occurs readily:



5.2 Lithiation

Analogous to the synthesis of phenyllithium is the conversion of 1-bromonaphthalene to 1-lithionaphthalene, a lithium-halogen exchange:



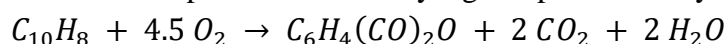
The resulting lithionaphthalene undergoes a second lithiation, in contrast to the behavior of phenyllithium.

These 1,8-dilithio derivatives are precursors to a host of peri-naphthalene derivatives.

5.3 Reduction and oxidation

With alkali metals, naphthalene forms the dark blue-green radical anion salts such as sodium naphthalenide, Na⁺C₁₀H⁻₈. The naphthalenide salts are strong reducing agents. Naphthalene can be hydrogenated under high pressure in the presence of metal catalysts to give 1,2,3,4-tetrahydronaphthalene (C₁₀H₁₂), also known as tetralin. Further hydrogenation yields decahydronaphthalene or decalin (C₁₀H₁₈).

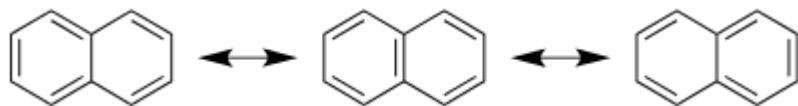
Oxidation with O₂ in the presence of vanadium pentoxide as catalyst gives phthalic anhydride:



This reaction is the basis of the main use of naphthalene. Oxidation can also be effected using conventional stoichiometric chromate or permanganate reagents.

6 MOLECULAR GEOMETRY

The molecule is planar, like benzene. Unlike benzene, the carbon-carbon bonds in naphthalene are not of the same length. The bonds $C1 - C2$, $C3 - C4$, $C5 - C6$ and $C7 - C8$ are about 1.37 \AA (137 pm) in length, whereas the other carbon-carbon bonds are about 1.42 \AA (142 pm) long. This difference, established by X-ray diffraction, is consistent with the valence bond model in naphthalene and in particular, with the theorem of cross-conjugation. This theorem would describe naphthalene as an aromatic benzene unit bonded to a diene but not extensively conjugated to it (at least in the ground state), which is consistent with two of its three resonance structures.



Because of this resonance, the molecule has bilateral symmetry across the plane of the shared carbon pair, as well as across the plane that bisects bonds $C2-C3$ and $C6-C7$, and across the plane of the carbon atoms. Thus there are two sets of equivalent hydrogen atoms: the *alpha* positions, numbered 1, 4, 5, and 8, and the *beta* positions, 2, 3, 6, and 7. Two isomers are then possible for mono-substituted naphthalene, corresponding to substitution at an alpha or beta position. Bicyclo[6.2.0]decapentaene is a structural isomer with a fused 4-8 ring system^[18] and azulene is another, with a fused 5-7 ring system. The point group symmetry of naphthalene is D_{2h} .

7 PRODUCTION

Most naphthalene is derived from coal tar. From the 1960s until the 1990s, significant amounts of naphthalene were also produced from heavy petroleum fractions during petroleum refining, but today petroleum-derived naphthalene represents only a minor component of naphthalene production. Naphthalene is the most abundant single component of coal tar. Although the composition of coal tar varies with the coal from which it is produced, typical coal tar is about 10% naphthalene by weight. In industrial practice, distillation of coal tar yields an oil containing about 50% naphthalene, along with twelve other aromatic compounds.

This oil, after being washed with aqueous sodium hydroxide to remove acidic components (chiefly various phenols), and with sulfuric acid to remove basic components, undergoes fractional distillation to isolate naphthalene. The crude naphthalene resulting from this process is about 95% naphthalene by weight. The chief impurities are the sulfur-containing aromatic compound benzothiophene (< 2%), indane (0.2%), indene (< 2%), and methylnaphthalene (< 2%). Petroleum derived naphthalene is usually purer than that derived from coal tar. Where required, crude naphthalene can be further purified by recrystallization from any of a variety of solvents, resulting in 99% naphthalene by weight, referred to as 80 °C (melting point). Approximately 1.3M tons are produced annually.

In North America, the coal tar producers are Koppers Inc., Ruetgers Canada Inc. and Recochem Inc., and the primary petroleum producer is Monument Chemical Inc. In Western Europe the well-known producers are Koppers, Ruetgers, and Deza. In Eastern Europe, naphthalene is produced by a variety of integrated metallurgy complexes (Severstal, Evraz, Mechel, MMK) in Russia, dedicated naphthalene and phenol makers INKOR, Yenakievsky Metallurgy plant in Ukraine and ArcelorMittal Temirtau in Kazakhstan.

8 HEALTH EFFECTS

What are the health effects of exposure to naphthalene? If you are exposed to large doses of naphthalene, your red blood cells could be damaged or destroyed. This condition is called hemolytic anemia. Children who eat mothballs made with naphthalene can damage their red blood cells. If you or a child show signs of being tired, decrease in or no appetite, and pale or yellow skin, these symptoms may indicate your exposure to naphthalene. Other symptoms of exposure include nausea, vomiting, diarrhea and blood in your urine. Eating or breathing naphthalene caused cataracts in some animals but it is not clear if it will have the same effect on humans. Cataracts can cloud your vision making it difficult to see.

The noses and lungs of mice exposed to naphthalene vapors for two years were inflamed and irritated. Naphthalene is not considered a cancer-causing substance. While there aren't any studies on the effects of naphthalene

on humans, naphthalene caused cancer in female mice but not the male mice. It did not cause cancer in male or female rats. Exposure to large amounts of naphthalene may damage or destroy red blood cells, most commonly in people with the inherited condition known as glucose-6-phosphate dehydrogenase (G6PD) deficiency, which over 400 million people suffer from. Humans, in particular children, have developed the condition known as hemolytic anemia, after ingesting mothballs or deodorant blocks containing naphthalene. Symptoms include fatigue, lack of appetite, restlessness, and pale skin. Exposure to large amounts of naphthalene may cause confusion, nausea, vomiting, diarrhea, blood in the urine, and jaundice (yellow coloration of the skin due to dysfunction of the liver).

The US National Toxicology Program (NTP) held an experiment where male and female rats and mice were exposed to naphthalene vapors on weekdays for two years. Both male and female rats exhibited evidence of carcinogenesis with increased incidences of adenoma and neuroblastoma of the nose. Female mice exhibited some evidence of carcinogenesis based on increased incidences of alveolar and bronchiolar adenomas of the lung, while male mice exhibited no evidence of carcinogenesis. The International Agency for Research on Cancer (IARC) classifies naphthalene as possibly carcinogenic to humans and animals (Group 2B). The IARC also points out that acute exposure causes cataracts in humans, rats, rabbits, and mice; and that hemolytic anemia (described above) can occur in children and infants after oral or inhalation exposure or after maternal exposure during pregnancy. Under California's Proposition 65, naphthalene is listed as "known to the State to cause cancer". A probable mechanism for the carcinogenic effects of mothballs and some types of air fresheners containing naphthalene has been identified.

9 HEALTH HAZARD INFORMATION

9.1 Acute Effects

- a. Acute exposure of humans to naphthalene by inhalation, ingestion, and dermal contact is associated with hemolytic anemia, damage to the liver, and, in infants, neurological damage. Symptoms of acute exposure include headache, nausea, vomiting, diarrhea, malaise, confusion, anemia, jaundice, convulsions, and coma.
- b. Cataracts have been reported in humans acutely exposed to naphthalene by inhalation and ingestion. Cataracts have also been reported in animals following acute oral exposure.
- c. Tests involving acute exposure of rats, mice, rabbits, and guinea pigs have demonstrated naphthalene to have moderate to high acute toxicity from ingestion and low to moderate acute toxicity from dermal exposure.

9.2 Chronic Effects (Noncancer)

- a. Chronic exposure of workers to naphthalene has been reported to cause cataracts and retinal hemorrhage.
- b. Chronic inflammation of the lung, chronic nasal inflammation, hyperplasia of the respiratory epithelium in the nose, and metaplasia of the olfactory epithelium were reported in mice chronically exposed to naphthalene via inhalation.
- c. Rats, rabbits, and mice chronically exposed to naphthalene via ingestion have developed cataracts and degeneration of the retina.
- d. Diarrhea, lethargy, hunched posture, rough coats, decreased body weight, and lesions in the kidneys and thymus were observed in rats and mice chronically exposed via gavage (experimentally placing the chemical in the stomach).
- e. EPA has calculated a Reference Concentration (RfC) of 0.003 milligrams per cubic meter (mg/m³) for naphthalene based on nasal effects in mice. The RfC is an estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer effects during a lifetime. It is not a direct estimator of risk but rather a reference point to gauge the potential effects. At exposures increasingly greater than the RfC, the potential for adverse health effects increases. Lifetime exposure above the RfC does not imply that an adverse health effect would necessarily occur.
- f. EPA has medium confidence in the RfC based on: 1) medium confidence in the principal study because adequate numbers of animals were used, severity of nasal effects increased at higher exposure concentrations, high mortality, and hematological evaluation not conducted beyond 14 days; and 2) low to medium confidence in the database because there are no chronic or subchronic inhalation studies in other animal species and there are no reproductive or developmental inhalation studies.

- g. The Reference Dose (RfD) for naphthalene is 0.02 milligrams per kilogram body weight per day (mg/kg/d) based on decreased body weight in male rats.
- h. EPA has low confidence in the RfD based on: 1) high confidence in the principal study because adequate numbers of animals were included and experimental protocols were adequately designed, conducted, and reported; and 2) low confidence in the database because of the lack of adequate chronic oral data, dose response data for hemolytic anemia, and two-generation reproductive toxicological studies.

9.3 Reproductive/Developmental Effects

- a. Hemolytic anemia has been reported in infants born to mothers who "sniffed" and ingested naphthalene (as mothballs) during pregnancy. The mothers themselves were anemic, but to a lesser extent than the infants.
- b. Signs of maternal toxicity (e.g., decreased body weight and lethargy) but no fetal effects were reported in rats and rabbits exposed to naphthalene via gavage.
- c. Maternal toxicity (increased mortality and reduced weight gain) and fetotoxicity (reduced number of live pups per litter) were observed in mice exposed via gavage.

9.4 Cancer Risk

- a. Workers occupationally exposed to vapors of naphthalene and coal tar developed laryngeal carcinomas or neoplasms of the pylorus and cecum. However, this study is inadequate because there were no controls, exposure levels were not determined, and subjects were exposed to complex mixtures containing other demonstrated carcinogens.
- b. Di- tri- and tetramethyl naphthalene contaminants of coal tar were found to be carcinogenic when applied to the skin of mice, but naphthalene alone was not.
- c. An increased number of alveolar/bronchiolar adenomas and carcinomas were reported in female mice exposed by inhalation.
- d. No carcinogenic responses were reported in rats exposed to naphthalene in their diet and by injection.
- e. EPA has classified naphthalene as a Group C, possible human carcinogen.

10 HAZARD SUMMARY

Naphthalene is used in the production of phthalic anhydride; it is also used in mothballs. Acute (short-term) exposure of humans to naphthalene by inhalation, ingestion, and dermal contact is associated with hemolytic anemia, damage to the liver, and neurological damage. Cataracts have also been reported in workers acutely exposed to naphthalene by inhalation and ingestion. Chronic (long-term) exposure of workers and rodents to naphthalene has been reported to cause cataracts and damage to the retina. Hemolytic anemia has been reported in infants born to mothers who "sniffed" and ingested naphthalene (as mothballs) during pregnancy. Available data are inadequate to establish a causal relationship between exposure to naphthalene and cancer in humans. EPA has classified naphthalene as a Group C, possible human carcinogen.

11 SOURCES AND POTENTIAL EXPOSURE

People may be exposed to naphthalene through the use of mothballs. Workers may be occupationally exposed to naphthalene during its manufacture and use, especially in coaltar production, wood preserving, tanning, or ink and dye production. Naphthalene is released to the air from the burning of coal and oil and from the use of mothballs. Coal tar production, wood preserving, and other industries release small amounts. Typical air concentrations of naphthalene in cities are about 0.18 parts per billion (ppb). Naphthalene has also been detected in tobacco smoke.

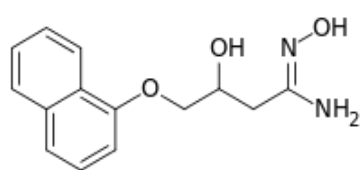
12 NAPHTHALENE DERIVATIVES

The partial list of naphthalene derivatives includes the following compounds:

Name	Chemical formula	Molar mass [g/mol]	Melting point [°C]	Boiling point [°C]	Density [g/cm ³]	Refractive index
Naphthoic acid	C ₁₁ H ₈ O ₂	172.18	157	300		–
Naphthoyl chloride	C ₁₁ H ₇ ClO	190.63	16–19	190 (35 Torr)	1.265	1.6552
Naphthol	C ₁₀ H ₈ O	144.17	94–96	278	1.224	–
Naphthaldehyde	C ₁₁ H ₈ O	156.18	1–2	160 (15 Torr)		
Nitronaphthalene	C ₁₀ H ₇ NO ₂	173.17	53–57	340	1.22	–
Fluoronaphthalene	C ₁₀ H ₇ F	146.16	–19	215	1.323	1.593
Chloronaphthalene	C ₁₀ H ₇ Cl	162.62	–6	259	1.194	1.632
Chloronaphthalene	C ₁₀ H ₇ Cl	162.62	59.5	256	1.138	1.643
Bromonaphthalene	C ₁₀ H ₇ Br	207.07	–2	279	1.489	1.670

13 USES

Naphthalene is an aromatic hydrocarbon found in coal tar or crude oil. Naphthalene is used in the manufacture of plastics, resins, fuels, and dyes. It is also used as a fumigant insecticide that works by turning directly from a solid into a toxic vapor. This process is called sublimation. Most products containing naphthalene in the U.S. are used to control clothes moths in airtight containers. Naphthalene is used mainly as a precursor to other chemicals. The single largest use of naphthalene is the industrial production of phthalic anhydride, although more phthalic anhydride is made from *o*-xylene. Many azo dyes are produced from naphthalene, and so is the insecticide 1-naphthyl-*N*-methylcarbamate (*carbaryl*). Other useful agrichemicals include naphthoxyacetic acids.



Hydrogenation of naphthalene gives tetralin, which is used as a hydrogen-donor solvent. Naphthalenesulfonic acids and sulfonates. Many naphthalenesulfonic acids and sulfonates are useful. Alkyl naphthalene sulfonate are surfactants, The aminonaphthalenesulfonic acids, naphthalenes substituted with amines and sulfonic acids, are intermediates in the preparation of many synthetic dyes. The hydrogenated naphthalenes tetrahydronaphthalene (tetralin) and decahydronaphthalene (decalin) are used as low-volatility solvents. Naphthalene sulfonic acids are also used in the synthesis of 1-naphthol and 2-naphthol, precursors for various dyestuffs, pigments, rubber processing chemicals and other chemicals and pharmaceuticals.

Naphthalene sulfonic acids are used in the manufacture of naphthalene sulfonate polymer plasticizers (dispersants), which are used to produce concrete and plasterboard (wallboard or drywall). They are also used as dispersants in synthetic and natural rubbers, and as tanning agents (syntans) in leather industries, agricultural formulations (dispersants for pesticides), dyes and as a dispersant in lead–acid battery plates. Naphthalene sulfonate polymers are produced by treating naphthalenesulfonic acid with formaldehyde, followed by neutralization with sodium hydroxide or calcium hydroxide. These products are commercially sold as superplasticizers for the production of high strength concrete.

13.1 Laboratory uses

Molten naphthalene provides an excellent solubilizing medium for poorly soluble aromatic compounds. In many cases it is more efficient than other high-boiling solvents, such as dichlorobenzene, benzonitrile, nitrobenzene and durene. The reaction of C₆₀ with anthracene is conveniently conducted in refluxing naphthalene to give the Diels–Alder adduct. The aromatization of hydroporphyrins has been achieved using a solution of DDQ in naphthalene.

13.2 Other uses

It is used in pyrotechnic special effects such as the generation of black smoke and simulated explosions. It is used to create artificial pores in the manufacture of high-porosity grinding wheels. In the past, naphthalene was administered orally to kill parasitic worms in livestock. Naphthalene and its alkyl homologs are the major constituents of creosote. Naphthalene is used in engineering to study heat transfer using mass sublimation.

14 CONCLUSION

To conclude my research paper, I reached to the point that concern regarding human exposure to naphthalene through inhalation has greatly increased due to its potential carcinogenicity, which was discovered in 2000. We derived representative ranges of residential, outdoor and personal concentrations of naphthalene, emphasizing the more recent literature. This literature is limited, especially for personal exposures. Considering what is available, we conclude that personal and residential concentrations are similar, while ambient concentrations are about an order of magnitude lower. Our estimate of representative ranges of indoor concentrations is about 0.2 to 2 µg m⁻³ for medians, and about twice that for averages.

We did not observe a decline in indoor concentrations over the past 10 to 15 years, in contrast to trends seen for other VOCs and PAHs, however, outdoor measurements did appear to decline. We anticipate that decreased indoor smoking, improved emission controls on vehicles, and substitution of the naphthalene in moth and other animal repellents and deodorizers has significantly reduced exposures in the U.S. However, available data are not ideal for quantitative trend studies. Most measurements fall below the current U.S. EPA reference concentration of 3 µg m⁻³ established for non-cancer effects, although measurements in several homes show concentrations approaching or exceeding 100 µg m⁻³. Outdoor exposures, except where there are strong industrial sources, are well below the RfC.

However, using the available cancer risk factors, some of which are draft and under review, indoor and outdoor concentrations correspond to individual risks in the 10⁻⁵ to 10⁻³ range, very high for an environmental exposure. The cancer risk factors have large uncertainties and are controversial, but in many assessments naphthalene ranks at or near the top of those substances posing inhalation cancer risks. This analysis suggests that further study, control and abatement is warranted. We anticipate much higher exposures and risks in countries where these controls are lacking, or where other sources are present.

We noted a number of important information gaps and research needs. Existing exposure data are limited, and monitoring surveillance should be improved. There is a need to validate and intercompare VOC and PAH measurement techniques. This will also ensure the comparability of studies and reduce uncertainties. The spatial and temporal variability of concentrations near roads, industrial and other sources, is poorly characterized.

Factors affecting indoor concentrations, including the causes of the highest levels, are not well understood, and populations at risk of high of exposure presently cannot be identified. Better information regarding product usage patterns, emission rates of consumer products, building materials, and other sources of naphthalene is needed, as are long term measurements. Future studies might address losses due to adsorption onto building materials, chemical reactions, and utilize multicompartments models to better understand current and estimate historical exposures.

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