Chapter

Formaldehyde Advantages and Disadvantages: Usage Areas and Harmful Effects on Human Beings

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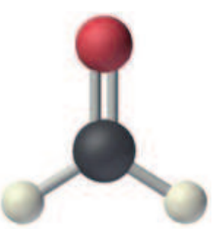
Abstract

Formaldehyde, a simple but important member of aldehydes, is highly reactive due to its strong electrophilic properties. It is a colorless, pungent, low molecular weight poisonous gas that can rapidly pass into gaseous phase at room temperature, can burn, and can dissolve very well in water. Formaldehyde, which is found in the natural structure of the organism, is used in many places from industrial areas to household materials and from the production of coatings in dentistry to the determination of cadavers in laboratories. In addition to having such a wide range of uses, it has harmful effects on human health as it can react spontaneously with various cellular elements. In this review, which is based on various sources, detailed information about the definition, properties, usage areas, and harmful effects of formaldehyde will be given.

Keywords: formaldehyde, properties of formaldehyde, benefits, harmful effects on human beings, source of formaldehyde

1. Introduction

Formaldehyde – a simple but important member of aldehydes – is a colorless, pungent, highly flammable, irritating, and poisonous low molecular weight gas in its pure form, meanwhile it dissolves very well in water, alcohols, and other polar solvents. Due to its strong electrophilic properties, it is highly reactive, readily undergoes polymerization, and can form explosive mixtures in air. It decomposes at temperatures above 150°C to methanol and carbon monoxide. In addition, it is easily photooxidized to carbon dioxide in sunlight.



Formaldehyde

CH_2O

Pure formaldehyde is produced as a liquid through catalytic oxidation of methanol. This process is carried out in a closed facility and results in a formaldehyde

Formaldehyde (CH_2O)	
IUPAC name	**Methanal**
Chemical name	Formaldehyde, methylene oxide, oxymethylene, methyl aldehyde, oxomethane, formic aldehyde
Chemical formula	CH2O (HCHO)
Molecular weight	30.026 g/mol
Color	Clear, colorless liquid
Density	0.8153 g/cm3 (−20°C)
Melting point	93–96°C (at 37% concentration)
Boiling point	−15°C (at 37% concentration)

Table 1.
Physical and chemical properties of formaldehyde.

solution in the water together with methanol in various concentrations. This product may be further refined or converted to the paraformaldehyde (polymerized form of formaldehyde) which is in the form of a white powder or flake. Formaldehyde gas is slowly given by paraformaldehyde. Pure formaldehyde is not available commercially, so it is usually transported or stored as a 37% (by weight) aqueous solution, which is known as formalin [1, 2]. The technical (specific) properties of formaldehyde, which must be taken into account during use of it and also appropriate equipment should be used with it, are given in **Table 1**.

The most common methods for formaldehyde detection are based on spectrophotometry. Besides spectrophotometric ways other methods such as high-performance liquid chromatography, gas chromatography, colorimetry, infrared detection, fluorimetry, polarography, and gas detector tubes are also used. Organic and inorganic chemicals, such as sulfur dioxide, other aldehydes, and amines, can interfere with these detection methods. The most sensitive of these methods is flow injection, which has a detection limit of 9 ppt (0.011 μg/m^3) and is high-performance liquid chromatography, which offers a detection limit of 0.0017 ppm (0.002 mg/m^3) [3, 4].

Formaldehyde is found in small quantities in every human cell because it is taken from outside the organism or it is derived from the metabolism of serine, glycine, choline, and methionine [5, 6]. Formaldehyde is excreted from the body through urine and stool, by metabolizing formic acid catalyzed formaldehyde dehydrogenase (FDH) enzyme in the liver and erythrocytes, or excreted through respiration by converting to carbon dioxide [7–9]. Formaldehyde tends to combine strongly with protein, nucleic acids, and unsaturated fatty acids in a nonenzymatic way. This combination causes cytotoxicity, inflammatory reaction, necrosis, allergy, and mutagenic effect to be seen by producing denaturation in proteins. In addition, formaldehyde shows antimicrobial activity and function detection in tissues that have lost their vitality [7, 10, 11].

2. Formaldehyde, usage areas, and harmful effects

2.1 Usage areas

Formaldehyde is a chemical that is widely used due to its chemical properties and is also found in the natural structure of the organism. It is particularly

important in the chemical industry because formaldehyde is an inexpensive starting material for a number of chemical reactions. It is used in the industrial field in the construction of plywood, chipboard, insulation materials, paint and plastic materials, textile industry, carpets, furniture, wall coverings, and household cleaning products [7, 12].

Formaldehyde is used in the storage of biological samples and mummification as it hardens proteins and prevents them from decomposition. Also, it is used as disinfectant because it kills insects and many microorganisms [13]. Formaldehyde, which has an important place in the field of medicine, is used in the anatomy laboratory for the determination of the cadaver and its long-term storage without decomposition and used in histology and pathology laboratories during the fixation stage of tissues. It is benefited from formaldehyde for the structure of coatings in dentistry, in the clinic for the treatment of persistent cystitis, and as a preservative in some drugs. In addition, the solution used in hemodialysis unit contains formalin [1, 14–16].

The use of formaldehyde in medical and other fields is 1.5% of the total production compared with its use in the manufacture of synthetic resins and chemical compounds. However, its use in these areas has great significance for human beings, because it can reach many people by means of various consumer goods. These products containing formaldehyde in medicinal and other technical areas are listed in **Table 2** [7].

Area	Use
Agriculture	Preservation of grain, seed dressing, soil disinfection, rot protection of feed, nitrogen fertilizer in soils, and protection of dietary protein in ruminants (animal nutrition)
Cleaning agent industry	Preservative in soaps, detergents, and cleaning agents against microbial contamination
Cosmetics industry	Preservative in soaps, deodorants, shampoos, etc. against microbial contamination; additive in nail hardeners, products for oral hygiene, makeup, hand cream, and shaving cream; and plant and equipment sanitation
Food industry	Preservation of dried foods, disinfection of containers, and preservation of fish and certain oils and fats, modifying starch for cold swelling
Leather industry	Additive to tanning agents
Medicine	Disinfection, sterilization, and preservation of preparations
Metal industry	Anticorrosive agent; vehicle in vapor depositing and electroplating processes
Petroleum industry	Biocide in oil well-drilling fluids and auxiliary agent in refining
Photographic industry	Developing accelerator and hardener for gelatin layers
Rubber industry	Biocide for latex, adhesive additive, and anti-oxidizer additive also for synthetic rubber
Sugar industry	Infection inhibitor in producing juices
Textile industry	Formaldehyde-releasing agents[a] provide crease resistance, dimensional stability, and flame retardance and binders in textile printing
Wood industry	Preservative

[a]*Some preservatives are formaldehyde releasers. Formaldehyde release upon decomposition depends mainly on the temperature and pH. Industrial and household cleaning agents, soaps, shampoos, paints/lacquers, and cutting fluids have formed the most common product categories for formaldehyde releasers. The three most common recorded formaldehyde release agents are bromonitropropanediol, bromonitrodioxane, and 2-chloroallylhexaminium chloride [17].*

Table 2.
Use of products containing formaldehyde in medicinal and other technical areas.

2.2 Impact area and harmful effects

Formaldehyde contains significant harm to human health as well as widespread use. Formaldehyde has a sharp odor that can be detectable at low concentrations, and its vapor and solutions are known as skin and eye irritants in human beings. The common effects of formaldehyde exposure are various symptoms caused by irritation of the mucosa in the eyes and upper respiratory tract.

Formaldehyde is classified by the International Cancer Research Institute as a Group 2A carcinogenic agent in 1995. As a result of the studies, formaldehyde is reported to contribute to the development of cancer of the nose and upper respiratory tract and skin cancer [18, 19].

OSHA has identified 52 professions that are risky in terms of formaldehyde exposure. The most frequently studied groups were the ones who were at risk for the effect of formaldehyde, which are listed below:

- Workers working at the production stage of formaldehyde-containing compounds
- Industry workers working in formaldehyde-containing products and adhesives (furniture and goods produced from the chipboard, MDF, plywood, varnish, lacquer, fire retardants, etc.)
- Workers in traffic or garages
- Anatomy, pathology, and histology laboratory staff (medicine and veterinary)
- Those who sterilize dialysis equipment and other medical supplies— dentists and nurses,
- Foundry employees
- Workers in paper, paper products, and recycling [20–22].

Research on persons working in industrial areas where formaldehyde production is performed or used showed that there is an increase in the number of people dying from brain cancer, blood cancer, and colon cancer compared to the normal population [2, 13]. Furthermore, the use of formaldehyde-containing products in homes and workplaces in daily life (wall paint, furniture, lacquer coatings, deodorants, cleaning products, etc.) and exposure to environmental factors (such as fuel oil and wood burning, exhaust gas, and cigarette smoke) further increase the impact of formaldehyde. It has been shown that formaldehyde, which is emphasized as carcinogenic by experimental studies, has harmful effects on many systems such as the respiratory system, nervous system, and digestive system [1, 7, 23]. Furthermore, it is stated that formaldehyde, which has adverse effects on the reproductive system, causes fertility problems by damaging to germinal cells, disrupts the morphological structure of testicle, and decreases sperm count and serum testosterone levels [24–26].

Formaldehyde is a genotoxic, mutagenic, teratogenic, embryotoxic, and carcinogenic chemical that includes gene mutations, chromosomal errors, single-chain fractures, sister chromatid exchange, and cell changes [2, 27, 28]. Respiratory system toxicity of formaldehyde occurs even in low concentrations (0.5 ppm). It causes clinical symptoms such as burning sensation in the nose and throat, difficulty of breathing, coughing, and wheezing in acute effects. At higher concentrations, pulmonary edema, inflammation, and pneumonia are

developing [2, 11, 12, 29]. It is stated that among workers exposed to formaldehyde, the mortality rate of lung cancer is 30% higher [30, 31].

Formaldehyde has been reported to have toxic effects on the central nervous system, skin, eyes, testes, and menstrual functions as well as the respiratory system [24, 32, 33]. After oral ingestion, formaldehyde produces a local corrosive effect in the upper gastrointestinal system. Necrosis, perforation, and bleeding develop after following symptoms such as nausea, severe diarrhea, and abdominal pain. Then, circulatory failure and severe metabolic acidosis occur and result in death within a few days [1]. In addition, in some studies, it has been stated that formaldehyde inhibits the activity of some enzymes and increases some enzyme activity [13, 34].

Formaldehyde tends to perform toxic effects by combining strongly with DNA, RNA, protein, and unsaturated fatty acids in a nonenzymatic way [10]. The neurotoxicity effects of formaldehyde are shown up in the form of headache, dizziness, depression, insomnia, and loss of appetite, while in long-term exposure, permanent neurotoxicity such as mood disorders, behavioral disorders, and epilepsy occur [32, 35, 36].

2.3 Formaldehyde sources in the environment

Formaldehyde enters to the environment from natural sources (including forest fires) and comes directly from human resources. Formaldehyde occurs naturally in large quantities in the troposphere during the oxidation of hydrocarbons. These hydrocarbons react with OH radicals and ozone forming formaldehyde and/or other aldehydes as intermediates in a series of reactions resulting in the formation of carbon monoxide and carbon dioxide, hydrogen, and water [37, 38]. In addition, terpenes and isoprene spread around by foliage and react with the OH radicals to form formaldehyde as an intermediate product. Because of their short lifetimes, this potentially important formaldehyde source is only important around the vegetation [39].

Human sources of formaldehyde include direct sources such as industrial uses in the field, fuel combustion, and off-gassing from building materials and consumer products. Formaldehyde, although is not present in gasoline, is an incomplete combustion product and consequently is released from internal combustion engines. The formaldehyde amount produced depends mainly on the composition of the fuel, the type of engine, the emission control applied, the operating temperature, and the age and condition of the vehicle being repaired. Therefore, emission rates are variable.

The major man-made sources affecting human beings are in the indoor environment. Primary sources (covering a range of fuels from wood to plastics) include cigarette smoke, chipboard and plywood, wood-burning stoves, fireplaces, furnaces, power plants, agricultural burns, furniture and fabrics, waste incinerators, gas from by heating systems, and cooking [40–47].

Furniture made from wood materials are widely used in indoor and outdoor living spaces. Depending on the developments in the glue sector, the rate of using synthetic materials in the furniture industry is increasing. This situation brings with it air pollution. Urea-formaldehyde (UF) glue, which is the most widely used adhesive for wood paneling and furniture production around the world, is one of the most common contaminants in indoor environments. For this reason, formaldehyde can be found in our daily indoor areas, in homes and in offices. Formaldehyde release value can be increased by increasing the ambient temperature and humidity. The formaldehyde level should normally be below 0.03 ppm in indoor environments. The level at which symptoms occurred was determined as 0.10–1.1 ppm range [18, 48].

Therefore, the indoor formaldehyde levels are clearly different from the concentrations in the outdoor air. Temperature, humidity, ventilation rate, age of the building, product usage, the presence of combustion sources, and the smoking habits of occupants affect indoor formaldehyde concentrations.

3. Conclusion

As a result, since formaldehyde has a harmful and even toxic effect on many tissues and organs in the body, it is necessary to keep the formaldehyde concentration below the 0.3 ppm level, which is the permitted limit in formaldehyde-working environments.

In macroscopic anatomy laboratories where formaldehyde is used more frequently, some precautions should be taken to prevent the harmful effects of formaldehyde. For this purpose, a sufficient concentration of 10% should not be exceeded for the determination of a suitable tissue. Materials waiting for detection should be closed in a way that does not contain air. The area in which the macroscopic examination is performed must be equipped to remove the formaldehyde vapor immediately from the environment. Laboratory personnel with chronic conjunctivitis and upper and lower respiratory diseases are removed from this environment until they are completely passed. The contact times of formaldehyde should be reduced as much as possible by providing appropriate conversions between laboratory personnel.

In addition, employees should be trained on environmental risk factors, toxic chemicals and protection from risk factors, and the use of gloves and masks, and it is also necessary to identify and map important emission areas and operations and to arrange/adjust the existing equipment [28, 49, 50]. Measures to be taken to against emission sources include increased ventilation, treatment of cadavers, and tissues with ammonium chloride in anatomy laboratories [51], covering machines, the use of local exhaust systems [52], and improvement of general ventilation [53]. Taking these measures in environments exposed to formaldehyde is necessary to reduce the exposure and minimize the health effects that may occur.

In spite of all these harmful effects, formaldehyde is still in use all over the world because of its cheap and good detection solution.

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