The Environmental and Health Impact of Paint Products

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Over the decades, some progress has been made to enhance the safety of paint components. However, concerns remain due to the presence of harmful chemicals in paints, such as Volatile Organic Compounds (VOCs), endocrine disruptors in binders, and caustic biocides. These compounds pose significant risks to the environment and human health contributing to environmental issues such as damage to aquatic ecosystems and health problems including cancer, nausea, dizziness, eye and respiratory tract irritation, organ damage, and reproductive and developmental issues. This comprehensive review examines the hazardous constituents found in contemporary paints and their far-reaching consequences on the world and underscores the urgency for safer alternatives. Additionally, this review focuses on practical methods for consumers to make informed and environmentally responsible paint choices, exploring eco-labelling systems offered by independent organizations. By shedding light on these issues, this review aims to raise awareness of the effects of paints on human and the environment and the significance of making safer paint choices.

Keywords: *Chemistry, Paints, Volatile Organic Compounds, Endocrine Disruptors, Biocides, Ecolabelling*

Introduction

Paint, a fundamental element for human expression and creativity, has a rich history dating back to ancient civilizations, evident in the caves adorned with ochre drawings. Paints were first created through traditional pigments in nature. Starting from the Egyptian blue, which was made from sand, lime, and copper ore mixed together and heated, red, produced by mixing and roasting mercury with sulfur, and white, made using lead and manure. The development of making colours using chemicals was innovative in terms of chemistry, but in terms of safety, it was also dangerous, causing severe pollution and health issues. This journey has not been without its environmental and health challenges.

Although nowdays paints contain much less hazardous chemical compounds than a decade ago as several hazardous chemicals have been reduced or replaced in paint, in the past, many harmful compounds were used due to lack of awareness and knowledge. For example, until the eary 1990s, Asbestos were used as a filler in the paint, due to its resilient and non-corrosive properties. However, Asbestos is toxic because it contains small fibers that can easily become airborne and inhaled by living organisms, which may then enter the lung, stomach, and even heart tissue linings and damage them. Therefore, buildings built before the 1980s have a highr risk of housing paints that may contain asbestos[1]. Moreover, lead paints were commonly used before 1978. However, rubbing and friction of the surface covered with lead paint caused lead dust, which may cause physical and neurological issues, including reproductive problems, anaemia, and kidney damage[2]. Legislation that limits the amount of lead used in coatings eliminated its use after 1990s, and suitable replacements for lead appeared, including zirconium, calcium, and cobalt-zirconium compounds. As seen, there has been notable progress in enhancing the safety of paint components[3].

However, concerns regarding the safety of paints still persist, due to remaining harmful chemical compounds in the paints. Most paints contain three essential ingredients: pigments, solvents, binders, and preservatives. Pigments are finely ground natural or synthetic compounds that provide colour and opacity to the paint. Solvents, essential for achieving the desired consistency and spread, have consistently been a source of concern, due to the presence of volatile organic compounds (VOC), known to evaporate into the air, contributing to ozone formation and associated health issues. Binders act as the adhesive, holding the pigment to the surface and providing the texture of the paint[4]. The acrylic binder is one of the major binders, enhancing paint's durability, waterproofing properties, and resilience. However, despite its contribution to enhancing the paint, it may have endocrine-disrupting qualities, which means it interacts with hormones organisms, resulting in negative consequences in human health. Additionally, paints contain preservatives such as fungicides and bacterial sides to protect paints and coatings against the growth of organisms on the surface. However, preservatives emit active ingredients, which may disrupt the ecosystem and impact organisms that may eventually find their way into the human food chain, indirectly posing health risks to humans. There are still remaining challenges in enhancing the paint's safety.

In this paper, we examine the harmful chemical compounds in pigments, binders, emulsifiers, and biocides in modern paints and their impact on the environment and human health. We also focus on practical methods for consumers to make safer and more informed paint choices, examining the eco-labelling strategy. Then we also examine healthier and more environmentally friendly alternatives for paints from a systemic viewpoint. Through this, this paper seeks to raise awareness about the impact paints have on people and the environment, as well as the need to choose safer paint options.

Results

Volatile Organic Compounds

VOCs are used in paints to solubilize the paint components and allow for paint application. When the paint dries, the solvents dissipate into the air during "off-gassing". "Off-gassing" happens when products release previously trapped gasses in a liquid or solid form[5]. Upon application of the paint to a surface, these carbon-based chemicals are vaporized into the air easily at room temperature. The most commonly used VOCs in paint are benzene, toluene, mixed xylenes, ethylbenzene (BTEX), high flash aromatic naphthas, and aliphatic hydrocarbons such as hexanes, heptane, and VM&P[6]. Off-gassing VOCs cause various health problems such as nausea, dizziness, irritation of the eyes, and respiratory tract, organ damage, and even cancer. For example, the World Health Organization (WHO) has reported a 20%-40% increased risk of certain types of cancer for people who regularly contact paint[7]. Even though some healthier paints may contain no or low VOCs, many paints available in the market contain VOCs.

Another safety concern of VOCs is the formation of ozone (O_3) from the emissions of these volatile components. O_3 is a tri-molecular allotrope of oxygen that exists as a colourless gas. While O_3 is naturally occurring in our atmosphere and plays a pivotal role in protecting the earth from U.V. radiation, exposure to O_3 irritates the respiratory system, headaches, lung tissues, and asthma[8]. VOCs released from paint react with nitric oxide (NOx) and sunlight to form O_3. This process starts when sunlight first breaks down nitrogen dioxide to form nitric oxide and oxygen radicals ($NO_2 + sunlight \rightarrow NO + O_3$). Oxygen radicals then react with atmospheric oxygen (O_2) to form O_3 ($O + O_2 \rightarrow O_3$). Next, ozone is consumed by nitric oxide to produce nitrogen dioxide and oxygen ($O_3 + NO \rightarrow NO_2 + O_3$). Nitrogen dioxide then reacts with various hydrocarbons (R), which is mainly from VOCs, to produce harmful products such as peroxyacetyl nitrate (PAN) ($NO_2 + R \rightarrow PAN$). The oxygenated VOCs also react with nitrogen oxide to produce more nitrogen oxides ($NO + RO_X \rightarrow NO_2$). The presence of VOCs in these two reactions is very significant[9]. Nitric oxide normally consumes ozone, as shown in the reaction above. However, with the presence of VOCs, nitric oxide and nitrogen dioxide are consumed instead, allowing the build-up of ground-level ozone.

Many studies show the significance of paint VOCs in ozone formation. One such study suggested that the choice of road marking paint significantly influences the environment, as the paint emits VOCs that possibly impact tropospheric ozone formation. For example, maximum Incremental Reactivities (MRI) calculations revealed that VOCs emitted by the aromatic solvent-containing road marking paint could produce up to 43,050 kg of tropospheric ozone annually from Kraków, Poland[10].

VOCs have significant impacts on our health and the environment. Through the "off-gassing" of drying paint, VOCs can cause serious health issues. Moreover, VOCs contribute to ozone and PAN formation, which have further respiratory health concerns. Therefore, avoiding paints with VOCs is a vital health initiative when choosing a paint[11].

Binder

Binders are film-forming mediums combined with pigment to allow the paint to be applied to a substrate. The paint binder allows durability, adhesion, and resistance to cracking. Therefore, the manufacturers of the paints need to find the most suitable binder for the particular usage of each paint, as binders heavily impact the paint's performance.

For example, some binders can enhance resistance to moisture or ultraviolet rays, while others affect the paint's adhesion properties. Alkylphenol ethoxylates (APEs) are binders used in acrylic paints[12]. However, despite its pivotal role in the paint, they have been demonstrated to have endocrine-disrupting qualities in addition to being extremely hazardous to fish and other aquatic species[13].

The entrance of these disruptors into the human body, whether through inhalation or skin contact, cause interactions with the hormones of organisms[14]. According to the U.S. Environmental Protection Agency, the breakdown products of APEs, specifically alkylphenols, have been detected in human breast milk, blood, and urine and are associated with reproductive and developmental effects in rodents. Moreover, in humans, the disrupters elevate the risk of cancer, reproductive impairment, cognitive deficits, and obesity[15].

For example, among all the APEs, nonylphenol ethoxylates (NPEO) are among the most widely used in various industries, including the paint sector. These compounds ultimately break down into nonylphenols, which exhibit endocrine-disrupting characteristics[16]. Owing to its low solubility and high hydrophobicity, meaning it repels water rather than absorbing or dissolving it, nonylphenol accumulates in environments

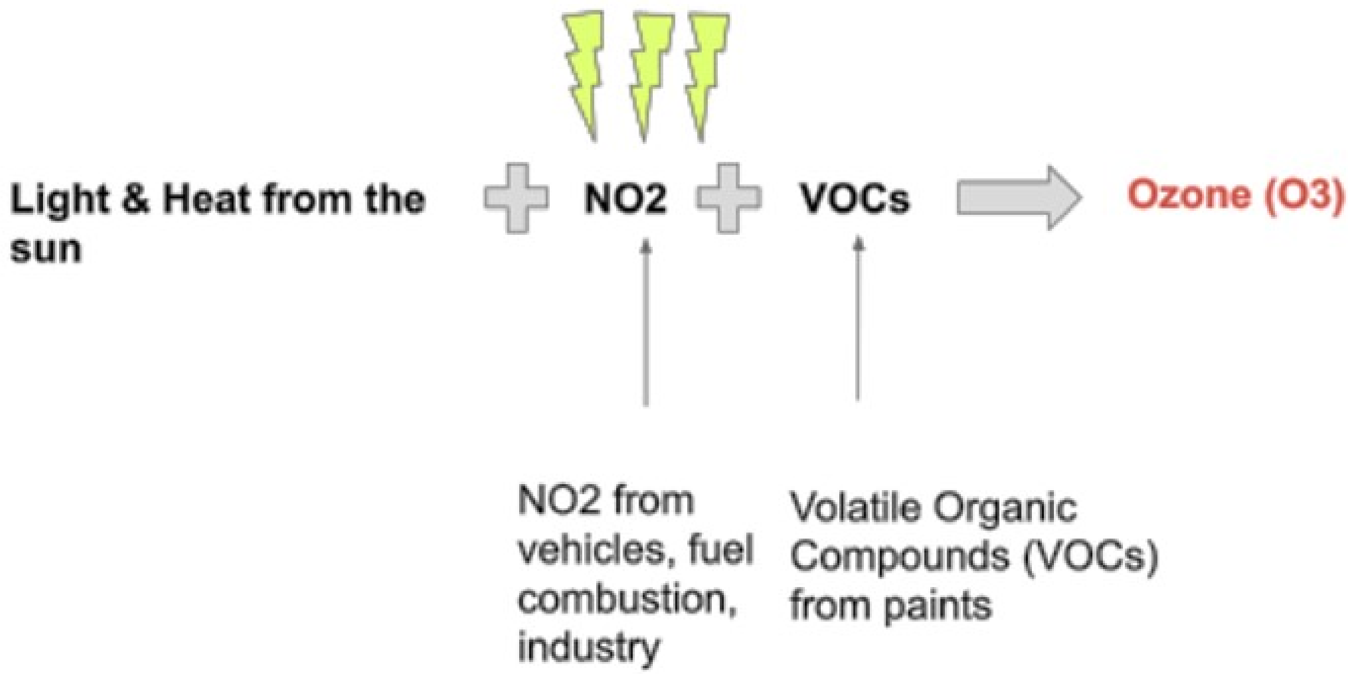

Fig. 1 Illustration of ozone formation from reaction of NOx and VOCs in the presence of light.

rich in organic matter, such as sewage sludge and river sediments. Their impacts on hormones extend to the feminization of aquatic organisms and a reduction in male fertility, resulting in profound alterations to the aquatic environment[17].

Other common binders include epoxy-based chemicals, which show high resistance to heat and chemicals and are thus suitable for corrosion protection. Epoxy resins are a class of synthetic resins, chemically characterized by the 'epoxide group', which are very reactive. The epoxy resin polymer is constituted of 1 to 3 monomers, each made up of one bisphenol-A molecule and one epichlorohydrin molecule[18]. Generally, the resin is mixed with a curing agent or hardener, generally a polyamine, when used. The hardener reacts with the 'free' epoxide groups and makes them into a tough, three-dimensional network. This network gives epoxy chemicals favourable products, including excellent adhesion to substrates, chemical resistance and liquid tightness[19].

However, due to the same properties epoxy products are causes of allergic skin disease, especially among workers in the construction industry using the binders. Workers who already have acquired an epoxy allergy will be faced with a stronger reaction after each contact next time. Furthermore, epoxy chemicals may also cause airway and eye irritation, and if serious, may even lead to cancers or diseases of the reproductive system[20].

Epichlorohydrin, which constitutes one of the monomers of epoxy resin, is a skin sensitizer. In addition, according to the EU classification, it is classified as carcinogenic in 'presumed human carcinogen'. The other constituent, bisphenol-A, is a skin sensitizer as well. It is also classified as reproduction toxic and weakly estrogenic[21].

Due to these detrimental effects of epoxy chemicals, people, especially workers, using epoxy binders or paints containing those chemicals should avoid skin exposure to and inhalation of those chemicals.

Biocides

Biocides are used in paint for protection against microbes, bacteria, or algae, increasing the resilience and shelf-life of paint products. Biocides used in the paint can be categorized into in-can preservatives, film preservatives, and antifouling preservatives. In-can preservatives are used during the product formation stage to protect the paint from microbial contamination, which often causes odors and reduces the paint's performance The preservatives, therefore, increase the shelf life of the product[22]. Aerobic bacteria and yeast may grow in places with oxygen inside the can, while anaerobic bacteria may grow in places without oxygen, usually deep inside the can. Bacteria change the pH of the paint, producing carbon dioxide and hydrogen sulfide, which creates odour.

Some common examples of in-can preservatives include isothiazolinone and formaldehyde donors. Isothiazolones are strong sanitizers that produce skin irritations and allergies. However, according to a study that analyzed the paints through liquid chromatography, isothiazolinone is still widely used in paints purchased in European countries, including Denmark, France, Germany, Sweden, and U.K.[23]. Similarly, formaldehyde donors are still used for its low cost, despite its health effects, including skin, eyes, and throat irritation, or even cancer.

Dry film preservatives control the fungal growth on the treated surface of the paint. Numerous environmental factors, including moisture levels, nutrients, and U.V. exposure, affect the paint's performance after it is treated on a surface. Those factors may cause vulnerability to fungal growth, so dry film preservatives are important for paints, especially exterior paints. Biocides with chemical stability in both wet and dry stages and long-term protection are needed. They should not cause colour changes or increase drying time[24].

The antimicrobial coating allows continuous disinfection of the paint surface from disease-causing microorganisms. The ingredients contained in the coating, such as silver and copper, destroy the membranes or enzymes of the molecule and produce oxidizers, ultimately destroying the protein structure of the microbes. Although it has the advantage of decreasing the transmission of microbes and viruses, there are still some health and environmental issues with using these coatings. For example, the antimicrobial coating can emit active ingredients, such as silver and copper, which may enter the ecosystem. In addition, it could have a toxic effect on fish, which then may be consumed by humans, causing long-term environmental issues[25].

Ecolabeling and Guidance for Safe Paint Choice

Ecolabels are designed to share safety information and environmental impact ratings on potentially harmful products. Ecolabels typically have three main objectives, informing the consumers, developing standards, and protecting domestic products. The standards of the ecolabel must be achieved for product certification. In September 2023, it was found that 2584 licences have been awarded for 88921 products on the EU market. The total number of EU Ecolabel licences keeps growing, showing a continued interest in green products from businesses, citizens, and retailers[26].

Currently, there are three types of ecolabels: Type 1, Type 2, and Type 3. Type 1 is called the 'gold' standard, as it has its own certifying body, including academic researchers and experts. By comparing with other products, the label evaluates the quality of a certain product[27]. The government often supports the label. One example of Type 1 ecolabel is the E.U. label, which requires paint products to have guaranteed minimized hazardous substances, reduced VOC content, and good performance[28]. Unlike Type 1, Type 2 ecolabels are certified by manufacturers to provide consumers with information. It usually focuses on one particular quality of a product, for example, whether it is compostable or not. Lastly, Type 3 provides information of the life cycle and environmental impact of the paint, without establishing minimum standards to meet. They do not focus on whether the product is more sustainable or less sustainable but inform the products' environmental problems[29]. The eco-labelling of paints is different for every country. For example, in Europe, product safety is ensured by the government's standard requirements of the E.U. label. While in the United States, safety labels are provided by external review. The most trusted label in the U.S. is the Green Seal label, with GS-11 being the best label for paint products.

Although criticisms exist, eco-labelling may help consumers to make informed and safe choices. Ecolabels have an impact on both consumers and producers. For consumers, ecolabels protects the basic right of their need for information and allows them to protect their health based on brand information. Ecolabling has an impact on consumer behaviour, and thus, product profit margins. It has been identified that consumers are willing to pay a price premium for products with a better health profile than other products. On the other hand, some studies suggest that due to different green labels communicating so many different aspects, they could become meaningless. When many ecolabels are used, it may lead to consumer scepticism. Some of the eco-labels have actually been criticized as being greenwashing.

Then, should a consumer select labelled products? It is known that of 22 wall paint products in the Norwegian Market, 20 are marked with the EU Ecolabel sign. Additionally, in Denmark, 664 different products are approved by the EU Ecolabel system. It means that almost every product qualifies for this label. The only value of the EU eco-label seems to be to identify about 10% of products with the weakest environmental profile, indicating the limitations of the ecolabels. This limitation highlights the significance of the involvement of non-government organizations (NGOs) in the development and setting of label criteria[30].

It requires significant effort to provide environmentally friendly products that are not harmful to human health. Some alternatives include those with low or no content of VOCs, called "low-VOC" and "zero-VOC" paints. A study investigated the VOC content of four commercially available low-VOC latex paints and performed emission analysis in small test chambers at ambient conditions. Low-VOC paints had TVOC values of around 10mg-3, much lower than TVOC value of high-VOC paints, 10mgm-3. However, significant aldehyde emissions were detected, where formaldehyde levels were even lasted for several days. Thus, the paints were not recommended for use in occupied buildings with rooms used by vulnerable people[31].

Another alternative regarding antifouling coatings was considered. Non-toxic antifouling strategies include developing formulas based on novel biocides and on natural compounds. For example, rosin-based coatings with low concentrations of ivermectin were effective in preventing barnacles colonization. Using green antifouling compounds from microorganisms, seaweeds and aquatic plants were also investigated. However, their use in commercial plants is slow due to the issue of supply.

Three active substances, including chlorohexidine, Tween 85, zinc peroxide and a biodegradable polymer were investigated as potential alternatives for biocidal antifouling paints. A chemical action of zinc peroxide and chlorohexidine was shown against microfouling, whereas a physical action of Tween 85 was shown. When these active substances were incorporated into the actual paint, which was investigated under real conditions, it presented an activity against micro and macro fouling for one season. Therefore, the study showed that these active substances in a biodegradable binder provide antifouling protection for several months, showing that obtaining antifouling activity with lower toxic substances is possible[32].

Conclusion

While paint product safety has come a long way, many aspects can still be improved. One of the main concerns with paint use is the presence of VOCs. Through off-gassing, the products with VOC content release chemicals that vaporize into the air. VOCs can cause multiple health issues, including dizziness, irritation, organ damage, and cancer. Moreover, VOCs released into the local environment react with nitric oxides to produce ozone. This concentrated source of ozone has health hazards as it can cause respiratory system irritation, headaches, lung tissues, and asthma. Another major safety concern with modern paints is the presence of endocrine-disrupting molecules found in binders. The most significant example of these are alkylphenol ethoxylates and lead, which contain endocrine disruptors that interact with the hormones of organisms, and cause significant environmental and health impacts. Lastly, biocides, including in-can preservatives, dry film preservatives, and antimicrobial coating, can harm the users' health. Although they are very useful in paints in controlling the fungal growth or disease-causing microorganisms, in-can preservatives can cause irritation and cancer, while antimicrobial coating harms the aquatic environment, which impacts human health as aquatic organisms may be consumed by humans. Due to the paint's adverse health and environmental effects, eco-labeling has become very important in keeping consumers safe and encouraging producers to make safer products. Eco-labeling shares information about the products and certifies environmentally safer ones. For safe paint choices, consumers should also follow some guidance provided. Moreover, alternatives for safer paint usage may include low VOC or zero VOC paints, despite their limitations, and three active substances in biodegradable binders.

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