Objective Review: Advanced Testing and Toxicity of Restricted Substances for Sustainable Leather Industry

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Abstract

Leather industry uses a great number of processing chemicals to make leather from animal hides. The toxicity, health and environmental impacts of many of these chemicals have been established leading to significant regulatory certifications and programs helping in trade and policy making. The focus of this review are the hazardous chemicals and auxiliaries relevant to leather industry, their categories, possible origins, analysis and toxicity with respect to humans and the environment and the regulatory mechanisms suggested for them through manufacturing restricted substance list (MRSL) 2.0.** Informative guidelines are provided about the most probable leather processing stage for the origin of these chemicals. Some alternative technologies, chemicals and ideas gaining popularity are also suggested as probable remedies. Recommended test methods are stated for the adequate monitoring of the hazardous chemicals. The nature and severity of chemical toxicity and corresponding limits set for their allowed use in formulations are graphically expressed for clarity and ease of understanding. The maximum number of compounds / isomers belong to classes comprising chlorinated paraffins, perfluorooctanoic acids (PFOA), perfluorooctanesulfonates (PFOS) and banned aromatic amines. Similarly, most of the restricted chemicals are used during the finishing stage and may be considered for eco-friendly alternatives. Likewise, the analytical equipment covering most testing requirements is GC-MS among other hyphenated techniques. Additionally, most critical chemicals from toxicity point of view are arsenic, cadmium and chromium (VI), whereas navy blue colorants and chlorinated aromatic compounds may be considered as less toxic among the restricted chemicals under the current scope. Surprisingly, the latest UV absorbents and polymeric fatliquors are comparatively non-toxic. Similarly, the most relaxed formulation limits are given for UV absorbers and 2-methoxypropylacetate whereas strict limits have been set for PFOA, PFOS, mercury, triclosan permethrin, sensitizing dyes etc. in MRSL 2.0.

Introduction

Leather industry is one of the oldest industries known. The popularity of leather products is because of their durability, feel, strength, quality, long service life and natural looks that still make them attractive among high-end markets. It takes a large number of different processing chemicals, many important time taking steps and a team of leather experts to make good quality leather from raw hides.[1] With the commencement and frequency of various toxicological and case studies related to human health and environment, some chemicals were classified as unsuitable for human use and/or detrimental for the environment. Unfortunately, certain hazardous chemicals are still in use because suitable alternates are either not available or they are not as efficient as the conventional chemicals in use. The information related to safety and toxicity, upon its availability stressed on the establishment of permissible limits for the target chemicals in leather processing chemicals.[2] It also compelled leather manufacturers to frequently monitor leather products to ensure that the presence of such compounds is under pre-defined limits.

Regulatory Standards and Certifications for Leather Sector Sustainability

The leather industry has been a major stake holder on the manufacturing and export side in many developing countries. This emphasizes the importance of appropriate reforms necessary in the leather sector to achieve the sustainability development goals (SDGs) set by the member states by the year 2030.[3] It is interesting to note that the certification programs already developed and implemented so far, directly address 12 out of 17 SDGs.

The very first regulation was implemented by Germany for Pentachlorophenol (PCP) and Azo Dyes in 1990.[4] Later on a number of certification programs were introduced to address social, economic, environmental and equality, security, and public health related issues focusing on leather and allied industries and businesses. Bluesign is an endorsement focused on human health,

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air emissions, water management and client well-being.[5] Likewise, Content Claim Standard (CCS), as the title suggests, is related to the third party verification of product contents and certification. Also, Cradle to Cradle is a certification focusing on material health, material reuse, social responsibility and sustainable use of energy etc. The system offers grading of manufacturers according to their level of compliance.[6] Moreover, the Fairtrade certification program provides reforms in social, economic and environmental aspects of small and medium leather manufacturing units in developing countries.[7] Aiding the global efforts, the European Union (EU) initiated Registration, Evaluation, Authorization and Restriction of Chemicals (REACH) in 2006 to address the management of hazardous chemicals in a more comprehensive way.[8]

Two certifications focusing on recycling are Global Recycle Standard (GRS) and Recycled Claim Standard (RCS). GRS is a certification program initially launched in 2008 for ecological and human health benefits. It emphasizes on the utilization of recycled materials along with checking and control of physical and chemical parameters before discharge of effluent into the environment. It also includes all the checks already suggested by Global Organic Textile Standard (GOTS)[9] and puts limitations on the use of synthetic substances. RCS is another standard focusing also on reuse and recycling of materials from input up to the final product. Similarly, the Higg Index was initiated by Sustainable Apparel Coalition (SAC) in 2012. Higg index works as a tool for the assessment of sustainability of the entire cycle of the end product, identifying room for necessary improvements.

Oeko-Tex is a globally acclaimed test standard initiated in Germany in the year 1995. Oeko-Tex certification is awarded to leather or leather products for one year. It ensures that the leather product and processing are both eco and human friendly.[10] Furthermore, Source Map ecolabel concentrates on the information on the starting points of a product's sections and also its social and natural footprints.[9] In the same way, Internationale Verband der Naturtextilwirtschaft (IVN) Natural Leather Standard was established in 1999. IVN provides two types of quality seals, Naturleder IVN certified and Naturtextil IVN certified BEST; mainly addressing social and environmental aspects.[9]

A prominent association of a group of leather manufacturing giants, retailers, brands and technical experts initiated the Leather Working Group (LWG) in 2005[11] and introduced a complete accreditation program to revolutionize the conventional leather making practices to green leather manufacturing. The standard addresses waste management, control of toxic chemicals, carbon footprint, energy and water usage optimization, and implementation of safety protocols.[12] The Leather Working Group has been a major driver of the industry towards sustainable leather manufacturing.[9]

With a similar reputation, the Worldwide Responsible Accredited Production (WRAP) program has been the world's biggest sector based program for leather consisting of compliance with 12 principles related to ethical workforce utilization, environmental sustainability, gender equality, health and security. In addition to these certification programs, two important socioeconomic certifications linking international trade are Sustainable Fair Trade Management System (SFTMS) and SA8000 Certification. The later has been an internationally recognized program for social reforms in the leather manufacturing sector, launched in 1997.[13]

Another pertinent development was the establishment of National Science Foundation (NSF) in 1994. The first assessment of NSF incorporates Zero Discharge of Hazardous Chemicals Manufactured Restricted Substances List (ZDHC MRSL). The second assessment called ToxFMD Screened Chemistry Program screens all chemicals used in the manufacturing process ensuring human well-being globally. Some other initiatives are Leather Sector – Sustainability Certification Program as an agreement between Institute of Quality Certification for Leather Sector (ICEC), Italy and Brazilian Leather Certification of Sustainability (CSCB) program in 2018 and Brazilian Carbon Disclosure Project (CDP).[11]

ZDHC MRSL 2.0

The first restricted substances list, ZDHC MRSL 1.0 was issued back in 2014. The next version, 1.1 was launched the next year.[8] The second revision of ZDHC MRSL (version 2.0) was published in January 2020.[2] It includes more than 450 compounds belonging to around 22 different classes of compounds (Table I).

The various chemical classes comprise of different number of compounds, isomers etc. Although, some chemicals contribute less in numbers but their screening is highly important due to their relative toxicity such as the metals like arsenic, chromium (VI) and chlorinated aromatic compounds. The actual compounds in each class have been detailed along with their chemical abstract service (CAS) numbers in the LWG chemical module.[2]

Table I

Details of analysis and formulation limits for restricted chemicals[14] relevant to leather

S. No.	Analyte / Class of Analyte	Test methods (if available)	Detection Techniques	Formulation Limits
1.	Nonylphenols (NP)	ISO 18218-2:2015 [IULTCS/IUC 28-2]	LC-MS or GC-MS	250 ppm
2.	Nonylphenolethoxylates (NPEO) and Octylphenolsethoxylates (OPEO)	EN ISO 18218-1:2015	LC-MS & GC-MS	500 ppm
3.	Octylphenols (OP)	ISO 18218-2 (2019)	LC-MS & GC-MS	250 ppm
4.	2-phenylphenol (OPP)	ISO 13365-1 & 2:2020	LC	5000 ppm
5.	Permethrin	Jinlan et. al., 2020[15]	LC-MS/MS & GC-MS/MS	250 ppm
6.	Triclosan	Jahangir et. al., 2020[16]	LC MS, DAD	250 ppm
7.	Dichlorobenzene	Similar to DIN 54232:2010	GC-MS	500 ppm
8.	Other isomers of chlorobenzene & chlorotoluene	Similar to DIN 54232:2010	GC-MS	Sum = 200 ppm
9.	Pentachlorophenol (PCP) and Tetrachlorophenol (TeCP)	EN ISO 17070	GC-MS	Sum = 20 ppm
10.	All other Chlorophenols	EN ISO 17070:2015	GC-MS	Sum = 50 ppm
11.	Dyes – Azo forming banned aromatic amines	ISO 17234-1 & 17234-2	LC, GC	150 ppm (for each)
12.	Navy blue colorants and Sensitizing Dyes	DIN 54231:2005	LC	250 ppm for both
13.	Restricted Dyes (Carcinogenic)	DIN 54231	HPLC	250 ppm
14.	Flame retardants	EN ISO 17881-1:2016	GC-MS	250 ppm
15.	Fatliquoring agent with Short-chain chlorinated paraffins, (SCCPs), (C_{10} – C_{13}) & Medium-chain chlorinated paraffins, (MCCPs), (C_{14} – C_{17})	prEN ISO 22699-2, ISO/DIS 18219-1(en)	GC-MS, GC/ECNI-MS	250 & 500 ppm respectively
16.	Glycols / Glycols Ethers	Wang, et. al., 2014[17]	GC MS [17], HPLC, LC-MS	50 ppm
17.	2-methoxypropylacetate	Based on US EPA 8270	HPLC, LC-MS, GC MS	1000 ppm
18.	Halogenated Solvents	Chorier 2014[18]	GC-MS	5 & 40 ppm
19.	Organotin Compounds	CEN ISO/ TS 16179:2012	GC-MS	1 – 20 ppm
20.	Polycyclic Aromatic Hydrocarbons (PAHs)	AFPS GS 2014	GC-MS	Sum = 200 ppm
21.	Benzo[a]pyrene (BaP) and Naphthalene	AFPS GS 2014	GC-MS	20 and 300 ppm respectively
22.	PFOS and PFOA	prISO FDIS 23702-1:2018	LC-MS	Sum = 2 ppm and 25 ppb respectively
24.	Phthalates	ISO/TS 16181	GC-MS	Sum = 250 ppm
25.	Arsenic (As), Cadmium (Cd), Mercury (Hg) and Lead (Pb)	DIN EN ISO 17072-1:2017	ICP-OES, AAS	50, 20, 4 and 100 ppm respectively
26.	Chromium (VI)	EN ISO 17075-1:2017	ICP-OES, AAS	10 ppm
27.	Antimony	DIN EN ISO 17072-1:2017	ICP	Dye 50/ Pigment 250 ppm
28.	UV Absorbers (Conventional)	DIN EN 62321-6:2016-05	LC-MS/MS, GC-MS	1000 ppm
29.	VOCs	DIN CEN ISO/TS 16189:2013	GC-MS	500 ppm
30.	Benzene	Similar to AFPS GS 2014	GC-MS	50 ppm

where

AAS = Atomic Absorption Spectroscopy
AFPS = German Product Safety Commission
DAD = Diode array detection
ECNI = Electron capture negative ion chemical ionization
ICP-OES = Inductively Coupled Plasma - Optical Emission Spectrometry
VOCs = Volatile organic compounds

Control at Process Inputs for Restricted Substances

An effective way of reducing hazardous chemicals in the product is to control them at the raw materials input level, i.e. during the initial stages of manufacturing. Even the water used for wet processing stages could introduce unwanted substances like PFOS and PFOA into the system, paralleled by retanning and fatliquoring stages. The probable origins of hazardous substances according to MRSL (ver. 2.0) are presented in Table II and Figure 1, highlighting the importance of input controls.

It can be observed that most chemical classes and individual chemicals fall in the finishing stage, followed by dyeing stage as well as product manufacturing. Other categories include curing, fatliquoring, pigment and chemical formulations, water used in processing etc. which can incorporate number of potentially toxic chemicals into the final product.

Alternate Processes and Chemicals

Alternates for many processing stages and chemicals have been successfully trialed but their economic feasibility and commercial

Table II

Probable sources of origin for various restricted substances in leather

Analyte / Class of Analyte	Most Probable Origin
Alkylphenols and alkylphenol ethoxylates	Detergents, degreasing agents, dye and pigment preparations, wetting agents, emulsifier/dispersing agent, impregnating agents etc.[2]
2-phenylphenol (OPP)	Some use is permitted as a preservative in formulations.[2]
Permethrin and Triclosan	*May be present in low quality anti-microbials and biocides used for preservation
All chlorophenols	*Used as anti-mould before being regulated.
Azo forming banned aromatic amines, Navy blue colorants and Sensitizing Dyes	*May originate from dyes and pigments
Restricted Dyes (Carcinogenic)	*May originate from dyes
Flame retardants (halogen containing)	*Banned, but may still be used in some chemical products used in leather finishing
SCCPs, ($C_{10} – C_{13}$) & MCCPs, ($C_{14} – C_{17}$)	Fatliquors
Glycols / Glycols Ethers	*Possible origin through solvents for finishing or printing agents and fat/oil diluters or dissolving agents.[2]
Halogenated Solvents	May originate from finishing chemicals and solvents
Organotin Compounds	*Probable origin in leather products could be through plastics, glue and polyurethane
Polycyclic Aromatic Hydrocarbons (PAHs)	*PAHs are added in plastics, rubbers, coatings and lacquers. They could be present in carbon black dyestuffs as impurities. In footwear industry, PAHs are frequently found in the outsoles and in screen printing pastes.
PFOS and PFOA	*Possible origin could be oil, water and stain repellents.[2]
Phthalates	*May be detected in leather products, originating through any plastic parts or adhesives used.
Heavy metals: As, Cd, Hg and Pb	Heavy metals are not intentionally used in leather. Arsenic may originate from polluted water.[19] Cadmium, mercury and lead could originate through certain pigment formulations used during finishing stage.
Chromium (VI)	*Could be detected due to oxidation of chromium (III)
Antimony	*May originate through certain pigment
UV Absorbers (Conventional)	*Used in some chemical formulations for stability against UV and visible light.
VOCs	*They are associated with solvent based polyurethane coatings at finishing stage and glues and adhesives

*Not intentionally used in leather.

Figure 1. Likelihood of MRSL compounds emerging from different leather processing stages

success still needs to be figured out. Halophyte plants containing large amount of salts have been suggested as a replacement for salt as hide preservatives and can also act as biocides owing to their terpene contents.[20] Similarly, dehairing can also be performed through an effective way by oxidative method replacing sodium sulfide with sodium percarbonate.[21] Successful trials on enzymatic dehairing have also been carried out with proteases isolated from *Aspergillus tamarri* species,[22] combination of proteases and lipases[23] and activated proteases within lesser time.[24]

The demand for chrome free tanning has increased since the deleterious effects of hexavalent chromium have been established. A recent study utilizes an epoxy modified dialdehyde starch, producing a biomass based tanning agent; replacing chromium in the tanning process towards a good quality leather.[25] Furthermore, an attempt to replace toxic organic and inorganic tanning agents with a compact glyoxal based tanning system also aiding in upgradation of low grade skins has shown promising results.[26]

Fatliquors introduced during leather processing may contain medium and short chain chlorinated paraffins. A proposed way of avoiding them is to use fatliquors based on vegetable oils.[27] More recent work suggests using polymeric fatliquors that have considerably higher performance as compared to the conventional fatliquors and are also compatible with chrome-free leather manufacturing systems.[28]

Similarly, effective strategies for reducing the use of VOCs have also been reported.[29] The accidental presence of hexavalent chromium should always be kept in check as well as the mass fraction of fungicides should be within the permissible limits. Likewise, an example of possible utilization of ionic liquids in leather processing has been explored with fiber opening properties. In combination

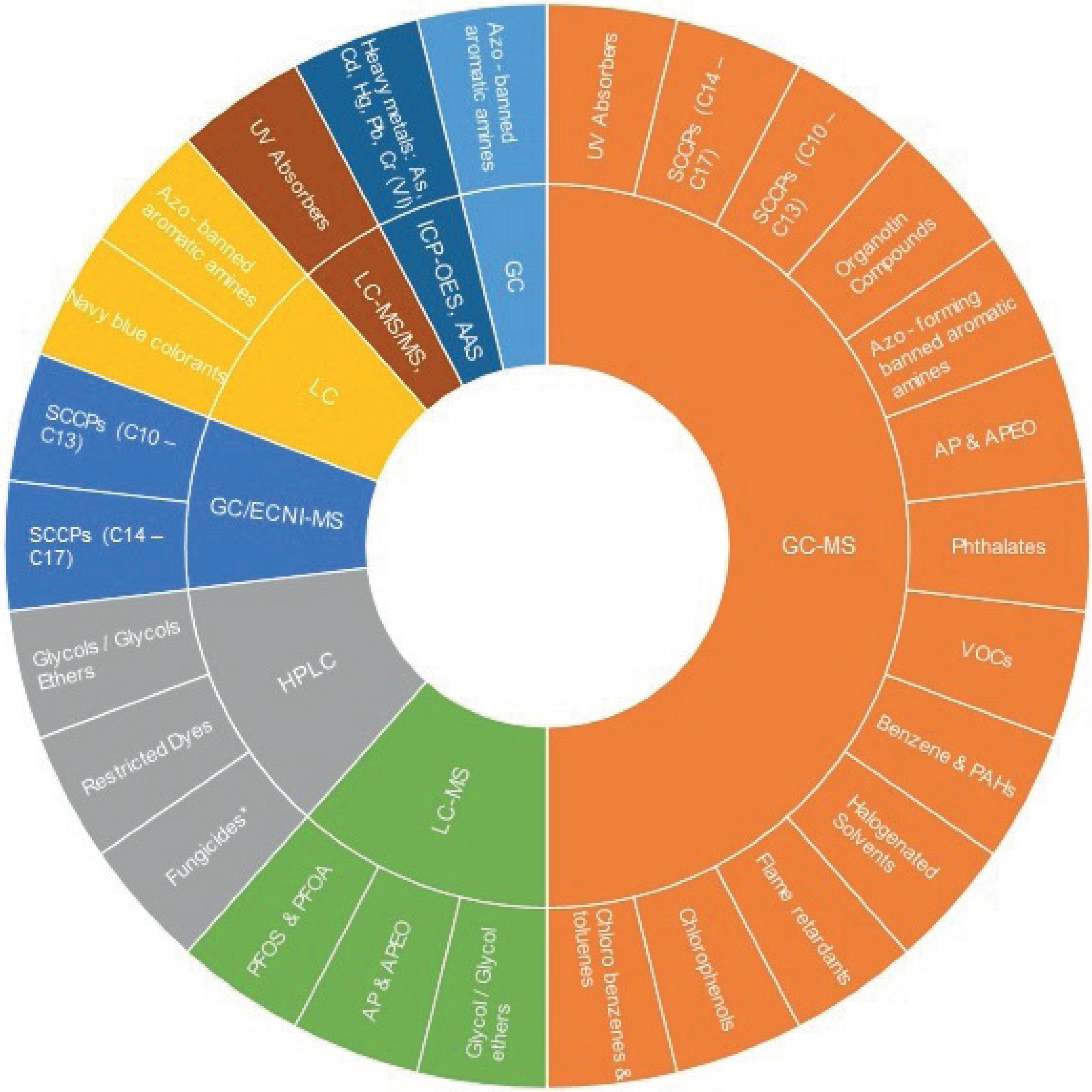

Figure 2. Recommended Analysis Techniques for MRSL (2.0) chemicals and compound classes

with certain enzymes, they could be a promising alternate for replacing dangerous chemicals like sodium sulfide and calcium hydroxide.[30] Many similar processes, chemical and technology alternatives have been reviewed by Covington and Wise.[31]

The more recent advances have brought the concept of modern tannery 4.0 with the aim of achieving near zero discharges, lowering wastages and enhancing productivity through state-of-the-art automation employing information communication technology and internet of things.[32] This information could also be helpful in troubleshooting repetitive positive tests for specific restricted compounds leading to their most probable source of origin.

Analysis Recommendations

The modern advancements in technology have provided adequate technical support and literature on quality assurance and testing of various toxic chemicals.[33] The analysis methods may include either digestion or extraction depending on the type of analyte. For some compounds additional steps of derivatization or reduction may be required. Various analytical techniques have been recommended for the analyses of restricted chemicals. Owing to the capabilities of the technique to analyze a wide variety of organic compounds it is not surprising that GC-MS is the technique of choice for a large number of chemicals mentioned in MRSL (2.0) as shown in Table I and Figure 2. For metal analysis, the best option is ICP-OES followed by AAS. For compounds with large and small organic moieties, GC, LC, HPLC, GC-MS, LC-MS and LC-MS/MS have been recommended (Table I and Figure 2). For chemicals like organotins and SCCPs, low resolution mass spectrometry (LRMS) and ECNI-MS have been suggested respectively. Similarly, for the typical analysis of perfluoroalkyl compounds LC-MS is preferred. Some analytes could be quantified with multiple techniques like glycols and glycol ethers, SCCPs and MCCPs, banned aromatic amines, UV absorbers (conventional), AP and APEO etc. A rough estimate of test costs could also be projected considering the general costs incurring on the recommended sophisticated hyphenated techniques. For some compounds the standard test methods for leather are still under development and will soon be available. However, supporting literature is available as analyses have been reported in other matrices (Table I).

Toxicity

Chemicals are widely used in leather industries such as basic chromium sulphate, synthetic tanning agents, fatliquors, resins, formaldehyde, biocides, surfactants, dyes, pigments and fire retardants, etc.[34,35] The use of hazardous leather chemicals may lead to acute and chronic toxicities in humans. The release of hazardous chemicals into the aquatic environment, i.e. seas, lakes and oceans, due to lack of proper management and effluent treatment prior to its discharge may lead to aquatic toxicity.[36] A comparative toxicity profile of the restricted compounds according to MRSL 2.0 is presented in Figure 3 in the form of a heat map chart with the effects of most toxic compounds highlighted by a reddish color tone and the least toxic by a dark greenish tone. The colors are assigned on the basis of the vitality of the body organs affected and the severity of the detrimental effect. The chemical classes and compounds are discussed in order of decreasing priority with the most toxic ones addressed first. The most harmful substances for the aquatic environment among the restricted substances are alkylphenol (AP), alkylphenol ethoxylates (APEO), chloro compounds and (PAHs).

Second to them are navy blue colorants, SCCPs and halogenated solvents, whereas organotin compounds are reported to have comparatively lower toxicities (Figure 3). According to toxicity studies exposure to chlorophenols[37], navy blue dyes[38], short chain chlorinated paraffins (SCCPs)[39] and some chlorobenzenes[39] may lead to chronic adverse effects on the aquatic life. SCCPs are categorized as persistent organic pollutants (POP). Certain organotins may also be persistent pollutants and could be harmful to the life in aquatic environment when exceeding specific concentration levels.[39] Certain PAHs[39] and dyes[40] can also cause toxicity of the aquatic environment. In the environment, alkylphenolethoxylates breakdown into alkylphenols, that are very noxious to aquatic environment if exceeding specific exposure levels.[39] Permethrin is toxic for bees being an environmental concern.[41]

The compounds posing threats to human health are monitored on priority basis and the most toxic compounds among the restricted substances are chromium (VI), arsenic and cadmium. The toxic effects of arsenic (especially in drinking water) are well known,[42] followed by mercury and lead as they affect brain and the central nervous system (CNS). Arsenic poisoning is a serious health issue disturbing millions of people worldwide. Short-term arsenic toxicity causes abdominal pain, vomiting, nausea and severe diarrhea. Additionally, peripheral neuropathy and encephalopathy are also on record. Long-term arsenic toxicity leads to multisystem illness.[43] Cadmium and hexavalent chromium are also classified as highly toxic compounds that could possibly cause cancer.

Cadmium exposure has been linked with cancers of the prostate, stomach, kidney, hematopoietic system and liver.[44,45] Some regulatory organizations such as the International Agency for Research on Cancer (IARC) and U.S. National Toxicology Program have identified cadmium compounds as human carcinogens.[46] Hexavalent chromium is a frequently reported job-related carcinogen linked with sinus, nasal and lung cancers.[47] Likewise, mercury can induce a variety of chronic and acute symptoms affecting several organs such as the heart, lungs, CNS and kidneys. It may also develop problems in liver, skin, muscles, gastrointestinal tract, and reproductive system and may cause harm to the newborn.[48] SCCPs are suspected of producing specific cancers. Continuous exposure to SCCPs could result in drying of skin and the formation of cracks.[39]

Among other severely toxic compounds are halogenated phenols[37] and halogenated aromatic solvents, banned aromatic amines[49], benzene, 2-thiocyanomethylthiobenzothiazole (TCMTB), restricted dyes, some flame retardants (halogen containing), PAHs, PFOA and OPP. Exposure to these compounds may lead to the development of cancers or tumors. Certain chlorobenzenes are noxious if inhaled or come in contact with the skin, when exceeding specific exposure levels.[39] Benzene shows carcinogenic potential for multiple organs in animals. Epidemiological research has revealed that it is leukemogenic in humans.[50] Dyes with carcinogenic or equivalent concern are reproductive toxicants or may pose mutagenic and/or skin contact threats.[40]

There are many biocides generally in use, however, the toxicity of only two is discussed, limiting to the scope of MRSL 2.0. Permethrin is a suspected thyroid disruptor and an irritant of skin and eyes. It has been designated as class 3, unclassifiable carcinogen by IARC.[41] Triclosan has been categorized as a possible carcinogen assigned to class 2B as suggested by IARC. It is highly corrosive in nature and exposure to the chemical may cause hypotension, pulmonary edema, myocardial failure, neurological changes, renal and liver toxicity, hemolysis and methemoglobinemia.[61]

Evidence has revealed that numerous halogen containing flame retardants are linked with detrimental health impacts on humans and animals including reproductive toxicity, thyroid and endocrine disruption, cancer, effects on the immune system, detrimental impacts on child and fetal, neurologic and development function.[55] In the case of PAHs, continuous exposure above specific concentrations could cause certain cancers to develop and some PAHs, may lead to infertility in humans or result in harm to fetus.[39] Likewise exposure

Figure 3. Toxicities of restricted substances expressed through heat map chart

to PFOS and PFOA can lead to developmental and reproductive problems in kidney, liver and immunological effects and tumors in animals. Most reliable conclusions are high levels of cholesterol in affected populations, with sparser findings relating to lower birth weights of babies, cancer (PFOA), thyroid hormone disturbance (PFOS) and effects on the immune system.[57] OPP has been linked to toxicity in humans, including reproductive carcinogenicity and neurotoxicity, developmental and acute toxicity.[60] Navy blue dyes are skin sensitizers.[38]

Certain other compounds have been connected to detrimental effects on neurologic functions and the human immune system such as some flame retardants (halogen containing), glycol ethers, organotin compounds, PFOA and PFOS, arsenic and OPP etc. Glycol ethers and lead may cause anemia and blood related disorders. In humans, acute exposure to high concentrations of glycol ethers causes pulmonary edema, narcosis and serious harm to kidney and liver. Continuous exposure to these compounds could cause blood and neurological effects, including anemia, tremor, fatigue, and nausea. No evidence is available for any carcinogenic potential of glycol ethers in humans however, they have been connected with liver damage.[56]

Certain organotins, above specific exposure levels, may confer immunotoxic effects and some may lead to infertility in humans or result in harm to fetus.[39] Compounds affecting the pulmonary system and lungs include chlorotoluenes, glycol ethers, phthalates and VOCs. Continuous exposure to certain halogenated solvents (e.g. chlorotoluene), above specific concentrations, could lead to specific cancers. Certain halogenated solvents may be noxious to aquatic life when present above specific concentration levels.[39] Arsenic and lead can disrupt the stomach. Short-term exposure to lead causes kidney damage, brain damage and gastrointestinal illnesses, whereas long-term exposure could result in detrimental effects on vitamin D metabolism, blood, kidneys, blood pressure, and central nervous system.[46] In humans, there is strong proof suggesting that high concentrations of cresols (VOC) are absorbed quickly during oral or dermal exposure, producing extreme toxicity (being corrosive) that could be fatal. Inhalation could cause respiratory tract irritation. No evidence exists related to the long-term toxicity of these compounds and there is insufficient information about the carcinogenic capability of cresols.[59] Chemicals like AP & APEO, some flame retardants (halogen containing), organotin compounds, PAHs and OPP may confer reproductive disorders and even infertility. These compounds have also been linked with damage to human fetus with the addition of phthalates. NP could lead to infertility in humans and result in harm to fetus.[39] Conventional UV stabilizers and absorbers in general cause developmental toxicities.[62,63] However, many recently discovered UV absorbing compounds are actually eco-friendly. For e.g. some marine natural products such as micosporine-like amino acids have been shown to absorb harmful UV radiations in UVA and UVB regions.[64]

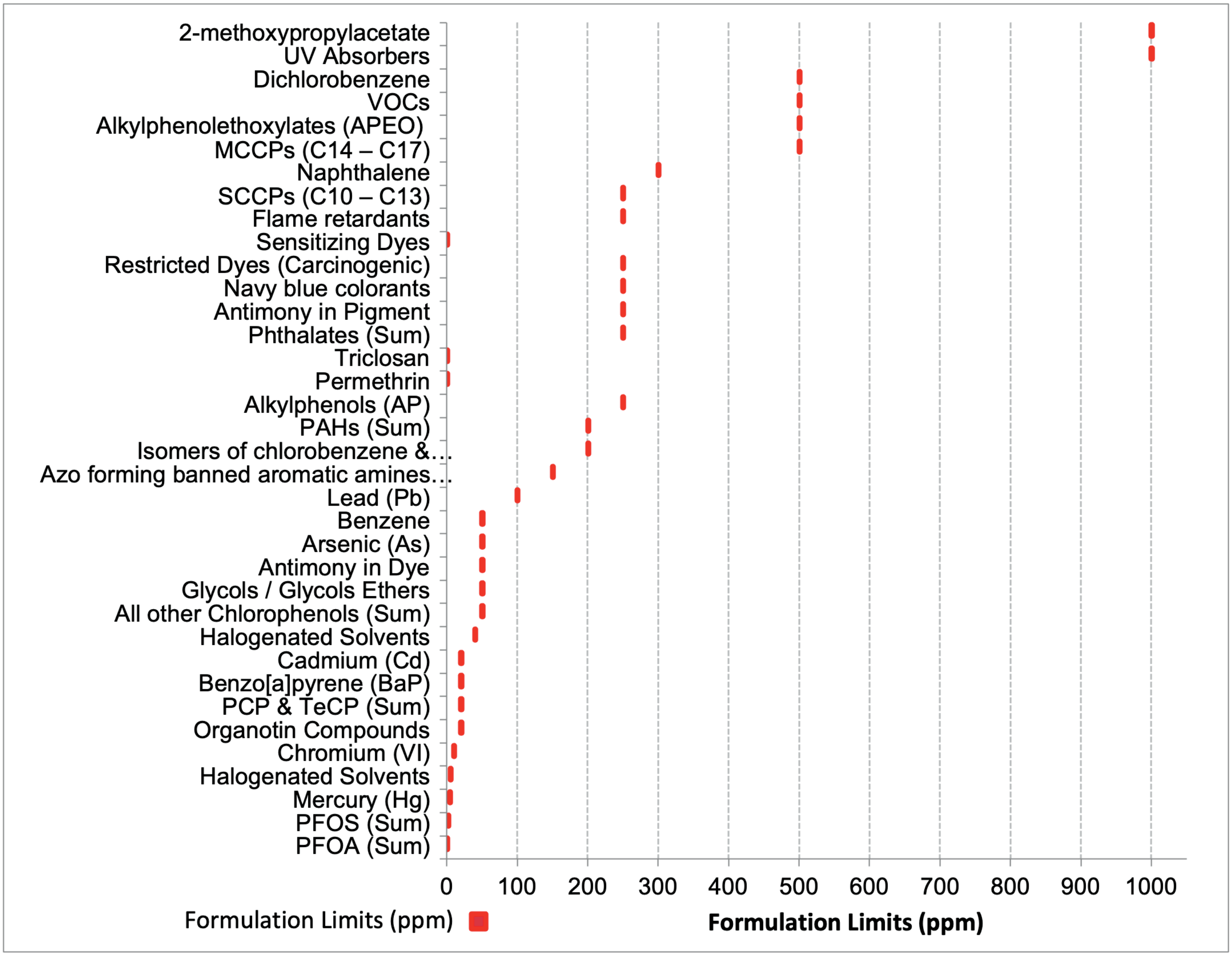

Figure 4. List of restricted substances (MRSL 2.0) with formulation limits (ppm)

There is evidence that phthalates affect male organs in newborn infants and may cause hormone imbalance, asthma and bronchial diseases.[58] Flame retardants (halogen containing), PFOS and phthalates have also been identified as hormone disruptors. Though, the newly developed flame retardants are comparatively non-toxic.[65] The comparatively less toxic compounds being those that do not penetrate the body deeply, affecting the skin only, such as colorants, SCCPs, OIT, *p*-chloro-*m*-cresol (PCMC) and some chlorinated benzene derivatives etc.

For human health, the level and pace of toxicity of the restricted chemicals and their property to invade human body serve as the decisive factors for setting their formulation limits (Figure 4). For the assessment of environmental concerns, the level of toxicity for the environment in general and the persistence of chemicals in the environment are considered.

Prospective Compounds

The listing of toxic compounds, their monitoring and search for alternates is a continuous process. In this regard a list has been formulated including aniline (free), diazene-1,2-dicarboxamide (ADCA), cyclic siloxanes, dimethylfumarate, carcinogenic dyes (or equivalent concern), flame retardants (halogen containing), formaldehyde, perfluorinated and polyfluorinated chemicals (PFCs), phenol, solvents and total heavy metals.[14] Another list of archived chemicals have been issued to strike out the use of chemicals banned earlier in order to avoid their reuse. Those include carcinogenic dyes (or equivalent concern), solvents and miscellaneous chemicals.[14]

Conclusion

The review is aimed to present a better and meaningful picture of the restrictions suggested in MRSL 2.0. Finishing has been identified as the leather processing stage having enormous potential for chemical replacements towards eco-friendly productions. The toxicity profiles of these chemicals also signify the importance of their screening and the justification for their formulation limits. GC-MS covers the analyses of most of the analytes highlighted in MRSL 2.0. The graphical presentation of data and grouping of information may lead to conclusive assessment, enabling leather manufacturers and chemical suppliers to have better controls and monitoring strategies for these chemicals. The guidelines for prospective chemicals in future revisions and testing most of the analytes under consideration are available where standard test methods have not been established.

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