The Effect of Formaldehyde Use in Sanitation

Report to the
WATER RESEARCH COMMISSION

by

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DISCLAIMER

EXECUTIVE SUMMARY

BACKGROUND

Besides its multiple other uses in industry, formaldehyde is used as an additive to inhibit the biodegradation within chemical toilets. This raises an obvious question about its effects on the receiving wastewater treatment facilities which accept the contents. A desktop study was consequently commissioned by the WRC and conducted at the University of Johannesburg. Formaldehyde is a simple CH_2O molecule which ranks amongst the 25 highest volume chemicals produced in the USA, with the annual production in the USA around 1.4 million tonnes at the turn of the century. It highest use is for the production of resins, followed by the industrial synthesis of many organic compounds. For the period 1992 to 2009, South Africa was a nett exporter of formaldehyde of an average of 100 tonnes per year. The amount of formaldehyde produced in South Africa could not be determined. When bought in bulk, the price of formalin (a 37% formaldehyde solution), is less than that of petrol or diesel.

Total formaldehyde emissions into the air are primarily caused by automotive exhaust fumes. This is the confirmed case in South Africa and well as in Canada. During 2009, automobiles contributed 94% of the formaldehyde emissions in Gauteng, with the remainder coming primarily from power generation. The ambient levels of formaldehyde in European and US cities are as high as 20 to 25 ug/m^3. Individuals are additionally exposed through cigarette smoke, new products that slowly release formaldehyde for the first few months from urea-formaldehyde adhesives, and the indoor combustion of biomass fuels. The oral exposure to humans is much less than through inhalation. Formaldehyde occurs naturally in fruits, fish and milk. In some cheeses and hams, formaldehyde is permitted as a bacteriostatic agent, leading to concentrations as high as 250 mg/kg. Instant coffee contains 10 to 16 mg/kg.

Formaldehyde does not raise any serious human health or environmental concerns, provided it is properly handled and stored. When released into the air, it is rapidly broken down by photolysis. When released into water, it is biodegraded within a few days. It is a well regulated chemical with extensive standards in different environments.

Formaldehyde finds extensive use in chemical toilets. The holding tank is dosed with chemicals, which inhibit the biological degradation of the waste and also add a satisfying fragrance to the wastewater. Most of the commonly used holding-tank chemicals contain formaldehyde and are toxic or inhibitory to wastewater at full strength, but completely biodegrades with dilution and time. It breaks down into simpler molecules (like carbon dioxide and water) through the natural action of oxygen, sunlight, bacteria and heat. The biodegradation is considered to be faster than most other deodorant products, and therefore formaldehyde-based products are considered the most effective holding tank chemicals available. It was not possible to determine how much of these formaldehyde-based toilet chemicals are used in South Africa every year. First, the formaldehyde content of the products varies widely. Second, there are some "formaldehyde-free" chemicals which appropriate an unknown part of the market share. Third, suppliers and users of these chemicals were not forthcoming in providing such information, despite repeated attempts.

OBJECTIVES AND AIMS

- Summarise the main chemical and toxicological properties of formaldehyde which may be of environmental concern.
- Review international and South African legislation, regulations and standards on the use of formaldehyde in portable toilets and other temporary ablution facilities.
- Establish the prevalence of formaldehyde-based chemicals used in temporary chemical toilets in South Africa.
- Assess the impact of these chemicals on wastewater treatment and the environment.
- Advise on the need and direction of more detailed investigation of tighter regulation of these chemicals for temporary ablution.

METHODOLOGY

Aim 1, Aim 2 and *Aim 4* were *rev*iewed mainly through documents from WHO, FDE, EPA, etc. as well as the regulations of individual states and countries. Formaldehyde and other chemical guidelines and regulations in the South African context were investigated through the use of literature online and in the UJ library.

Aim 3 was difficult to assess as the chemicals used by different portable toilet contractors are their proprietary chemicals and thus it was not possible to get any data from the suppliers of chemical toilets. Samples were taken of three different temporary toilet chemicals to measure the formaldehyde concentration in each of these chemicals.

RESULTS AND DISCUSSION

The addition of chemical toilet waste to biological wastewater treatment facilities poses two potential problems. First, the waste from chemical toilets is about 20 times more concentrated than that of normal domestic wastewater. Second, the presence of formaldehyde in the waste may inhibit the biological activity in the wastewater treatment facility. If the volume of chemical toilet waste is large in relation to the capacity of the treatment plant, its discharge could upset the proper working of the plant. For shock loads of formaldehyde to aerobic systems, the half-kill dose (= 50 % reduction in biological activity) is as much as 200 mg/litre. For continuous loading, the minimum half-kill dose is reported as about 20 mg/litre, but bacteria will acclimate to eventually remove larger concentrations of formaldehyde. For anaerobic treatment, the critical formaldehyde concentration is slightly higher than for aerobic treatment. When formaldehyde is discharged to septic tanks, it could lead to bacterial die-off and clogging of the french drain. The critical concentration is reported to be about 250 mg/litre, which is much higher than the estimated values of formaldehyde in chemical toilets.

Normal wastewater treatment facilities should never come close to these concentrations. An interesting case study is offered by the new King Shaka airport near Durban. The airport has a small, dedicated wastewater treatment plant for the airport, which also accepts the wastewater from 3.7 million airline passengers per annum. Even in this extreme case, the aircraft wastewater amounts to about 1.2% of the total inflow. The chemicals added to the aircraft holding tanks are diluted to 0.1%, which means that the chemical concentration entering the wastewater treatment plant, even with the assumption of no biodegradation, is only about 0.001 mg/litre.

CONCLUSIONS

The overall conclusion is that the use of formaldehyde in chemical toilets does not pose a problem to normal wastewater treatment facilities below a conservative estimate of say 20 mg/litre, whether it is a septic tank, aerobic treatment or anaerobic treatment. Given the low concentration of formaldehyde in the chemicals used, the large dilution when added to the holding tanks, and the rapid biodegradation of formaldehyde in a wastewater environment, this is a value which is very unlikely to be reached, of which no examples could be found. Even in the unusual case of King Shaka airport, the levels of formaldehyde is at least about four orders of magnitude lower than the level suggested.

RECOMMENDATION

After a preliminary quantification of the concentrations of formaldehyde discharged to wastewater treatment facilities, there is no reason to believe that this is an imminent problem. No further studies are warranted at this time.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AAAL	Ambient Air Action Level
ACGIH	American Conference of Industrial Hygienists
CAS	Chemical Abstracts Service
CREL	Ceiling Recommended Exposure Limit
DOT	US Department of Transportation
EPA	Environmental Protection Agency
HUD	US Department of Housing and Urban Development
IDLH	Immediately Dangerous to Life and Health
MAC	Maximum Allowable Concentration
MAK	Airborne Exposure Limit used by Deutsche Forschungsgemeinschaft (DFG)
MLR	Minimum Risk Level
NIOSH	National Institute of Occupational Safety and Health
NOEL	no-observed-effect level
NSRL	No Significant Risk Levels
OEL	Occupational Exposure Limit
OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Level
ppm	part per million
REL	Reference/Recommended Exposure Level (8-hour TWA) (NIOSH)
SCOEL	EU Scientific Committee on Occupational Exposure Limits
STEL	Short-Term Exposure Limit
TLV-C	Threshold Limit Value – Ceiling
TWA	Time-weighted Average
US FDA	US Food and Drug Administration
USA CIR	USA Cosmetic Ingredient Review
WHO	World Health Organization

1 INTRODUCTION AND OBJECTIVES

1.1 Introduction

The WRC has identified a possible concern about the use of formaldehyde in chemicals that are widely used in chemical toilets. If formaldehyde, which is used for its bacteriostatic properties, be discharged in high volumes and/or concentrations to wastewater treatment systems, the operation of these systems could be impaired. Should this concern turn out to be real, then a further round of research and possible regulation would have to follow.

The Water Research Group at the University of Johannesburg was contracted to do a desk-top study as the first step. The project started in July 2010 and was scheduled for completion at the end of 2010.

1.2 Objectives

- Summarise the main chemical and toxicological properties of formaldehyde which may be of environmental concern.
- Review international and South African legislation, regulations and standards on the use of formaldehyde in portable toilets and other temporary ablution facilities.
- Establish the prevalence of formaldehyde-based chemicals used in temporary chemical toilets in South Africa.
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2 FORMALDEHYDE

2.1 Composition

Molecular Formula: CH_2O (WHO, 2005; USDHHS, 1999; WHO, 2002; Pohanish, 2008)
Common Formula: HCHO (Patnaik, 1997; Jung et al., 2001; Pohanish, 2008)
CH_3OH in water (Mallinckrodt Chemicals, 2009)

Identification numbers

CAS #: 50-00-0 (Schardein & Macina, 2006; Arts et al., 2006; WHO, 2005; Patnaik, 1997; Nazaroff & Weschler, 2004)

EPA Hazardous Waste: U112 (USDHHS, 1999)

Conversion factor in air: 1 ppm = 1.23 mg/m^3 at 25°C (WHO, 2005; Arts et al., 2006; WHO, 2002; Patnaik, 1997; USDHHS, 1999).

1 mg/m^3 = 0.813 ppm (USDHHS, 1999)

Table 1: Alternate synonyms and trade names for formaldehyde

Synonym	Reference
Formic aldehyde	Schardein & Macina, 2006; USHHS, 1999; WHO, 2002; Pohanish, 2008; EPA, 2010
Methanal	Schardein & Macina, 2006; Patnaik, 1997; Pohanish, 2008; USHHS, 1999; EPA, 2010
methylene oxide	Schardein & Macina, 2006; USHHS, 1999; Pohanish, 2008; Dikshith, 2009; Patnaik, 1997; EPA, 2010
Oxomethane	Schardein & Macina, 2006; USHHS, 1999; Pohanish, 2008; Patnaik, 1997; WHO, 2002; EPA, 2010
Formalin	Schardein & Macina, 2006; USHHS, 1999; Dikshith, 2009; EPA, 2010
Quaternium	Hess-Kosa, 2001
Quaternium 15 is a formaldehyde-release agent	Hess-Kosa, 2001
diazolidinyl urea	Hess-Kosa, 2001
methyl aldehyde	Hess-Kosa, 2001; Dikshith, 2009; WHO, 2002; Pohanish, 2008; USHHS, 1999; EPA, 2010
formaldehyde 37%	Dikshith, 2009
morbicid acid	Dikshith, 2009

Synonym	Reference
Morbicid	Pohanish, 2008; USHHS, 1999; EPA, 2010
FA	Pohanish, 2008; USHHS, 1999; EPA, 2010
Dynoform	Pohanish, 2008; USHHS, 1999
BFV®	Schardein & Macina, 2006; Pohanish, 2008; USHHS, 1999; EPA, 2010
Formalith®	Schardein & Macina, 2006; Pohanish, 2008; USHHS, 1999; EPA, 2010
Ivalon®	Schardein & Macina, 2006; Pohanish, 2008; USHHS, 1999; EPA, 2010
Lysoform®	Schardein & Macina, 2006; Pohanish, 2008; USHHS, 1999; EPA, 2010
Fannoform	Pohanish, 2008; USHHS, 1999
Formol	Pohanish, 2008; USHHS, 1999; EPA, 2010
Fyde	Pohanish, 2008; USHHS, 1999; EPA, 2010
Hercules 37M6-8	Pohanish, 2008; USHHS, 1999
Hoch	Pohanish, 2008; USHHS, 1999; EPA, 2010
Karsan	Pohanish, 2008; USHHS, 1999; EPA, 2010
Low dye-fast dry ink	Pohanish, 2008; USHHS, 1999
Magnifloc 156C flocculant	Pohanish, 2008; USHHS, 1999
Methylene glycol	Pohanish, 2008; USHHS, 1999; EPA, 2010
NCI-C02799	Pohanish, 2008; USHHS, 1999; EPA, 2010
Oxymethylene	Pohanish, 2008; USHHS, 1999; EPA 1991; EPA, 2010
Polyoxymethylene	Pohanish, 2008; USHHS, 1999
Glycols	Pohanish, 2008; USHHS, 1999
Steriform	Pohanish, 2008; USHHS, 1999
Superlysoform	Pohanish, 2008; USHHS, 1999; EPA, 2010
Tetraoxymethylene	Pohanish, 2008; USHHS, 1999
Trioxane	Pohanish, 2008; USHHS, 1999
Paraform	EPA, 2010
Polyoxymethylene glycols	EPA, 2010

Formaldehyde is ubiquitous, being found both indoors and outdoors, naturally occurring and man-made (Hess-Kosa, 2001). It is the most common occurring aldehyde in the environment (Doel, 2009) and constitutes about 50% of all aldehydes present in air (Patnaik, 1997). The physiochemical properties of formaldehyde are listed in Table 2 below . Formaldehyde is a flammable, colourless gas with a pungent, suffocating odour (WHO, 2005; Arts et al., 2008;

USHHS, 2005; Patnaik, 1997; Dikshith, 2009; Pereira & Zaiat, 2009; ATSDR, 1999; Mallinckrodt Chemicals, 2009; WHO, 2002; USDHHS, 1999).

Table 2: Physicochemical properties

Property	**Value**	**Reference**
Physical state	Colourless gas	WHO, 2005
Boiling point	-19.2°C	WHO, 2005
Melting point	-118°C	WHO, 2005
Relative density	1.04 (air = 1)	WHO, 2005
Vapour pressure	52.6 kPa at -33°C	WHO, 2005
Water solubility	Freely miscible at 25°C	WHO, 2005
Log octanol-water partition coefficient	–1	WHO, 2005
liquefies at	–19.5°C	Patnaik, 1997
solidifies at	–92°C	Patnaik, 1997
Density	1.07 (air = 1)	Patnaik, 1997
Molecular Weight	30.03	Patnaik, 1997; USDHHS, 1999
Specific weight	0.78	Pohanish, 2008
Henry’s Law constant	*$3.27x10^{-7}$ atm-m^3/mol*	*WHO, 2005*
	3.4×10^{-7} atm-m3/mol at 25°C	EPA, 2010b
	2.2×10^{-2}-3.4 x 10^{-2} Pa-m3/mol at 25°C	EPA, 2010b; WHO, 2002
	3 x 10-5 kPa-m3/mol	WHO, 2005

Formaldehyde is derived from reactions between unsaturated organic compounds and ozone, hydroxyl radicals (Nazaroff & Weschler, 2004; USHHS, 1999). Formaldehyde is released into the air through the combustion of organic materials (Hess-Kosa, 2001; FCI, 2007; Doel, 2009; USCPSC, 1997; WHO, 2002). These combustion processes account, either directly or indirectly, for the majority of formaldehyde released into the environment (USHHS, 1999; USHHS, 2005; FCI, 2007). It is formed in the troposphere by photochemical oxidation of many types of natural and anthropogenic organic compounds, including automotive exhaust, cigarette smoke and formaldehyde-based products (Doel, 2009; WHO, 2002; USHHS, 1999; Patnaik, 1997). Formaldehyde is also potentially emitted into air from all of the products containing formaldehyde, exceeding 3000 in both home and office products (Schardein & Macina, 2006).

Formaldehyde is not a persistent air pollutant, as it is highly reactive with photochemicaly generated hydroxyl radicals, undergoing direct photolysis, as well as rapid hydrolysis when in contact with water vapour. The atmospheric half-life of formaldehyde is very short (ranging from a less than an hour to a few days) in most climatic conditions, but is strongly dependent on intensity of sunlight, temperature and humidity or moisture content (Doel, 2009).

Formaldehyde gas is stable in the absence of water (Dikshith, 2009; USHHS, 2005), but it is incompatible with oxidizers, alkalis, acids, phenols, and urea (Dikshith, 2009). Formaldehyde is a reactive and readily polymerized gas at normal temperature (Arts et al., 2006; Patnaik, 1997). In aqueous solutions, formaldehyde is present as a hydrate and tends to polymerize (Arts et al., 2006).

It is highly soluble in water (Hess-Kosa, 2001; Patnaik, 1997; Dikshith, 2009), up to 55% (USHHS, 2005), or 550,000 mg/L (Mao & Woskie, 1994), and in organic solvents (Patnaik, 1997). This aqueous solution of formaldehyde is referred to as formalin (Hess-Kosa, 2001; OSHA, 2002) and has been used since the introduction of formaldehyde in 1889 (Bedino, 2003). Formalin is a combination of formaldehyde, methanol (Tweedy, 2005) and water (Bedino, 2003). In fact, most commercial formaldehyde is produced and sold as formalin, containing 37-50% formaldehyde by weight (Dikshith, 2009; USHHS, 2005; Pohanish, 2008; Jung et al., 2001). Methanol (15%) acts as a polymerization inhibitor (USHHS, 2005; Pohanish, 2008) and stabilizer, as formalin is otherwise unstable (Bedino, 2003). Methanol is the choice stabilizer as it is a natural by-product in the manufacture of formalin (Bedino, 2003). Formaldehyde in formalin does not exist as an aldehyde, with 99.9% formalin solutions existing as methylene glycol (Bedino, 2003).

Formaldehyde is a normal mammalian metabolite (WHO, 2005) and is present in tissues, cells, and bodily fluids (Heck & Casanova, 2004; ATSDR, 1999chr). This everyday metabolism causes no harm to humans (USHHS, 1999), with the average person processing about 42.5 g formaldehyde each day through normal human metabolism (FCI, 2007). It is a normal component of human blood, and is an essential intermediate in all cells at concentrations about 2.0-2.6 μg/g of blood (Wolkoff & Nielsen, 2010). It is produced endogenously (Doel, 2009) in mammals, including humans, as a consequence of oxidative metabolism of many xenobiotics (USHHS, 1999; USHHS, 2005) and is essential in biosynthesis of certain amino acids (USHHS, 1999).

Formaldehyde is also found in many of our foods, both from the nature and through contamination by humans, for example the addition of preservatives (Hess-Kosa, 2001; Jung et al., 2001). Formaldehyde is, however, proscribed in food (and most other industries) due to its possible carcinogenicity (Jung et al., 2001).

Decades of scientific study have yielded a wealth of knowledge and understanding concerning the impact of formaldehyde exposure (FCI, 2007). As a result, there are regulations in place that protect the whole population when formaldehyde is handled and used appropriately (FCI, 2007).

2.2 Manufacture

Formaldehyde is manufactured both in South Africa and around the world. The manufacture of methanol, formaldehyde and urea-formaldehyde were started in Modderfontein, South Africa during the late 1950s (DEAT, 2006).

Formaldehyde is commercially synthesized from methanol (USHHS, 2005; WHO, 2002), which has been common practice since the widespread use of formaldehyde (USHHS, 1999). Oxidation of methanol to formaldehyde is done in the gas phase, with an excess of methanol preventing the solution from explosing (De Swaan Arons et al., 2004).

Two primary methods of manufacturing formaldehyde from methanol are currently used. The first method uses silver as a metal catalyst in its reactions, using both exothermic and endothermic reactions. This method yields approximately 86-90% formaldehyde (USHHS, 1999). The second method uses a metal oxide catalyst in which formaldehyde is produced from an exothermic reaction occurring under atmospheric pressure at high temperatures (300-400°C) (USHHS, 1999). Paraformaldehyde can also be converted to formaldehyde through heating (USHHS, 1999).

2.3 Application

Formaldehyde is extensively used in many industries (Dikshith, 2009; Arts et al., 2006; FCI, 2007; USCPSC, 1997). It is one of the most important chemicals for research and industry alike due to its low cost, high purity, and high reactivity (Pereira & Zaiat, 2009; USDHHS, 1999). It is also commonly used in most laboratories and morgues (Tweedy, 2005; ATSDR, 1999; Nemerow et al., 2009) and has been used for tissue and organ preservation for over a century, which has greatly assisted the advance of biological science (FCI, 2007). Formaldehyde has also been used as an intermediate in the synthesis of chemicals (Dikshith, 2009; USHHS, 1999), ranging from amino and phenolic resins to slow release fertilizers (USHHS, 1999) in the form of aqueous-methanolic solutions (Terelak et al., 2005). The total number of products containing formaldehyde exceeds 3000 (Schardein & Macina, 2006). Some of the uses of formaldehyde are listed in Table 3.

Formaldehyde's main industrial use in the USA is in the production of resins (USHHS, 1999), with its second largest use is in the industrial synthesis of a number of organic compounds (WHO, 2005).

Urea-formaldehyde resins are used as foam insulation in buildings and mining (USHHS, 1999). They are also used as the main adhesives in the forest industry because of their low cost, ease of use under a wide variety of curing conditions, low curing temperatures, water solubility, resistance to microorganisms and to abrasion, hardness, excellent thermal properties, and it is colourless (Gómez et al., 2009).

In consumer goods, formaldehyde is generally used in concentrations less than 1%. This small amount ensures that products do not spoil by microbial contamination (USHHS, 1999). This induces its use in cosmetic products: soaps, shampoos, hair preparations, deodorants, lotions, make-up, mouthwashes, sun-tan lotion and hand cream, bath products, mascara and eye make-up, cuticle softeners, nail creams and other nail products, vaginal deodorants, and shaving creams (USHHS, 1999). Even though less than 1% is commonly used, concentrations as high as 4.5% have been found in nail hardeners, which may result in high short-term exposure (USHHS, 1999). Trace amounts of formaldehyde are either due to its direct use in the product or as a result of the disinfection of the manufacturing equipment (USHHS, 1999). Formaldehyde is also used in small concentrations (between 0-5%) as disinfectants in different indoor cleaners (Wisniewski, 2005).

In the agriculture industry, formaldehyde has been used as a fumigant, as a preventative for mildew and spelt in wheat, and against rot in oats (USHHS, 1999). This is seen as an acceptable fumigant alternative to methyl bromide, a fumigant used mostly to control pests in soil, which was listed under the Montreal Protocol as an ozone depleting substance in 1992 (UNEP, 1998).

The use of formaldehyde in the medical field is relatively small (USHHS, 1999). But, it has been used to treat tympany, diarrhoea, mastitis, pneumonia, and internal bleeding in animals (USHHS, 1999). It is also used in hospitals to fumigate rooms after termination of viral haemorrhagic fever treatment (Swanepoel, 1987).

Table 3: Formaldehyde uses

Usage	**Reference**
Production of synthetic resins: Indoor urea-formaldehyde resin & Outdoor phenol- and melamine-formaldehyde	Hess-Kosa, 2001; Schardein & Macina, 2006; Arts et al., 2006; WHO, 2005; USHHS, 2005; Dikshith, 2009; WHO, 2002; Nemerow et al., 2009; Pohanish, 2008; USHHS, 1999; Laxen et al., 2009; USCPSC, 1997; Burrows, 2007
Adhesives	Arts et al., 2006; Dikshith, 2009; Nemerow et al., 2009; USHHS, 1999; FCI, 2007; Laxen et al., 2009
Latex	Pohanish, 2008; USHHS, 1999
Paper products	Hess-Kosa, 2001; Gómez et al., 2009; Dikshith, 2009; ATSDR, 1999; Nemerow et al., 2009; Carson & Mumford, 2002; Pohanish, 2008; USHHS, 1999; FCI, 2007; Laxen et al., 2009; USCPSC, 1997
Deodorants	Hess-Kosa, 2001; USHHS, 1999; FCI, 2007
Fabric dyes	Hess-Kosa, 2001; Pohanish, 2008; USHHS, 1999; FCI, 2007; Laxen et al., 2009
Inks	Hess-Kosa, 2001; Pohanish, 2008; FCI, 2007
Disinfectants	Hess-Kosa, 2001; Schardein & Macina, 2006; Arts et al., 2006; USHHS, 2005; Dikshith, 2009; Eiroa et al., 2005; ATSDR, 1999; WHO, 2002; Nemerow et al., 2009; Pohanish, 2008; USHHS, 1999; FCI, 2007; Laxen et al., 2009
Air fresheners	Hess-Kosa, 2001
Liquid Cleaning Products	Hess-Kosa, 2001; Nazaroff & Weschler, 2004; Wisniewski, 2005; USHHS, 1999; Laxen et al., 2009
Pesticides	Hess-Kosa, 2001; Carson & Mumford, 2002; Pohanish, 2008; Laxen et al., 2009
Preservatives	Hess-Kosa, 2001; Schardein & Macina, 2006; Arts et al., 2006; USHHS, 2005; Eiroa et al., 2005; OSHA, 2002; ATSDR, 1999; FCI, 2007
Paints	Hess-Kosa, 2001; Gómez et al., 2009; Dikshith, 2009; Carson & Mumford, 2002; USCPSC, 1997
Permanent press clothing	Hess-Kosa, 2001; Gómez et al., 2009; Dikshith, 2009; Nemerow et al., 2009; FCI, 2007; USCPSC, 1997; Burrows, 2007
Cosmetics: deodorant soaps, hairspray, styling mousse, fluoride toothpaste, mouthwash, mascara, talcum powder, hair colouring, and fingernail polish	Hess-Kosa, 2001; Arts et al., 2006; WHO, 2005; ATSDR, 1999; WHO, 2002; Nemerow et al., 2009; De Groot et al., 1994; USHHS, 1999; FCI, 2007; USCPSC, 1997; Burrows, 2007

Usage	**Reference**
Shampoos and conditioners	Hess-Kosa, 2001; USHHS, 1999; FCI, 2007
Pharmaceutical products	Hess-Kosa, 2001; ATSDR, 1999; WHO, 2002; Nemerow et al., 2009; Pohanish, 2008; USHHS, 1999; FCI, 2007
Production of wood products	Schardein & Macina, 2006; Gómez et al., 2009; Dikshith, 2009; ATSDR, 1999; WHO, 2002; USHHS, 1999; FCI, 2007
Production of plastics	Schardein & Macina, 2006; USHHS, 1999; FCI, 2007; Laxen et al., 2009
Production of fertilisers	Schardein & Macina, 2006; Arts et al., 2006; ATSDR, 1999; WHO, 2002; USHHS, 1999
Foam insulation	Schardein & Macina, 2006; Dikshith, 2009; Nemerow et al., 2009; Carson & Mumford, 2002; USHHS, 1999; Laxen et al., 2009
Textile finish	Schardein & Macina, 2006; Dikshith, 2009; Laxen et al., 2009
Stabilizer	Schardein & Macina, 2006
Antibacterial food additive	Schardein & Macina, 2006; WHO, 2002; USHHS, 1999
Manufacture of lubricants	Arts et al., 2006; USHHS, 1999
Embalming fluids	WHO, 2005; Dikshith, 2009; Nemerow et al., 2009; Pohanish, 2008; USHHS, 1999; FCI, 2007
Textiles	WHO, 2005; USHHS, 2005; Gómez et al., 2009; Pohanish, 2008
Wastewater emulsion breaking	Burke & Gaines, 2006
Moulding products	Gómez et al., 2009; Dikshith, 2009
Automobile tires	Gómez et al., 2009; WHO, 2002; Nemerow et al., 2009
Building materials	Dikshith, 2009; FCI, 2007
Carpets	Dikshith, 2009; CDC, 2008; Carson & Mumford, 2002; USHHS, 1999; FCI, 2007
Photographic industry	ATSDR, 1999; Pohanish, 2008; USHHS, 1999; FCI, 2007
In agriculture as a preservative for grains and seed dressings	USHHS, 1999;
Manufacture of automobiles	FCI, 2007
Vaccinations	FCI, 2007

There has been a steady decline in the usage of formaldehyde in all industries. In 1997 the U.S. Consumer Product Safety Commission (USCPSC) concluded that “manufacturers have reduced formaldehyde emissions from pressed wood products by 80-90% from the levels of the 1980’s (USCPSC, 1997).

2.4 Extent of Use in the USA

Formaldehyde has been produced commercially since the early 1900s and has ranked in the top 25 among the 50 highest volume chemicals produced in the USA. In 1992 it was ranked 22nd most produced chemical in the USA (USHHS, 1999). The annual production of formaldehyde was estimated to be around 1.4 million tonnes in the USA (Hess-Kosa, 2001).

According to the US EPA’s Toxic Chemicals Release Inventory (TRI), annual environmental releases of formaldehyde for 2008 indicated that a total formaldehyde release into the air in the USA was 3,086 tonnes and 125.1 tonnes in water, with a total of 8,211 tonnes released into the environment (TRI, 2008). These figures indicate that the total amount of formaldehyde production is substantially more than the amount released into the environment. It is further evident that the total amount of formaldehyde released into the water is only a small fraction (1.5%) of the total amount of formaldehyde discharged into the environment.

2.5 Extent of Use in South Africa

In South Africa, the database for the Department of Trade and Industry (2010) indicates that on average, 108 tonnes of formaldehyde was exported and 7.8 tonnes was imported over the period of 1992-2009. The maximum reported export of formaldehyde was 2,275 tonnes in 1993 and a minimum of 43 tonnes in 2008. The maximum and minimum imports of formaldehyde are 89 tonnes in 1996 and 0.44 tonnes in 2008. Figure 1 below indicates annual variations in both import and export quantities in South Africa. Neither the total amount of formaldehyde produced, nor the total amount discharged into the environment in South Africa was found in literature.

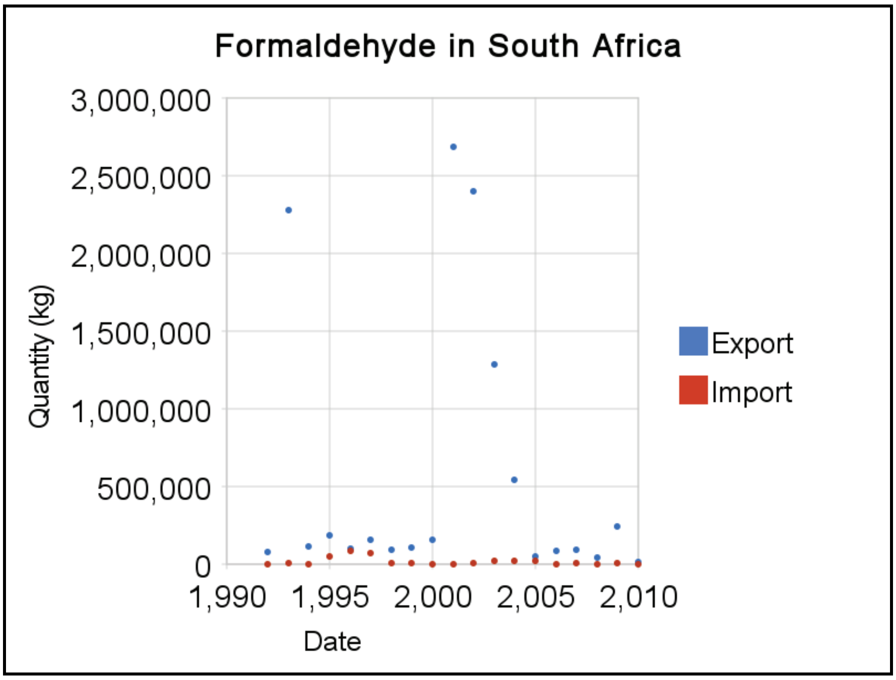


Figure 1: Import and export of formaldehyde in South Africa

Table 4 below indicates the total formaldehyde emissions in the Gauteng Province, in tonnes per annum. The table reveals that from the available data, automotive exhaust fumes are the largest generators of formaldehyde in the Gauteng Province. This was also the case in Canada, where the largest direct human source of formaldehyde was found to be due to automotive exhaust fumes (WHO, 2002). These emissions into the atmosphere cannot be seen as indicative values for every province in South Africa, as the Gauteng Province has both a high density and its population is made up of mostly urban dwellers.

Table 4: Formaldehyde emissions within the Gauteng Province (Liebenberg-Enslin & Hurt, 2009)

Industrial, Commercial & Institutional Fuel Burning	Electricity Generation	Vehicles	Total
0,03	40,00	584,76	624,79

2.6 Formaldehyde Exposure

The general population is primarily exposed to formaldehyde through inhalation (WHO, 2005). Natural sources of formaldehyde include forest fires, animal wastes, microbial products of biological systems, and plant volatiles (USHHS, 1999; WHO, 2002; Liebenberg-Enslin & Hurt, 2009). Fire-fighters are exposed to formaldehyde concentrations as high as 9,840 µg/m^3 during knockdown (bringing the main body of fire under control) and 490 µg/m^3

during overhaul (searching for and extinguishing hidden fire). Formaldehyde levels of 370 µg/m^3 have been measured inside a fire fighter's self-contained breathing apparatus (USHHS, 1999).

Another source of formaldehyde is cigarette smoke (Wolkoff & Nielsen, 2010; ATSDR, 1999; FCI, 2007; Laxen et al., 2009), with cigarette smoke contributing as much as 10% to 25% of indoor exposure (USHHS, 2005; USHHS, 1999). Smoke plumes contain in the order of 100 µg/m^3 formaldehyde (Wolkoff & Nielsen, 2010). Smokers are exposed to high levels of formaldehyde (about 380 µg/day) (WHO, 2005). Non-smokers can also be exposed to formaldehyde through side stream smoke, which can contain between five and fifty times higher concentrations than main stream smoke (USHHS, 199; Laxen et al., 2009). Normal exhalation, even in non-smokers, contains in the order of 1 to 10 µg/m^3 formaldehyde (Wolkoff & Nielsen, 2010; Arts et al., 2008).

Formaldehyde levels increase as temperature and relative humidity increase, and decreases with increased air movement (Wolkoff & Nielsen, 2010; CDC, 2008; USCPSC, 1997). For every 6°C increase in temperature, the formaldehyde level doubles. For an increase in relative humidity from 30 to 70 percent, the exposure levels may increase by 40 percent. Increased air movement will minimize stagnant air pockets and localization of gaseous formaldehyde at the point of off-gassing (Hess-Kosa, 2001).

Table 5: Taste and odour thresholds of formaldehyde in air and water

	Taste threshold	**Odour threshold**	**Reference**
Air	50 mg/L	25 mg/L	WHO, 2005
Air	61.5 mg/m^3	620-1,200 µg/m^3	USHHS, 1999; Hess-Kosa, 2001
Air		49-490 µg/m^3	Arts et al., 2008
Water	61.5 mg/m^3		USHHS, 1999
Air		120 µg/m^3	Wolkoff & Nielsen, 2010
Air		984 µg/m^3	Pohanish, 2008

Its odour is detected and recognized by most human beings at concentrations below 1,230 µg/m^3 (Arts et al., 2006; USHHS, 1999), as can be seen in Table 5 above. Odour detection of formaldehyde occurs at concentrations of approximately 120 µg/m^3 (Wolkoff & Nielsen, 2010). This concurs with Arts el al (2006) who found detection limits between 62 and

222 µg/m^3. Odour is, however, not a reliable warning for the presence of formaldehyde because the worker's ability to smell formaldehyde is quickly extinguished (Tweedy, 2005).

Products slowly releasing formaldehyde include products bonded with urea-formaldehyde adhesives (Gómez et al., 2009) including medium-density fibre board, particleboard, and plywood, all of which contain phenol-formaldehyde or urea-formaldehyde resin glues (Wolkoff & Nielsen, 2010; Wang et al., 2007; Hess-Kosa, 2001; Patnaik, 1997; Dikshith, 2009). This is due to latent formaldehyde (USHHS, 1999). Formaldehyde off-gassing of furnishings generally takes place within the first months of purchase, with older furniture rarely contributing to elevated levels of formaldehyde in the air (Hess-Kosa, 2001).

Other products that release formaldehyde include those with fungicides, e.g., waterborne lacquers, paints, consumer products, and cosmetics, and electronic equipment such as photocopiers and laser printers (Wolkoff & Nielsen, 2010; USHHS, 1999). Glass wool insulation with similar types of binders also emits Formaldehyde (Wolkoff & Nielsen, 2010). Indoor formaldehyde concentrations can also be increased due to combustion, for example simple stoves using biomass fuels (Petzer, 2009; Laxen et al., 2009). This is prevalent in South Africa due to the reliance of approximately 5 million low-income households on fossil fuel combustion (mostly kerosene) for heating (14%), cooking (21%) and lighting (13%), which emit formaldehyde along with other pollutants (Muller et al., 2003). Table 6 below indicates the emission rates and formaldehyde levels in different products from which formaldehyde exposure can occur.

Table 6: Release rates for different products (USHHS, 1999)

	Release rate	**Emission rates**	**Calculated formaldehyde level**
bare urea-formaldehyde wood products (1/4 to 3/4")	8.6 to 1,578 µg/m^2/hr		
coated urea-formaldehyde wood products	1 to 461 µg/m^2/hr		
permanent press fabrics	42 to 214 µg/m^2/hr		
decorative laminates	4 to 50 µg/m^2/hr		
fiberglass products	16 to 32 µg/m^2/hr		
bare phenol-formaldehyde wood products	4 to 9 µg/m^2/hr		
Paper grocery bags		0.4 µg/m^2/hr	

	Release rate	Emission rates	Calculated formaldehyde level
Paper towels		< 0.3 µg/m^2/hr	
wet latex paint		591 µg/m^2/hr	
more expensive latex paint		326 µg/m^2/hr	
wet fingernail hardener		215,500 µg/m^2/hr	
wet nail polish		20,700 µg/m^2/hr	
wet commercially applied base urea-formaldehyde floor finish		421 µg/m^2/hr	
wet commercially applied topcoat urea-formaldehyde floor finish		1,050,000 µg/m^2/hr	
during embalming procedures			0.44+-0.23 µg/m^3

Exposure in Manufacture

The National Occupational Exposure Survey (1981-1983) indicated that 1,329,332 workers were potentially exposed to formaldehyde (ATSDR 1999). From 1972 to 1974 it was estimated that 1.6 million workers were exposed to formaldehyde in more than 60 industrial categories (USHHS, 2005). The National Academy of Science estimates that 10 to 20 percent of the general population is susceptible to the irritating properties of formaldehyde at levels below 123 µg/m^3 (Hess-Kosa, 2001). There are however considerable individual variation in sensitivity to formaldehyde (Pohanish, 2008).

Workers in industries where formaldehyde is used or released may receive potentially high exposures (USHHS, 1999). Occupational exposures of formaldehyde occur in the production of aqueous formaldehyde (formalin) and its use in the chemical industry and in the manufacture of wood products, textiles, synthetic vitreous insulation and plastics (Doel, 2009).

Exposure in Outdoor Air

Airborne formaldehyde exposure, the most common route of exposure, ranges from around 0.5 µg/m^3, the mean natural background concentration, up to 100 µg/m^3 in short term peak levels (Doel, 2009; FCI, 2007). Even in remove, unpopulated areas, formaldehyde exposure range from 2.5 to 7.4 µg/m^3 (USHHS, 1999).

Ambient air concentrations of formaldehyde are between 1.3 and 17.2 µg/m^3 in many European countries (Arts et al., 2008), with concentrations falling below 10 µg/m^3 in European cities. Concentrations of about 20 µg/m^3 have been found in some major European capitals (Wolkoff & Nielsen, 2010). In 1994, the US EPA reported urban ambient outdoor exposures in the USA of 14 to 25 µg/m^3 (Hess-Kosa, 2001).

Exposure in Indoor Air

Exposure to formaldehyde is generally significantly higher indoor than outdoor, with a safe indoor air level of 123 µg/m^3 formaldehyde considered safe (Arts et al., 2008; USCPSC, 1997; USHHS, 1999). The primary ways of controlling indoor formaldehyde exposure are through the reduction of formaldehyde sources, in new housing and furnishings, and increasing the air flow within the house (Wolkoff & Nielsen, 2010).

Prior to strict manufacturing specifications and state regulations, the highest residential exposures were associated with mobile homes, which houses approximately 2.2 million people in the USA (USHHS, 2005), and conventional residences insulated with urea-formaldehyde foam (Hess-Kosa, 2001; Wang et al., 2007). Mean formaldehyde levels in homes with no urea-formaldehyde foam insulation range from 25 to 60 µg/m^3 whereas levels in mobile homes have been recorded over 100 µg/m^3 (Doel, 2009).

Concentrations of formaldehyde in public buildings, in both Europe and the USA, generally lie below those measured in homes (Wolkoff & Nielsen, 2010). The range of reported exposures in homes is 120 to 4,530 µg/m^3 (Hess-kosa, 2001). Mean formaldehyde concentrations generally lay below 50 µg/m^3 in homes, with a mean range of 5 to 100 µg/m^3, and below 25 µg/m^3 in public buildings (Wolkoff & Nielsen, 2010). Formaldehyde in highly populated areas and industrial urban air in the USA ranged from 12 to 23 µg/m^3 (and sometimes 60 µg/m^3) (USHHS, 1999).

Exposure in Water

Humans should not be exposed to formaldehyde in drinking water (ATSDR, 1999; USHHS, 1999). Formaldehyde is considered to be highly soluble in water, and its Henry's law constant suggests that it will be very unlikely to volatilize from water (WHO, 2005; USHHS, 1999). The estimated half-life is between 24-168 hours for surface water and 48-336 hours in groundwater (WHO, 2002). Exposure by inhalation during showering is therefore expected to be low (WHO, 2005). Also, little adsorption to sediment would be expected to occur

(USHHS, 1999). Because formaldehyde is rapidly metabolized, bioaccumulation is not expected to be important (USHHS, 1999). Formaldehyde is degraded by various mixed microbial cultures obtained from sludges and sewage (WHO, 2002).

Formaldehyde is released into water from the discharges of both treated and untreated industrial waste water. Formaldehyde can also be formed in seawater by photochemical processes (USHHS, 1999).

Exposure to formaldehyde by the oral route can occur, but exposure is not as common as by the inhalation route (USHHS, 1999). Traces of formaldehyde in raw water entering a water treatment plant were found between 2-7 µg/L (AWWA, 1991). In water, formaldehyde is hydrated and found largely in the form of methylene glycol and its oligomers. It arises in drinking-water mainly from the oxidation of natural organic (humic) matter during ozonation and chlorination (WHO, 2005; WHO, 2002; USHHS, 1999; AWWA, 1991). A study of full-scale treatment plants in France showed that formaldehyde concentrations increased 2-4 times the raw water levels (1-25 µg/L) following ozonation (WHO, 2005). Formaldehyde concentrations up to 30 µg/L have been found in ozonated drinking-water (WHO, 2005). Drinking-water treated with ozone is unlikely to contain formaldehyde at concentrations exceeding 50 µg/L and so will be a minor source of exposure (WHO, 2005). Formaldehyde was found to decrease after ozonation through sedimentation and filtration processes (AWWA, 1991). Concentrations of formaldehyde in water may be reduced by changes to disinfection practice or by GAC treatment to below 30 µg/L (WHO, 2005). In a study with sand filters operated with different contact times, formaldehyde levels were reduced by 60% after a 2-min EBCT (WHO, 2005). Formaldehyde can also enter drinking-water via leaching from polyacetal plastic fittings in which the protective coating has been broken (WHO, 2005).

Formaldehyde levels in rainwater collected in California are low, ranging from not detectable to 60 µg/L. Measured concentrations of formaldehyde range from 120 to 6,800 µg/L in fogwater; from 1,400 to 1,800 µg/L in cloudwater; and from 250 to 560 µg/L in mist samples (USHHS, 1999). According to the TRI in 2008, the formaldehyde release into the USA surface waters was 125.11 tonnes, amounting to 1.5% of the total environmental release of formaldehyde (TRI, 2008).

Exposure in Food

Formaldehyde occurs naturally in fruits, up to 60 mg/kg, and marine fish (WHO, 2002). Concentrations ranging from 3 to 23 mg/kg have been reported in a variety of foods (WHO, 2005). It is a common by product in the metabolism of many foods (Burrows, 2007), such as brussel sprouts and cabbage when they are cooked (FCI, 2007). Animals ingest as much as 0.25% formaldehyde in their diet (WHO, 2002). Subsequently, concentrations of formaldehyde in fresh milk have a mean value of 0.027 mg/kg (WHO, 2002). Formaldehyde may also be found in a variety of foods due to its use as a bacterio-static agent in production and its addition to animal feed to improve handling characteristics (WHO, 2002).

Formaldehyde is used in the sugar industry to inhibit bacterial growth during juice production (WHO, 2002; USHHS, 1999; Burrows, 2007). Where formaldehyde has been permitted to be used as a bacteriostatic agent in smoked ham and some varieties of Italian cheese, concentrations have been high (up to 267 mg/kg) (WHO, 2002). Concentrations of formaldehyde in alcoholic beverages range from 40 to 1,700 µg/L in Japan, 20 to 3,800 µg/L in Brazil (WHO, 2002). Canned soft drinks in Canada had a formaldehyde concentration of 7,400-8,700 µg/kg, brewed coffee containing 3,400-4,500 µg/kg, and instant coffee containing 10,000-16,000 µg/kg formaldehyde in the USA (WHO, 2002). In Taiwan, formaldehyde concentrations in bottled and packaged drinking-water were all below the detection limit of 129 µg/L (WHO, 2005).

Exposure in Public Transportation

Formaldehyde levels were reported between 1.7-9.5 µg/m^3 in aircrafts, in aircrafts, and 17-9.5 µg/m^3 in trains (Wang et al., 2007). These values are comparable to formaldehyde concentrations in office building, with concentrations between 11-66 µg/m^3 (Wang et al., 2007).

2.7 Human Health

A wealth of scientific understanding exists concerning formaldehyde's potential effects on human health, as it has been under scientific review for several decades by government agencies worldwide, academic institutions, and industry, making formaldehyde one of the most studied chemicals in use today (FCI, 2007).

The effects of formaldehyde are more concentration-dependent rather than exposure duration (Arts et al., 2008). The toxicity of formaldehyde is route-dependent and health effects are restricted to portals-of-entry (USHHS, 1999; Wolkoff & Nielsen, 2010; Heck & Casanova, 2004). Irritation at the point of contact is seen by inhalation, oral, and dermal routes (USHHS, 1999), with the primary routes being inhalation and dermal contact (USHHS, 2005; Doel, 2009). Due to its rapid solubility in water, exposure to formaldehyde vapours produces local irritation in mucous membranes as it is corrosive to mucosal tissue (USHHS, 1999). Irritation of the upper respiratory tract is the major characteristic of the non-cancer health effects of formaldehyde (Mao & Woskie, 1994). Formaldehyde is also a common allergen (Tweedy, 2005) and a genotoxicant (Arts et al., 2008; USHHS, 1999).

Formaldehyde is a normal metabolic product of all animal species metabolism, with varying endogenous levels present at all times (USHHS, 1999). Although absorption, distribution, metabolism, and excretion of formaldehyde are similar across all species, the differences in upper respiratory tract anatomy and physiology likely affect how inhaled formaldehyde acts in each of the different species (USHHS, 1999). USSHHS (1999) provides an in depth explanation of the biological reactivity of formaldehyde within the human body.

Being a normal components of intermediary metabolism, formaldehyde isn’t stored to any significant extent in any tissue, or fat, of the body but is rapidly absorbed (USHHS, 1999). Once absorbed, formaldehyde is very quickly metabolized and is usually converted to a non-toxic chemical called formate. Formate is quickly removed by the supporting blood supply either through excretion in urine (primarily as formic acid), incorporation into other cellular molecules, or oxidization into carbon dioxide which is exhaled (USHHS, 1999). Exhalation was the major route of excretion of formaldehyde from inhaled exposure, accounting for 39.4% of the low dose and 41.9% of the high dose (USHHS, 1999).

The exact mechanism by which formaldehyde exerts its toxicological effects is not completely known (Doel, 2009; USHHS, 1999). It is probable that formaldehyde toxicity occurs when intracellular levels saturate formaldehyde dehydrogenase activity, overwhelming the natural protection against formaldehyde, and allowing the unmetabolized intact molecule to exert its effects locally (USHHS, 1999). Excretion does not appear to be a factor in the toxicity of formaldehyde (USHHS, 1999).

It is unlikely that formaldehyde is responsible for any significant toxicological effects in organs other than the respiratory tract, particularly after inhalation or dermal exposures that might be encountered in the workplace or home given the rapid metabolic capability of tissues (USHHS, 1999). Neither the organs of the endocrine system nor the liver are a major target organ for formaldehyde toxicity after inhalation or oral exposure (USHHS, 1999). The available weight of evidence indicates that distant site effects from formaldehyde may occur only when the capacity for local disposition of formaldehyde is exceeded (USHHS, 1999). The effects of formaldehyde on the nervous system are only major after large doses are ingested (USHHS, 1999). These amounts are larger than are generally found indoors

(Laxen et al., 2009). The minimum risk levels (MRL) are presented in Table 7 below for both inhalation and oral digestion of formaldehyde over different exposure times.

Table 7: Minimum Risk Levels (MRL) associated to formaldehyde (USHHS, 1999)

	Inhalation	Oral
Acute-duration (14 days or less)	49 μg/m^3	-
Intermediate-duration (15-354 days)	37 μg/m^3	300 μg/kg/day
Chronic-duration (365 days or more)	9.8 μg/m^3	200 μg/kg/day

Formaldehyde binds readily to RNA, and single-stranded DNA to induce DNA-protein cross-links and breaks in single-stranded DNA (WHO, 2005). Formaldehyde concentrations between 5-10% will precipitate protein, which is the reason for its use in current histological techniques (USHHS, 1999; WHO, 2005)

In adults, neither respiratory symptoms or physician-diagnosed chronic bronchitis or asthma were significantly related to formaldehyde air concentrations (USHHS, 1999; FCI, 2007). This was based on studies by both the Agency for Toxic Substances and Disease Registry and the National Academy of Sciences (FCI, 2007). Studies have also indicated that asthmatic individuals are no more sensitive to the irritant effects of formaldehyde than healthy people (FCI, 2007).

Based on the extensive amount of data, there is widespread scientific recognition that when formaldehyde is handled and used properly and in accordance with government and industry guidelines, standards and regulations, consumers and workers are appropriately protected (FCI, 2007).

Known Health Effects

Direct exposure to formaldehyde, or a formalin solution, has had a range of effects on humans, from negligible to major (Watson et al., 2004). Inhaled particles from formaldehyde products are negligible in comparison to gaseous formaldehyde (Wolkoff & Nielsen, 2010).

The known health effects are now considered for different exposure levels (low and high) and for different routes of exposure.

Low Exposure Level

Known health effects due to low level exposures typically found in indoor air quality include irritation of the eyes, including watery eyes, burning eyes. These are for concentrations above 0.1% formaldehyde (Tweedy, 2005; Pohanish, 2008) or above 1,230 µg/m^3 (Arts et al., 2008; FCI, 2007). Above 2,460 µg/m^3 (Arts et al., 2008; Hess-Kosa, 2001; FCI, 2007) symptoms include burning nose, coughing and irritation of the throat (Hess-Kosa, 2001; Dikshith, 2009; Tweedy, 2005; Doel, 2009; Mallinckrodt Chemicals, 2009; CDC, 2008; Pohanish, 2008; USHHS, 1999). The effects of irritation are temporary and reversible (FCI, 2007).

Some more peculiar health effects of low level formaldehyde exposure includes sleeping difficulties, anxiety, fatigue, unusual thirst, dizziness, diarrhoea, menstrual cramps, headaches, memory loss, and decreased reaction time with increased formaldehyde concentrations (Hess-Kosa, 2001; Dikshith, 2009; USHHS, 1999).

High Exposure Level

High concentrations may cause irreversible eye damage (Mallinckrodt Chemicals, 2009). Concentrations between 12,300-24,600 µg/m^3 (Hess-Kosa, 2001; Doel, 2009) formaldehyde vapour inhaled for long periods can cause laryngitis, bronchitis, or bronchial pneumonia. Prolonged exposure may cause conjunctivitis (Tweedy, 2005; Pohanish, 2008). In severe cases, there may be lung irritation and bronchospasm. More elevated acute exposures *may* include coughing, wheezing, chest pain and tightness, increased heart rate, and bronchitis. There have also been reports of asthma attacks, nausea, vomiting, headaches, and nose bleeds. Exposures in excess of that normally found in indoor air quality situations (e.g., industrial exposures) may result in pulmonary edema, pneumonitis, and death (Hess-Kosa, 2001; Dikshith, 2009; ATSDR, 1999; Pohanish, 2008). The point where formaldehyde becomes an immediate danger to life and health has varies in literature, with USHHS (1999) reporting 24,600 µg/m^3 and OSHA (2002) and Nemerow et al. (2009) indicating a concentration of 123,000 µg/m^3 is immediately dangerous to health or life. This variation could be due to more data and information about how formaldehyde acts and causes danger to people’s health.

Airborne Exposure

The main focus of research on formaldehyde in relation to human health is directed at airborne concentrations as there is insufficient data for other media and only limited data to what happens after ingestion (WHO, 2002).

Airborne formaldehyde is an acute contact irritant in humans and laboratory animals, causing irritation of the eyes and upper respiratory tract during an inhalation exposure (USHHS, 1999). Results from human and animal studies consistently indicate that the upper respiratory tract is a critical target of airborne formaldehyde at concentrations ranging from 490 to 24,600 µg/m^3 (USHHS, 1999). The other critical target organs to airborne formaldehyde are the nose and the eyes, with the lungs being a secondary target at high exposure levels (USHHS, 1999), above 1,000 µg/m^3 (Wolkoff & Nielsen, 2010). A study concluded that when dogs inhale formaldehyde at concentrations between 150,000-289,000 µg/m^3, very little formaldehyde vapour would actually reach the lower respiratory tract (USHHS, 1999).

Eye, nose, and throat irritation occurs at concentrations in the range of 490-3,700 µg/m^3 (USHHS, 1999). Eye irritation is one of the most common complaints among people exposed to airborne formaldehyde, with mild to moderate eye irritation reported at low-level concentrations in the range of 490-4,900 µg/m^3 (USHHS, 1999).

Studies have shown that extensive inhalation exposure does not result in a significant increase of formaldehyde concentration in the blood (Wolkoff & Nielsen, 2010; Heck & Casanova, 2004; USHHS, 1999). The metabolism of formaldehyde is so fast that 500 µg/m^3 exposure does not increase urinary formate excretion. Further, little, if any, intact formaldehyde can be found in the blood of humans or animals due to its short life-time of less than 1.5 minutes (Wolkoff & Nielsen, 2010; Heck & Casanova, 2004). The lack of toxicity in hematological effects is likely related to rapid metabolism prior to the formaldehyde reaching the blood and blood-forming components (USHHS, 1999).

Dermal Exposure

Formaldehyde liquid, excluding both gaseous formaldehyde and formalin, is a widely recognized skin irritant and dermal sensitization agent in humans (USHHS, 1999). Dermal absorption in monkeys has been shown to be quite low (0.5% of the applied dose); most was either lost to evaporation or bound within the skin (USHHS, 1999). Formaldehyde is a susceptible cause of occupational skin disease in both coal and gold mines (Kruger et al , 2008).

Dermal contact with formaldehyde can cause white discoloration, smarting, cracking and scaling (Mallinckrodt Chemicals, 2009; Pohanish, 2008). Dermal exposures may result in skin irritation, contact dermatitis, and allergic sensitization (Hess-Kosa, 2001; USHHS, 1999) however; this is at concentrations much higher than encountered in drinking water (WHO, 2005). In some cases, symptoms involve eczema to the eyelids, face, neck, scrotum, and flexor surfaces of the arms. Sometimes it may involve the fingers, back of the hands, wrists, forearms, and parts of the body exposed to friction (Hess-Kosa, 2001; Doel, 2009). After dermal exposure, the adverse effects of formaldehyde are usually localized to the contact area, although other systemic reactions have been reported (USHHS, 1999). There is insufficient evidence that formaldehyde sensitizes the respiratory tract (USHHS, 1999).

Experiments with guinea pigs and mice indicated that repeated exposure of skin to concentrations for acute periods as low as 0.4% can be damaging (i.e., produce erythema, epidermal hyperplasia, or increased skin-fold thickness) (USHHS, 1999).

Oral Exposure

Oral exposure to formaldehyde can occur, but is not as common due to the instability of formaldehyde in aqueous solutions (USHHS, 1999). After oral exposure, the target tissues are those that come into contact with formaldehyde as it makes its way to the stomach and intestines (i.e., lips, oral pharynx, esophagus) (USHHS, 1999). Ingested formaldehyde is readily absorbed by the gastrointestinal tract (WHO, 2005; USHHS, 1999). Ingestion of formaldehyde doesn’t either cause adverse haematological effects in humans (USHHS, 1999). Formaldehyde is a corrosive agent after oral exposures of acute, intermediate, and chromic durations (USHHS, 1999).

Little information is available on the oral absorption characteristics of formaldehyde in humans; however, there is a sharp increase in formate levels in the blood (USHHS, 1999). The apparent half-life for formaldehyde after ingestion was 3.3 hours (USHHS, 1999).

Ingestion of formaldehyde can cause severe abdominal pain, violent vomiting, headache, seizures, lethargy, and diarrhoea. Larger doses may cause unconsciousness and death (Mallinckrodt Chemicals, 2009; Pohanish, 2008; USHHS, 1999). Less than 28.3 grams of ingested formaldehyde can damage the throat, stomach and intestine (Pohanish, 2008). This value is significantly higher than any of the concentrations found in literature and is not common, unless in undiluted concentrations. The oral cavity and the stomach are considered to carry most of the toxicity of formaldehyde after ingestion (USHHS, 1999).

Case reports of acute poisoning in humans ingesting doses of formaldehyde greater than 200 mg/kg have reported gastrointestinal effects and symptoms that reflect the chemical reactivity of formaldehyde and have reported other effects (USHHS, 1999).

Reproduction and Development

Formaldehyde is one of the smallest organic human developmental toxicants (Schardein & Macina, 2006). Both WHO and IARC concluded that there was unconvincing evidence that formaldehyde is a teratogen in either animals or human beings (USHHS, 1999). It is not considered to have reproductive or developmental effects in humans due to its rapid metabolism and reactivity (FCI, 2007; Mao & Woskie, 1994).

A study noted that possible developmental effects in humans exposed to formaldehyde found no statistically significant difference in incidence of low birth weights among groups of mothers who lived in residential districts with differing ambient air levels of formaldehyde (USHHS, 1999).

Studies have shown that formaldehyde can *potentially* induce spontaneous abortion or miscarriage in the human when exposures occur early in pregnancy (Schardein & Macina, 2006; Tweedy, 2005; Pohanish, 2008). However, animal studies for formaldehyde exposure in air, drinking water or diet, or applied to the skin also indicate that the reproductive organs are not a critical target for formaldehyde toxicity (USHHS, 1999). Thus, it is argued that reproduction and development are not affected by formaldehyde concentrations.

Cancer

The evidence for the carcinogenicity of formaldehyde is controversial (Mao & Woskie, 1994). Formaldehyde has been reported as a suspected carcinogen (Gómez et al., 2009; USHHS, 2005; Doel, 2009; Dikshith, 2009; Tweedy, 2005; Arts et al., 2006; WHO, 2005; OSHA, 2002; Carson & Mumford, 2002; Pohanish, 2008; USHHS, 1999), while it has also been reported a carcinogen (Patnaik, 1997; IARC, 2004) through inhalation (WHO, 2005). In June 2004, the International Agency for Research on Cancer reclassified formaldehyde as carcinogenic to humans (IARC, 2004; CDC, 2008; FCI, 2007). However, there is little evidence that formaldehyde is carcinogenic in humans by the oral or dermal route (WHO, 2005; USHHS, 1999). The US EPA did not, up to today, derive cancer risk estimates for oral exposure to formaldehyde (USHHS, 1999).

The conclusions of 40 reported epidemiological studies are equivocal (USHHS, 1999). As the epidemiological reports on formaldehyde and cancer increased there was an accompanying decline in interest in the carcinogenicity of formaldehyde (Cole & Axten, 2004).

The National Cancer Institute (NCI) found a causal association between formaldehyde and nasopharyngeal cancer, however, a reanalysis found little evidence to support these results (Marsh & Youk, 2005; Doel, 2009; WHO, 2002; Nemerow et al., 2009; USHHS, 1999). The matter still remains the subject of significant scientific and regulatory policy debate (Doel, 2009; Nemerow et al., 2009). Further, there is also no evidence of formaldehyde being a leukemogen (Cole & Axten, 2004; Heck & Casanova, 2004). However, it is implausible that formaldehyde would be capable of causing leukemia (FCI, 2007). There is little convincing evidence for a causal relationship between formaldehyde and extra-respiratory cancer (USHHS, 1999).

The available information demonstrates that formaldehyde exposure only poses a carcinogenic hazard under conditions that both induce toxicity and cause sustained regenerative proliferation (Doel, 2009), with exposure concentration being more important than exposure duration (USHHS, 1999). Further animal studies suggest little likelihood that chronic exposure to non-irritating levels of formaldehyde in drinking water will increase cancer risks in humans (USHHS, 1999). At the low levels to which people are exposed, most scientists believe that there is essentially no risk of cancer in humans (FCI, 2007).

Children

Children's unique physiology and behaviour can influence the extent of their exposure to hazardous chemicals (USHHS, 1999). Children and adults are likely to be exposed to formaldehyde, specifically, in exactly the same way (USHHS, 1999). The same type of effects that occur in adults, discussed above, are expected to occur in children. The main route of exposure for children is also through its presence in air (USHHS, 1999). However, there is increasing evidence to indicate that children may be more sensitive to formaldehyde respiratory toxicity than adults (Laxen et al., 2009).

Death

Cases of death in humans acutely exposed to airborne formaldehyde were not located in literature. Death has been recorded after ingestion of formaldehyde in connection with attempted suicides (USHHS, 1999). One case recorded a 41 year old woman, who swallowed 120 mL formalin, dying 28 hours after admission in hospital (USHHS, 1999).

In rats, lifetime administration of 5,000,000 µg/L formaldehyde in drinking water (approximate dose of 300 mg/kg/day) resulted in early mortalities (USHHS, 1999). The LD50 (lethal dose) for rats is 100 mg/kg (Mallinckrodt Chemicals, 2009).

Treatment

There are no known antidotes to formaldehyde poisoning in humans, particularly after oral exposure (USHHS, 1999). If there is any possibility that an employee's eyes or skin may be splashed with formaldehyde solutions, containing 0.1% or greater formaldehyde (Tweedy, 2005), they should be flushed with copious amounts of water (USHHS, 1999).

After oral exposure, vomiting should not be induced, since formaldehyde is highly corrosive. The stomach contents can be diluted with milk or water by mouth if the patient is alert and responsive, otherwise gastric lavage may be indicated (USHHS, 1999).

The primary concern after oral intoxication with large amounts of formaldehyde is correcting the severe acidosis and decreased blood pressure that this chemical induces. Treatment should aim at increasing the blood pressure to a somewhat normal state (sympathomimetic drugs may be used) as well as treating the acidosis with bicarbonate (USHHS, 1999). There are no available biomarkers for humans to indicate the level of exposure to formaldehyde (USHHS, 1999).

2.8 Environmental health concerns

Formaldehyde is released to the environment from both anthropogenic and natural sources (WHO, 2002). However, formaldehyde is easily broken down in the presence of sunlight to carbon dioxide and water (FCI, 2007). Generally, the background formaldehyde level both indoors and outdoors is an average of approximately 25 µg/m^3 in daily life (Wolkoff & Nielsen, 2010).

The environmental fate of formaldehyde in air has been well studied (USHHS, 1999). Under atmospheric conditions, formaldehyde is photo-oxidized in sunlight to carbon dioxide (Mao & Woskie, 1994). Formaldehyde breaks down in air to produce formic acid and carbon monoxide (USHHS, 1999). When formaldehyde is released into the air, it is readily degraded by photolysis and photochemically produced hydroxyl radicals, having an expected half-life of less than one day (Mallinckrodt Chemicals, 2009), with a half-life of 6 hours measured for photolysis in simulated sunlight (USHHS, 1999). In clean air, formaldehyde has a half-life of 19 hours and about half of that time in polluted air (USHHS, 1999). Its half-life is approximately 50 minutes during the daytime, but in the presence of nitrogen dioxide, this drops to about 30 minutes (Mao & Woskie, 1994). It is readily removed from the atmosphere by dry and wet deposition (Mallinckrodt Chemicals, 2009; USHHS, 2005; USHHS, 1999). Because of its high solubility, there will be efficient transfer into rain and surface water, which may be important sinks (USHHS, 1999).

Formaldehyde released into water is expected to readily biodegrade within a few days. However, it does not evaporate significantly nor is there significant bioaccumulation (Mallinckrodt Chemicals, 2009; USHHS, 1999; FCI, 2007). In water, formaldehyde is hydrated; it does not have a chromophore that is capable of absorbing sunlight and photochemically decomposing (USHHS, 1999). It does not last a long time in water and is not commonly found in drinking water supplies (USHHS, 1999).

A study reported the effects of formalin discharged into seawater, concluding that there is no evidence of formalin causing acute toxicity in marine ecosystem (Jung et al., 2001). Formaldehyde concentrations did not accumulate, but decreased exponentially over time (Jung et al., 2001; ATSDR, 1999; Nemerow et al., 2009). In non-aerated seawater, formaldehyde took 8, 9, 10, 13 and 19 days to degrade below detection at 25, 50, 100, 150 and 200 mg/L formalin, respectively (Jung et al., 2001). Therefore, formaldehyde is not likely to cause adverse effects on terrestrial or aquatic organisms (WHO, 2002). In aquatic animals, formaldehyde resulting from formalin exposure hasn’t either been shown to accumulate in their edible tissue above the normal range of endogenous formaldehyde (Jung et al., 2001).

2.9 International Laws and Regulations

Formaldehyde is an extensively regulated material. Thus, consumers and workers are appropriately protected when formaldehyde is handled and used in accordance with current government regulations (FCI, 2007). Internationally, there is no generally agreed upon

standard for formaldehyde concentrations and a wide range in occupational limits are found from 20 μg/m^3 (NIOSH) to 2,500 μg/m^3 (in the UK) with the trend being to reduce 8 hour TWA's to below the lower limit cytotoxic threshold value of 700 μg/m^3 (Doel, 2009). The international trend is to reduce formaldehyde exposure limits in air to 369 μg/m^3 (Doel, 2009). One of the more commonly accepted limits for formaldehyde is 123 μg/m^3 (Hess-Kosa, 2001). A range of international regulations are presented in
Table 8 (page 28) and Table 9 (page 29), with the latter showing the regulations for different countries.

In the USA, federal agencies that develop regulations, which are enforced by law, include the EPA, Occupational Safety and Health Administration (OSHA), and the Food and Drug Administration (FDA). The Agency for Toxic Substances and Disease Registry (ATSDR) and NIOSH both develop recommendations, however, these are cannot be enforced by law (USHHS, 1999). The US EPA has performed an extensive four volume study on the hazards associated with formaldehyde through inhalation. The document is in draft form, however, it is accessible for review (EPA, 2010b).

The CPSC (Consumer Product Safety Commission in the U.S.A.) states that products containing 1% or more formaldehyde must contain a warning label (USHHS, 2005). DOT considers formaldehyde as a hazardous material and special requirements have been set for marking, labelling, and transporting this material (USHHS, 2005).

The US Environmental Protection Agency (US EPA) lists formadehyde as a hazardous air pollutant, being one of 33 air pollutants that cause the greatest threat in urban areas. They have also placed limits on the volatile organic compound emissions (VoC) during manufacturing of formaldehyde (USHHS, 2005). The US EPA has an ambient air action level is 123 μg/m^3 for formaldehyde, which encompasses most of the health effects and is seldom exceeded outdoors (Hess-Kosa, 2001). The US Department of Housing and Urban Development (HUD) has regulated the indoor air quality to 490 μg/m^3 (Nemerow et al., 2009). WHO has recommended an air quality guideline of 100 μg/m^3 as a 30 minute average for protection of general population (Doel, 2009; CDC, 2008; Laxen et al., 2009), with an indoor air quality action level of 150 μg/m^3 (Hess-Kosa, 2001). An air quality guideline of 100 μg/m^3 is considered protective against both acute and chronic sensory irritation in the airways in the general population (Wolkoff & Nielsen, 2010). A threshold of 370 μg/m^3, suggested by FCI (2007) would protect against nearly all irritation.

Some states in the USA have even more restrictive limits, setting guidelines or standards for formaldehyde in ambient air ranging from zero (North Carolina and North Dakota) to 0.77 μg/m^3 (Massachusetts) to 5.0 μg/m^3 (New York) to 7.2 μg/m^3 (Pennsylvania) to 7.5 μg/m^3 (South Carolina) to 12.0 μg/m^3 (Connecticut, South Dakota and Virginia) to 18.0 μg/m^3 (Indiana) to 71.0 μg/m^3 (Nevada) to 75.0 μg/m^3 (Washington) (Pohanish, 2008). Hess-Kosa (2001) provides an 8-hour exposure limit of 18 μg/m^3 (Connecticut) and 110 μg/m^3 (Vermont). Under California's Proposition 65, Formaldehyde is listed as a TAC having a NSRL for formaldehyde are 40 μg/day and a REL of 3 μg/ m^3 (Nazaroff & Weschler, 2004). California Office of Environmental Health Hazard Assessment (OEHHA) has recently implemented a 1 hour formaldehyde acute reference exposure level of 55 μg/m^3. OEHHA has suggested both an 8-hour and a chronic reference exposure level of 9 μg/m^3 (Wolkoff & Nielsen, 2010). Many, or most, of these stringent State guidelines may, however, be unattainable (Hess-Kosa, 2001).

Table 8: Regulated limits of formaldehyde in the air

Organization	**TWA**	**TLV**	**TLV-C**	**STEL**	**IDLH**	**REL**	**CREL**	**AAAL**	**MAC**	**Reference**
		369 μg/m^3		369 μg/m^3						Schardein & Macina, 2006
SCOEL	250 μg/m^3									DOEL, 2009; Wolkoff & Nielsen, 2010
ACGIH			369 μg/m^3							USHHS, 2005; Hess-Kosa, 2001; Mallinckrodt Chemicals, 2009; CDC, 2008; Pohanish, 2008
HUD									492 μg/m^3	
NOISH					24,600 μg/m^3	19.7 μg/m^3	123 μg/m^3			USHHS, 2005; Dikshith, 2009; Pohanish, 2008

Organization	**TWA**	**TLV**	**TLV-C**	**STEL**	**IDLH**	**REL**	**CREL**	**AAAL**	**MAC**	**Reference**
WHO								148 μg/m^3		Hess-Kosa, 2001
US EPA								123 μg/m^3		Hess-Kosa, 2001
OSHA	923 μg/m^3			2,460 μg/m^3						USHHS, 2005; Dikshith, 2009; OSHA, 2002; Mallinckrodt Chemicals, 2009; CDC, 2008; Pohanish, 2008; USHHS, 1999; FCI, 2007
OSHA								615 μg/m^3		Tweedy, 2005

Health Canada has developed two residential guidelines for formaldehyde, an hour averaged exposure value of 123 μg/m^3 and an 8-hour averaged exposure value of 50 μg/m^3 considered preventive of allergic sensitization or asthma in children (Wolkoff & Nielsen, 2010).

Table 9: Regulations around the world for Formaldehyde limits in air (Pohanish, 2008)

Country	TWA	MAK	STEL	VME	VLE	MAC-TGG	KZG	TGV	NVG	Date	
Egypt	3,690 μg/m^3									1993	carcinogen
Australia	1,230 μg/m^3		2,690 μg/m^3							1993	carcinogen
Austria		615 μg/m^3								1999	suspected carcinogen
Belgium	1,230 μg/m^3		2,690 μg/m^3							1993	carcinogen
Denmark	369 μg/m^3									1999	

Country	TWA	MAK	STEL	VME	VLE	MAC-TGG	KZG	TGV	NVG	Date	
France				615 µg/m^3	1,230 µg/m^3					1999	carcinogen
Hungary			738 µg/m^3							1993	carcinogen
The Netherlands						1,845 µg/m^3				2003	
Norway	615 µg/m^3									1999	
The Philippines	6,150 µg/m^3									1993	
Poland	500 µg/m^3		1,000 µg/m^3							1999	
Russia	615 µg/m^3		500 µg/m^3							1993	
Sweden								1,230 µg/m^3	615 µg/m^3	1999	
Switzerland		615 µg/m^3					1,230 µg/m^3			1999	
Thailand	3,690 µg/m^3		6,150 µg/m^3							1993	
Turkey	6,15 µg/m^3									1993	
United Kingdom	2,460 µg/m^3									2000	carcinogen

Other countries have regulated a ceiling concentration of formaldehyde at 369 µg/m^3. These countries include Argentina, Bulgaria, Columbia, Jordan, South Korea, New Zealand, Singapore, and Vietnam (Pohanish, 2008).

WHO (2004) provided a guideline values of 900 µg/L formaldehyde in drinking-water. However, because the tolerable concentration of formaldehyde is significantly larger than the amount of formaldehyde found in drinking water, a formal guideline is not necessary (WHO, 2005). The US EPA has set a concentration limit of formaldehyde in drinking-water at 1,000 µg/L (ATSDR, 1999). In the UK, the maximum amount of formaldehyde discharge into non-fishing streams is also 1,000 µg/L (Carson & Mumford, 2002). The drinking water guideline in different states in the USA is shown in Table 10 below. In the USA, the process wastewater discharges from the manufacture of formaldehyde is by the Clean Water Effluent Guidelines given in the Code of Federal Regulations (USHHS, 1999 citing EPA, 1987).

Table 10: Drinking water guidelines in the USA (USHHS, 1999; EPA, 1990; Pohanish, 2008)

State	Guideline value
California, CA	30 µg/L
Maryland, MD	10 µg/L
Maine, ME	30 µg/L
New Jersey, NJ	100 µg/L

USHHS (1999) has set an intermediate oral MRL of 300 µg/kg/day, with a chronic oral MRL of 200 µg/kg/day. The US EPA has set the oral reference dose for formaldehyde is 200 µg/kg/day for causing gastrointestinal damage (USHHS, 1999).

Table 11: Regulations of Formaldehyde in water (Pohanish, 2008)

	permissible ambient goal	MAC	comment
US EPA	41.4 µg/L		based on health effects
Russia		10 µg/L and 50 µg/L	for domestic purposes
Russia		250 µg/L	for fishery purposes

Formaldehyde is identified as the hazardous constituent in waste and has been assigned with the hazardous waste number U122 under RCRA. Appropriate treatment processes for wastewater containing formaldehyde, given in 40 CFR 268.42, include wet air oxidation, chemical, or electrolytic oxidation followed by carbon adsorption, or incineration (USHHS, 1999).

2.10 South African Regulations

In South Africa, formaldehyde is recognised as a suspected human carcinogen (Department of Labour, 1995). It has set the TWA OEL-CL and short term OEL-CL at 2,500 µg/m^3 (Department of Labour, 1995). This is currently the same as the UK (Doel, 2009). Doel

(2009) suggests that the appropriate South African formaldehyde limit for occupational exposures should rather be 700 µg/m^3 (8-hr TWA), with ambient air quality set at a level of 100 µg/m^3 for formaldehyde.

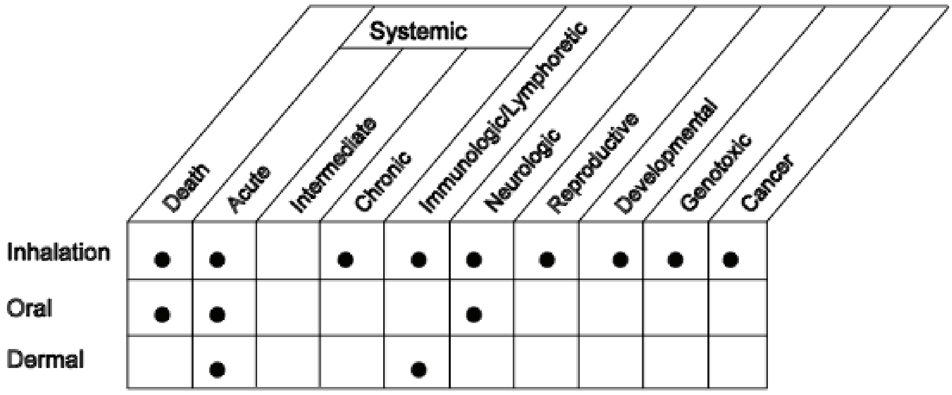
In a document about odour treatment of emissions at sewage pump stations, eThekwini Municipality indicated an odour threshold of 370 µg/L for formaldehyde. Formaldehyde does not, however, add considerably to the odours present in sewage (Graham, 2006)

2.11 Conclusions

Formaldehyde is found ubiquitously in the environment and is produced both by naturally and man-made. The chemical is a needed substance in the world today and is used in a variety of different industries.

Humans are exposed to small concentrations of formaldehyde every day, and it is also naturally found in the human body as a metabolite. Formaldehyde has a range of health risks through inhalation, oral, or dermal routes. The health effects range from irritation (which are reversible) to severe. The effects of formaldehyde are restricted to portals-of-entry and the effect of formaldehyde on distant organs is not plausible under low concentration levels found in the environment. Formaldehyde is a known carcinogen in animals, however, scientific studies of the causality between formaldehyde and cancer in humans is equivocal. And formaldehyde is still considered a probable carcinogen, and not a known carcinogen, by a range of international regulatory agencies.

Formaldehyde is a highly regulated chemical. International regulations are sufficient to cover formaldehyde exposure through oral, dermal, and airborne concentrations. These regulations ensure that formaldehyde does not cause detrimental health effects in either humans or the environment. Reported known health effects are shown in Figure below.



		Systemic								
	Death	Acute	Intermediate	Chronic	Immunologic/Lymphoretic	Neurologic	Reproductive	Developmental	Genotoxic	Cancer
Inhalation	●	●		●	●	●	●	●	●	●
Oral	●	●				●				
Dermal		●			●					

Figure 2: Known health effects of formaldehyde in humans (USHHS, 1999)

South African guidelines are the same as the UK regulations for airborne concentrations of formaldehyde. However, there are currently no regulations or guidelines for formaldehyde in drinking water specific to South Africa. However, the WHO indicated that there is no need for formaldehyde concentrations in drinking water due to its rapid degradation and low concentrations.

3 TEMPORARY ABLUTION FACILITIES

Temporary ablution facilities are found universally. They can be used for either personal or public use. These facilities can be found on RVs (recreational vehicles), boats, buses, airplanes, and trains. They are also used at a variety of festivals where people congregate for a short period of time, at refugee camps, and during any construction project where in situ toilet facilities are not available. These facilities include any toilet that requires chemical treatment for inhibiting biological degradation of the waste.

Temporary ablution facilities are constructed with a top structure, the toilet seat, and an attached holding tank, where the faeces and urine is stored. The holding tank, as the storage facility is generally referred to, is designed such that waste can be contained for less than a week, generally between 3-5 days. The time is dependent on the amount of human waste produced, the ambient temperature in the environment, and the dosage of the chemicals in the tank. The holding tank is dosed with chemicals, which inhibit the biological degradation of the waste and also add a satisfying fragrance to the wastewater. Most of the commonly used holding-tank chemicals, including formaldehyde, are designed to be toxic or inhibitory to wastewater at full strength, but biodegrades with dilution (Novak et al., 1990) and time.

Research at Thetford, a company selling both formaldehyde and formaldehyde-free based temporary ablution chemicals, has found formaldehyde to be completely biodegradable in holding tanks (Burrows, 2007). It breaks down into simpler molecules (like carbon dioxide and water) through the natural action of oxygen, sunlight, bacteria and heat (Burrows, 2007). The biodegradation is considered to be faster than most other deodorant products, and therefore formaldehyde-based products are considered the most effective holding tank chemicals available (Burrows, 2007).

There are a number of other, different products available for the use of temporary ablution facilities. Traditionally, formaldehyde was used in most products. However, due to the explosion of research, regulations, and subsequent public perception surrounding formaldehyde, a wave of new products have subsequently entered the market. These products are explicitly sold as formaldehyde-free. Both formaldehyde and formaldehyde-free products are available for purchase in South Africa. Some, but not all of the chemical solutions, are biodegradable. There are even home made products that have worked well in RVs and boats (ExplorOz, 2004).

It has been recommended that formaldehyde should be avoided in the use of chemical toilet products as it kills off the bacteria in the holding tanks (septic tanks) and thus prevents the bacteria from decomposing, and treating, the wastewater, which causes septic tanks to clog (Department of Toxic Substance Control, 2009). The Prohibited Chemical Toilet Additives law, passed in 1979 in California, prohibits the use of a non-biodegradable toxic chemical in chemical toilets (Department of Toxic Substance Control, 2009). This does not necessarily exclude formaldehyde-based products, as formaldehyde has been shown, in both anaerobic and aerobic treatment, to be biodegradable.

3.1 Prevalence of Formaldehyde in Chemical Solution

It is important to remember that formaldehyde effluent does not only originate from temporary ablution facilities but also from industrial sources, including the manufacture of textiles, wearing apparel, industrial chemicals, and misc products of petroleum and coal (WHO, 2004). For example, the formaldehyde concentration in effluent from a resin factory is between 7-4,000 mg/L (Gómez et al., 2009). The sources of formaldehyde-based wastewater were discussed in detail in the Application Section in the first part of the report.

Formaldehyde costs R5.46/kg when buying in bulk (more than 220kg) (Protea Chemicals, 2010). This is sold as formalin, a 37% formaldehyde solution.

In the USA, RVs are a major source of temporary ablution facilities (Pearson et al., 1980). The formaldehyde concentration found in RV wastewater was found to be 75 mg/L, and was not considered inhibitory at the time (Pearson et al., 1980). The recommended dosage of formaldehyde in holding tanks is in the range of 500-600 mg/L (Novak et al., 1990). The formaldehyde-based chemical was inhibitory for a concentrated solution of approximately 550 mg/L (Novak et al., 1990).

Most odour-control chemicals used in temporary ablution facilities are diluted to 5% of the concentrate solution, at 1 litre per 20 litre water. However, as low as 0.1% dilution has been used in odour-control chemicals used in airplane toilet facilities. The concentrated solution typically is a combination of disinfection chemicals, colorant, and a perfume or deodoriser.

On average, Camp World in Randburg sells 48L formaldehyde based and 24L non-formaldehyde based odour-controlling chemicals used for personal use. This amounts to 2.5 kilolitre formaldehyde-based and 1.25 kilolitre non-formaldehyde based chemicals per annum. Although these figures are insignificant for design applications, they can be extrapolated further for other Camp World branches nationwide.

A suspected source of temporary ablution wastewater was from its use in airplanes. In these facilities, the waste is kept in holding tanks until landing, where the waste is disposed of in wastewater treatment facilities. The wastewater effluent is considered as industrial or non-domestic wastewater due to the addition of odour-controlling chemicals in the holding tanks.

However, after investigating the construction designs of the newly built King Shaka International Airport located outside Durban, South Africa, it was evident that there was no need for further investigation in this area (PDNA, 2008). It was estimated that annually approximately 3.7 million international passengers will fly into the airport. There is approximately 1.1 kilolitre wastewater produced in a single international flight and 186 litre wastewater produced in a single domestic flight. This amounts to 5.7 megalitre wastewater per annum at the King Shaka International Airport. However, this value is only 1.2% of the total wastewater produced from the whole airport. The chemicals in the aircraft wastewater are diluted to a concentration of 0.1%. This means that the chemical concentration after dilution with the total airport wastewater is approximately 0.001168 ml/l.

The airplane wastewater is first collected from the airplanes into a combined holding tank to provide consistent biological and chemical loading into the wastewater treatment facility. No treatment occurs in the holding tank. Here the waste is merely diluted with the wastewater from the entire airport. From there the wastewater is treated in a wastewater treatment plant.

The amount of formaldehyde used in the chemical toilet products varies considerably. Three domestic products were sampled, analysed and found to have formaldehyde concentrations of 1,327 mg/L, 388 mg/L and 34.1 mg/L. Each of these products prescribe 1:20 dilution in water, which would yield a theoretical diluted value of 66 mg/L, 19 mg/L and 1.7 mg/L formaldehyde. This diluted concentration of formaldehyde is the maximum theoretical value obtainable from chemical toilets as the retention time and the biological activity in the holding tank both have an effect on the concentration of formaldehyde.

3.2 Chemicals Used

The labels on the products of the odour-control chemicals are scant and only indicate the prevalence or lack of formaldehyde. The formaldehyde-free products seem to be aimed at customers who are “environmentally conscious”. However, some of these formaldehyde-free products have the same health risks, namely toxic to eyes, skin, and inhalation. Thus, the formaldehyde free chemicals may contain chemicals that are toxic, but are much less regulated. Meaning that they could be as dangerous, or more, dangerous to the environment and to human health. The effect of the different chemicals has not been investigated as it is outside the scope of the project. It is noted here to provide a holistic overview of available chemicals for disinfection or odour-control in temporary ablution facilities.

The disinfecting chemicals used in temporary ablutions commonly consist of formaldehyde and bromine. These chemicals are combined with a perfume, or deodorizer, to leave a refreshing smell in the ablution facility (Protea Chemicals, 2010). The chemicals used in temporary ablution facilities are available in liquid, tablet, sachet or dry powder (Let's Getaway, 2010). Chemicals other than formaldehyde are discussed briefly later in the report.

3.3 Characteristics of Waste

The wastewater from temporary ablution facilities is much more concentrated than domestic wastewater. This is not only due to the addition of odour-controlling chemicals. However, it is mainly due to the reduction of water used in these facilities. Domestic toilets use 20 times more water than RV toilets (Novak et al., 1990). Subsequently, RV black water was found to have an average COD of about 15 000mg/L and suspended solids 7 500 mg/L (Pearson et al., 1980). Both RV black water and RV grey water is much stronger than domestic wastewater, with an average COD of 500 mg/L and suspended solids of 200 mg/L (Pearson et al., 1980). Another study found RV wastewater to contain about 20-15 times more waste per gallon than typical household waste (Burrows, 2007; Novak et al., 1990). Thus, it has been argued that formaldehyde is not the culprit in the failure of a wastewater treatment plant overload (Burrows, 2007).

This spike in concentrated waste from temporary ablution facilities can cause the failure of the wastewater treatment plant, as it operates best with a consistent biological loading. Pearson et al. (1980) found that under peak conditions, septic tank systems available for RV waste treatment in California had a retention time of 1 hour or less, which provides inadequate time for the biological treatment of even domestic wastewater. Dilution, as is performed at the King Shaka International airport, can be performed before the concentrated wastewater is combined with domestic waste in order to provide consistent biological loading. The dilution will also assist in diluting the chemicals used and also increase the time the chemicals are active in the wastewater. This increased time will significantly assist in biodegrading the chemicals, especially formaldehyde.

3.4 Discharge of Formaldehyde

Formaldehyde in temporary ablutions are typically discharged in diluted solutions, but at worst in undiluted concentrations. The retention time before disposal is important, as the formaldehyde concentration will naturally decompose over time, even in the temporary ablution holding tank.

The non-formaldehyde based chemicals for personal use, found in camping shops, can be disposed of directly into long drop toilets, or septic tanks, available at camping facilities. However, the formaldehyde-based chemicals were recommended to pour directly into the municipal sewers and not into septic tank systems. This means that there is potentially a considerable amount of formaldehyde-based toilet chemicals already being disposed directly into the sewers.

3.5 Municipal Treatment

The effects of formaldehyde in wastewater treatment are important, as formaldehyde-rich wastewater may cause microbial inhibition in biological processes (Gómez et al., 2009; Eiroa et al., 2005). Any untreated formaldehyde discharged into the environment could cause damage to the aquatic life (Pereira & Zaiat, 2009). Formaldehyde is known to be biodegradable in both aerobic and anaerobic wastewater treatment systems (Eiroa et al., 2005; USHHS, 1999).

It has been found that wastewater treatment for formaldehyde and urea effluent is dependent on the COD concentration and COD/N ratio (Gómez et al., 2009). Wastewater with high concentrations of formaldehyde is characterized with a high chemical oxygen demand (COD) (Gómez et al., 2009).

It is advised that formaldehyde be avoided in confined spaces, including sewers, due to the possibility of an explosion, unless the sewer is designed to prevent the build-up of explosive concentrations (Pohanish, 2008). A guideline value of 50,000 µg/L for the maximum permissible concentrations of formaldehyde in sewage was found for the City of Tshwane (City of Tshwane Metropolitan Municipality, N.D.).

Prevalence of Formaldehyde in Wastewater Treatment Facilities

Formaldehyde effluent was found in different concentrations and is found in Table 12. Wastewater containing 4,500 mg/L formaldehyde has a higher resistance to microorganisms when biomass concentration was increased by immobilization using biomass-supporting particles (Gómez et al., 2009).

Table 12: Formaldehyde concentrations found in effluent

Concentration	Origin of wastewater effluent	Reference
4,500 mg/L	petrochemical wastewater	Gomez et al., 2009
200-4000 mg/L	industrial production of adhesives	Pereira & Zaiat, 2008
220-4000 mg/L	Resin Factory	Gomez et al., 2009

The effect of formaldehyde on wastewater has been evaluated using a half-kill dose, and is shown in Table 13. The half-kill does is the toxic dose for a 50% reduction in biological activity (Pearson et al., 1980). These half-kill dose values from literature are considerably different. This is considered to be due to the considerably different composition of wastewater. The critical toxic concentration of formaldehyde was dependent on the compounds of wastewater (Lu & Hegemann, 1998). However, there is no consensus on a specific inhibition concentration of formaldehyde on microbial activity (Pereira & Zaiat, 2009).

Table 13: Formaldehyde half-kill dose in wastewater treatment

Concentration	Half-kill dose	Reference
72.072 mg/L	in anaerobic digestion	Sykes, 2003
100 mg/L	in continuous-loading of raw domestic wastewater	Pearson et al., 1980
200 mg/L	in shock-loading of raw domestic wastewater	Pearson et al., 1980
19 mg/L	using bacterial growth inhibition test	Alsop et al., 1980
300 mg/L	synthetic wastewater (glucose) in anaerobic batch assays	Lu & Hegemann, 1998
150 mg/L	wood-glue wastewater in anaerobic batch assays	Lu & Hegemann, 1998

The half-kill dose concentration of 19 mg/L for formaldehyde using a bacterial growth inhibition test could be different due to the laboratory samples used (Alsop et al., 1980). This was the lowest value and was the only value found using this specific test. It is important to realise that once the microorganisms are acclimated to formaldehyde, they are able to remove large quantities of formaldehyde. However, without acclimation, the amount of formaldehyde removed will be low. This could be the case in this test and the value is shown for completeness.

The half-kill dose of formaldehyde is considerably lower than the concentrations found in industrial effluent. However, dilution or pre-treatment can effectively reduce the formaldehyde concentration in the effluent.

Anaerobic Treatment

Anaerobic treatment is good for wastewater with high organic concentration, it requires very little energy (Lu & Hegemann, 1998) and it produces less sludge compared to aerobic treatment (Gomez et al., 2009). Anaerobic treatment is recommended for highly concentrated COD wastewater, as the amount of methane generated can compensate for the energy cost in maintaining the temperature of the reactor. It is also recommended for wastewater with a high ratio of COD/N, which is common for wastewater effluent found in urea-formaldehyde industries.

During the anaerobic process, formaldehyde is converted to CO_2 and CH_4 and urea is hydrolyzed to ammonia (Gomez et al., 2009). Formaldehyde is readily converted to methane by anaerobic treatment in the range of 400 mg/L (Novak et al., 1990). It is likely that formaldehyde is first oxidised into formate and then converted for methanol under anaerobic conditions (Gómez et al., 2009).

The anoxic removal of high formaldehyde concentrations is possible in the presence of other organic compounds (Eiroa et al., 2006). Biodegradation of formaldehyde was more stable under anoxic than anaerobic conditions for urea-formaldehyde wastewater (Gomez et al., 2009).

Formaldehyde was found to be toxic under anaerobic degradation, as formaldehyde can directly react with protein, DNA, RNA of the organisms under anaerobic conditions, causing them to either die or inhibiting their activity (Lu & Hegemann, 1998; Pereira & Zaiat, 2009; Gomez et al., 2009). This toxicity was dependent on the formaldehyde concentration, the wastewater composition and the retention time before testing (Lu & Hegemann, 1998). The inhibition generally increases with increasing concentrations of formaldehyde (Lu & Hegemann, 1998).

Gomez et al. (2008) found more parameters affecting the toxicity of formaldehyde in anaerobic treatment:

- Nature of the co-substrates
- Operational mode (batch or continuous)
- Type of reactor (suspended or attached growth systems)
- Formaldehyde/microorganisms ratio
- COD/formaldehyde ratio

Even though formaldehyde is toxic in anaerobic treatment, most research indicates that formaldehyde is successfully degraded by anaerobic treatment in continuously fed reactors operated under long retention times (Pereira & Zaiat, 2009). Continuous-loading of formaldehyde is considered more favourable for bacterial acclimation (Gomez et al., 2009, with formaldehyde removal averaging 77%, varying quite steadily from 100% removal at a dose of 10 mg/L to 46% removal at 3000 mg/L (Pearson et al., 1980).

Table 14 below cites inhibitory formaldehyde concentrations in anaerobic treatment. Formaldehyde concentrations above 200mg/L reduce the activity of anaerobic biodegradation to 10% of the uninhibited activity (Lu & Hegemann, 1998). The viability of organisms, at concentrations of 5000mg/L, appeared to be sharply reduced (Novak et al., 1990). Nontoxic levels of formaldehyde appear to be in the range of 100 to 200 mg/L, but higher levels may be accommodated by first acclimating the biomass.

Table 14: Biodegradation of formaldehyde in anaerobic treatment

Value	Research or Application	Reference
50-100 mg/L	50% inhibition concentration of anaerobic gas production	Pearson et al., 1980
20-100 mg/L	inhibitory effect of FA on gas production from anaerobic batch reactors	Novak et al., 1990
400 mg/L	FA converted to methane by anaerobic treatment in this range	Novak et al., 1990
200 mg/L	FA could reduce the activity of anaerobic biodegradation to 10% of the uninhibited activity	Lu & Hegemann, 1998

Anaerobic treatment of wastewater containing formaldehyde was found to be possible when the COD/formaldehyde ratio is higher than 1,000 (Gómez et al., 2009). High concentrations of formaldehyde, up to 3,890 mg/L, could be removed using it as the single carbon source (Gómez et al., 2009; Eiroa et al., 2005). Formaldehyde removal in the presence of other carbon sources is also of significant practical interest (Gómez et al., 2009).

Wood-glue wastewater, with 100 mg/L formaldehyde concentrations, showed inhibition between 78-98% for the first 8 days and after 8 days there was no inhibition (Lu & Hegemann, 1998). The adaptation time for biodegradation depends on the growth rate of bacteria and other microorganisms and the concentration of formaldehyde (Lu & Hegemann, 1998). Thus, the higher the concentration of formaldehyde, the longer the hydraulic retention time is required for anaerobic treatment (Lu & Hegemann, 1998). The anaerobic treatment efficiency can be increased through pre-dilution or pre-treatment, by chemical or physical methods (Lu & Hegemann, 1998).

Aerobic Treatment

Aerobic treatment removes organic matter (Gómez et al., 2009). Formaldehyde is degraded by activated sludge and sewage within 48-72 hours (USHHS, 1999). Treatment of wastewater that contains formaldehyde by the activated sludge process is possible as long as sufficient dilution occurs (Novak et al., 1990). The addition of methanol to the formaldehyde concentration increases the biodegradation rate of formaldehyde in aerobic treatment (Gomez et al., 2009)

In urea-formaldehyde resin effluent, formaldehyde is oxidized to CO_2 and water, and urea is hydrolyzed during aerobic treatment. The generated ammonia is oxidized to nitrate if the operational conditions are suitable for nitrification. Degradation of formaldehyde in aerobic treatment can occur by two possible paths (Gomez et al., 2009):

- Initiated by a dismutation reaction, yielding formic acid and methanol as products
- Via formic acid

The addition of surfactants, dyes, and perfumes into a formaldehyde solution, commonly used in temporary ablution holding tanks, causes an increase in foaming of the activated sludge (Novak et al., 1990). Foaming causes a loss of biomass, which can reduce the performance of the treatment plant (Novak et al., 1990). For activated sludge systems, the dosing limit of temporary ablution chemicals appears to be dictated more by the foaming problem than by inhibition by formaldehyde (Novak et al., 1990).

Septic Tank

In septic tanks, the addition of formaldehyde-based odour-control chemicals kill off the bacteria required for biological treatment and decomposition of waste is inhibited. This means that septic tanks cannot adequately treat the waste. This can cause solids to clog the french drain, as the solids will be inadequately treated and be allowed to pass through the septic tank (US EPA, 1999; Department of Toxic Substance Control, 2009). This conclusion was also found by Pearson et al. (1980), indicating that disposal of RV wastewater in a septic tank system appeared to impair the operation of, and cause premature failure of, the french drain systems. Septic tank systems generally were able to operate successfully at up to 50% of the recommended holding tank dose with concentrations of approximately 250 mg/L (Novak et al., 1990).

Formaldehyde Removal in Wastewater Treatment Facilities

The biodegradation of formaldehyde has been identified as being dependent on formaldehyde concentration and a variety of other factors. An example of the efficiency of COD removal with the addition of different concentrations of formaldehyde is shown in Figure 3 below. The graphs are shown for synthetic and real wastewater produced from a wood-glue factory. Table 15 and Table 16 provide removal efficiencies of formaldehyde and COD under different formaldehyde concentrations.

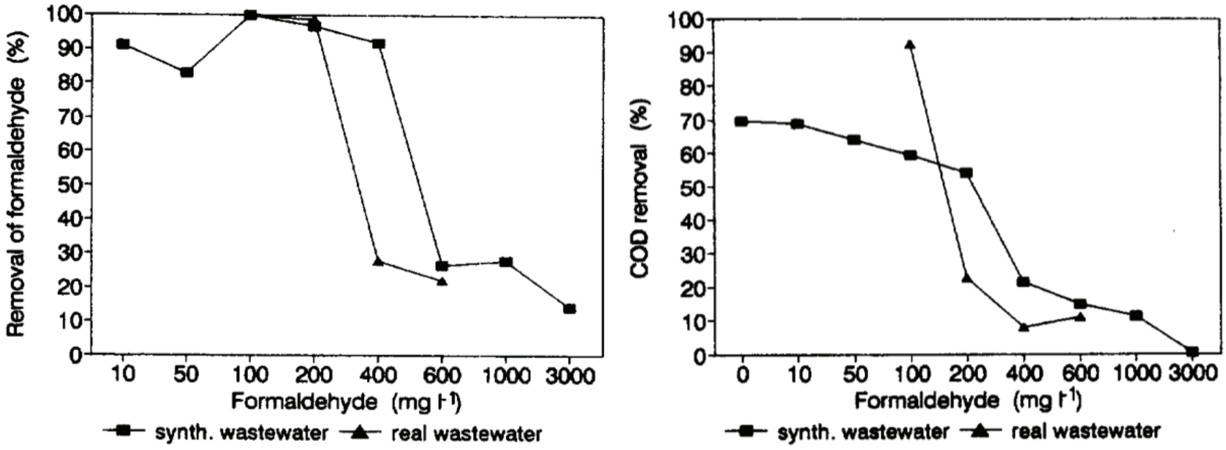


Figure 3: Example of formaldehyde and COD removal at different formaldehyde concentrations (Lu & Hegemann, 1998)

Odour-controlling chemicals were initially considered to be inhibitory to wastewater treatment, but results showed that organisms acclimated rapidly (Novak et al., 1990). Formaldehyde was assumed by Pearson et al. (1980) to have been removed from the wastewater by volatilization.

Table 15: Removal of formaldehyde in wastewater treatment

Value	% Removed	Removal of formaldehyde	Reference
10 mg/L	100%	in RV wastewater using anaerobic treatment	Pearson et al., 1980
3,000 mg/L	46%	in RV wastewater using anaerobic treatment	Pearson et al., 1980
< 400 mg/L	+90%	in synthetic wastewater (glucose)	Lu & Hegemann, 1998
3000 mg/L	14%	in synthetic wastewater (glucose)	Lu & Hegemann, 1998
< 200 mg/L	+98%	in wood-glue wastewater	Lu & Hegemann, 1998
> 400 mg/L	< 28%	in wood-glue wastewater	Lu & Hegemann, 1998
31.6-1104.4 mg/L	over 99% (average 99.3%)	in synthetic wastewater in an anaerobic sequencing batch biofilm reactor, where formaldehyde degraded within first 5 hr of 8 hr cycle	Pereira & Zaiat, 2009
2,087-2,200 mg/L	99.9%	Removal from aminoplastic resin-producing industry wastewater in the laboratory through pre-denitrification systems, using anoxic and aerobic reactors	Eiroa et al., 2006

The effluent from urea-formaldehyde-resin processes has high COD (50-200 g/L) and formaldehyde (2-4 g/L) concentrations. These concentrations are significantly reduced values of COD (5-7 g/L) and formaldehyde (0.2-0.4 g/L) after aerobic treatment (Lu & Hegemann, 1998).

Table 16: Removal of COD in wastewater treatment containing formaldehyde

Value	% Removed	Removal of COD	Reference
10 mg/L	70% COD	from synthetic wastewater (glucose)	Lu & Hegemann, 1998
> 400 mg/L	< 21.4% COD	from synthetic wastewater (glucose)	Lu & Hegemann, 1998
> 3,000 mg/L	0% COD	from synthetic wastewater (glucose)	Lu & Hegemann, 1998
100 mg/L	92.4% COD	from wood-glue wastewater	Lu & Hegemann, 1998
200 mg/L	22.8% COD	from wood-glue wastewater	Lu & Hegemann, 1998

OUR (oxygen uptake rate)

The SOUR (specific oxygen uptake rate) was measured for odour-controlling chemicals in temporary ablution facilities in a study by Novak et al. (1990). They found that the SOUR declined immediately after formaldehyde was added, as shown in Figure 4. However, after one day of continuous loading, the SOUR increased. This indicates acclimation had occurred. After the SOUR peaked it rapidly declined to a level similar to that which existed prior to the introduction of the odour-control chemical (Novak et al., 1990). The slight difference before and after suggest that some of the odour-control chemical is nondegradable and the pattern of COD decline suggests washout of this non-degraded portion (Novak et al., 1990).

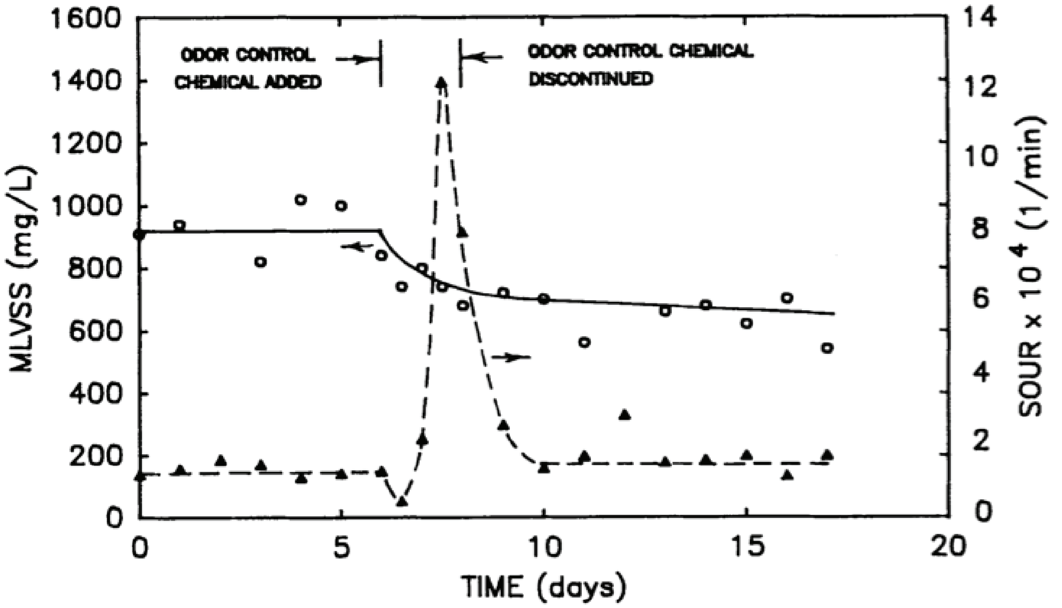


Figure 4: SOUR in an activated sludge reactor dosed with formaldehyde (Novak et al., 1990)

3.6 Alternatives for Formaldehyde

There are a number of different chemicals that are currently used to replace the use of formaldehyde in odour-controlling chemicals for use in temporary ablution facilities. The chemicals include:

- Glutaraldehyde
- Borax
- Cloudy Ammonia
- Quaternary Ammonia
- Bronopol
- Pine o Clean

These chemicals are described briefly in order to provide a holistic overview of the environmental and health risks associated with their use.

Glutaraldehyde

Glutaraldehyde (Cas 111-30-8) is a colourless liquid with a pungent odour, which is soluble in water (Pohanish, 2008). Glutaraldehyde has a Henry's Constant: 1 ppm = 4.09 mg/m^3 @ 25°C & 1atm (Pohanish, 2008).

Commercially, glutaraldehyde is typically available in 2%, 25% and 50% solutions in water, with other dilutions occasionally seen and used. A 2% glutaraldehyde solution is generally equated to a classical formaldehyde solution of 5-8% (Bedino, 2003).

Glutaraldehyde is used in leather tanning; in embalming fluids; as a germicide; as a cross-linking agent for protein and polyhydroxy materials; as a fixative for tissues; as an intermediate (Pohanish, 2008). It is mainly used in hospitals where it is used as a high-level disinfectant (OSHA, 2006a). In the medical field, glutaraldehyde has shown superior capabilities (since the 1960s) to formaldehyde as both a disinfectant and a sterilizer (Bedino, 2003). However, there seems to be an increased trend in reducing the use of glutaraldehyde in hospitals, similar to the reduced use of formaldehyde in other industries (Sustainable Hospitals, 2001).

Due to the carcinogenic nature of formaldehyde along with a host of other toxic health implications, glutaraldehyde is suggested as an adequate alternative to formaldehyde in odour-controlling chemicals (Protea Chemicals, 2010). Glutaraldehyde does not have as severe a pungent odour as that of formaldehyde (Mao & Woskie, 1994). And, the exposure risks associated with glutaraldehyde are a fraction of those linked to formaldehyde (Bedino, 2003). However, the cost of glutaraldehyde is 4-5 times more than formaldehyde (Mao & Woskie, 1994).

Guidelines for the use of glutaraldehyde are shown in Table 17. Its odour threshold is 0.04 ppm (Pohanish, 2008). Studies have found adverse respiratory health effects from below 0.2 ppm glutaraldehyde and it is a recognized cause of occupational asthma (Sustainable Hospitals, 2001). It is also a potent occupational skin irritant and sensitizer (Sustainable Hospitals, 2001). The health risk associated with glutaraldehyde target organs such as the eyes, skin, and respiratory system (OSHA, 2006b). However, it is not classified as a human carcinogen (OSHA, 2006b). Potential symptoms of glutaraldehyde exposure include Irritation of eyes, skin, respiratory system; dermatitis, skin sensitization; sneezing, cough, wheezing, chest tightness, shortness of breath, asthma, chronic bronchitis; headache; nausea, vomiting; lacrimation; abdominal pain; diarrhoea (OSHA, 2006b). It is important to note that OSHA does not have a PEL (OSHA, 2006b; Pohanish, 2008).

Table 17: Relevant limits of glutaraldehyde (OSHA, 2006a; Pohanish, 2008)

	TWA	**MAK**	**REL**	**TLV-15 min STEL**	**STEL**	**VLE**	**Ceiling**	**Regulation Date**
NIOSH			0.2 ppm				0.2 ppm	
ACGIH				0.05 ppm			0.05 ppm	
Australia	0.7 mg/m^3							1993
Austria		0.8 mg/m^3						1999
Belgium	0.2 mg/m^3				0.82 mg/m^3			1993
Denmark	0.8 mg/m^3							1999
Finland							0.1 ppm	1999
France						0.8 mg/m^3		1999
Norway	0.8 mg/m^3							1999
Russia					5 mg/m^3			1993
Sweden					0.8 mg/m^3			1999
United Kingdom	0.2 mg/m^3							2000

	TWA	MAK	REL	TLV-15 min STEL	STEL	VLE	Ceiling	Regulation Date
Argentina, Bulgaria, Columbia, Jordan, South Korea, New Zealand, Singapore, Vietnam				0.05 ppm				

This brief introduction to the use and risks associated with glutaraldehyde indicate that there are concerns associated with its use. Thus, although it is seen as an alternative to formaldehyde in odour-controlling chemicals, the associated environmental and health effects may be similar, if not equivalent.

Borax

Borax (CAS 1303-96-4) is an odourless white crystal powder, which is soluble in water (Ash & Ash, 2004; Pohanish, 2008), with a solubility of 6% at 20°C (Pohanish, 2008) or 1 g/ 16 ml water (Ash & Ash, 2003). It is widely used in many industries as a pH buffer, oil emulsifier in detergents, enzyme stabilizer, and many others (Ash & Ash, 2004). It is further used in ant poisons, for fly control around refuse and manure piles, and as a larvicide (Pohanish, 2008).

Borax has been regulated with an OSHA PEL is 10 mg/m^3 (Ash & Ash, 2004), NIOSH REL of 5 mg/m^3 TWA (Pohanish, 2008), ACGIH TLV/TWA 5 mg/m^3 (Ash & Ash, 2003). The lethal dose (LD50) in rats (oral) is 2660 mg/kg (Ash & Ash, 2003; Pohanish, 2008). It can be harmful to plants and other species (Ash & Ash, 2004). It is moderately toxic to humans by ingestion, with severe health effects in children with doses of 5-10 g (Ash & Ash, 2003). It shows low acute oral and dermal toxicity, with inhalation of 10 mg/m^3 causing mild irritation to nose and throat (Ash & Ash, 2004). There is no evidence that borax is carcinogenic (Ash & Ash, 2004; Pohanish, 2008). However, possible toxic effects on human reproduction are evident (Pohanish, 2008).

Borax should be diluted to the recommended provisional limit (0.10 mg/L) in water before disposal (Pohanish, 2008). It should have a pH between 6.5 and 9.1 before final disposal in the sewers or natural streams (Pohanish, 2003).

The ambient water limit of borax as defined by the US EPA is 43 µg/L (Pohanish, 2008). The Canada Drinking Water Quality is 5.0 mg/L IMAC, with the Mexico Drinking Water Criteria is 1.0 mg/L (Pohanish, 2008).

Quaternary Ammonium Compound

Quaternary ammonium is a widely used preservative (Pearson et al., 1980). However, it is difficult to identify its concentration in wastewater due to the high background concentration of ammonia in wastewater (Pearson et al., 1980).

Bronopol

Bronopol (CAS 52-51-7) is an odourless off-white crystal powder (Ash & Ash, 2003; Ash & Ash, 2004). It is soluble in water (Ash & Ash, 2003). Its recommended dosage is between 0.01-0.1% (Ash & Ash, 2003). It is regulated by the US FDA, US EPA, and USA CIR (Ash & Ash, 2004).

It is used as an antimicrobial, preservative for a variety of industries, bactericide in cosmetics/toiletries, and a biocide in metalworking fluids, and industrial water systems. It is also an antiseptic in food-packaging (Ash & Ash, 2003; Ash & Ash, 2004).

Bronopol is poisonous through ingestion, toxic by skin contact, and is an eye and skin irritant. It has an oral LD50 of 180 mg/kg (rats) (Ash & Ash, 2003; Ash & Ash, 2004).

3.7 Disposal Regulations

In the USA, wastewater containing formaldehyde should be handled as hazardous waste and sent to a RCRA (Resource Conservation and Recovery Act) approved incinerator or disposed in a RCRA approved waste facility (Mallinckrodt Chemicals, 2009).

A reasonable wastewater treatment system for RV waste should adequately handle 100 mg/L formaldehyde, which provides for a 66% reduction in anaerobic biological degradation (Pearson et al., 1980). Anaerobic treatment should rightly be increased by a factor 2 to 3 to account for inhibition of biodegradation caused by preservatives at levels found in RV wastes (Pearson et al., 1980). Since formaldehyde is known to be biodegradable at 100 to 200 mg/L, a limit on the discharge of formaldehyde-based chemicals to 25% of the design daily wastewater inflow would appear to be sufficient to permit degradation of the formaldehyde (Novak et al., 1990).

4 CONCLUSIONS

Formaldehyde is ubiquitously found in the environment, both naturally and manmade. It is mass produced and is one of the top 25 chemicals produced in the USA, with the main use in resins.

The main health hazards are from airborne formaldehyde levels. Oral exposure is much less than through inhalation. The health risks vary from negligible to major. The main concern with airborne formaldehyde exposure is cancer risks. However, formaldehyde is considered a *suspected* carcinogen and the research is still equivocal. There is little evidence of formaldehyde being carcinogenic in humans via the dermal or oral routes. Formaldehyde is a highly regulated chemical. As long as it is used within guideline concentrations, there are no significant associated health risks to humans.

Formaldehyde is extensively used in chemical toilets. The holding tank is dosed with chemicals, which inhibit the biological degradation of the waste and also add a satisfying fragrance to the wastewater. Most of the commonly used holding-tank chemicals contain formaldehyde and are toxic or inhibitory to wastewater at full strength, but completely biodegrades with dilution and time.

It was not possible to determine how much of these formaldehyde-based toilet chemicals are used in South Africa every year. First, the formaldehyde content of the products is vastly different. Second, there are some “formaldehyde-free” chemicals which appropriate an unknown part of the market share. Third, suppliers and users of these chemicals were not forthcoming in providing such information, despite repeated attempts.

The overall conclusion is that the use of formaldehyde in chemical toilets does not pose a problem to normal wastewater treatment facility below a conservative estimate of 200 mg/litre, whether it is a septic tank, aerobic treatment or anaerobic treatment. Given the low concentration of formaldehyde in the chemicals used, the large dilution when added to the holding tanks, and the rapid biodegradation of formaldehyde in a wastewater environment, this is a value which is very unlikely to be reached, of which no examples could be found. Even in the unusual case of King Shaka airport, the levels of formaldehyde is at least about four orders of magnitude lower than the level suggested.

5 RECOMMENDATION

The quantities of formaldehyde used in chemical toilets are much too small to reach the critical concentrations which could impact on the receiving wastewater treatment systems. Furthermore, the rapid biogradation in the water environment prevents the build-up of formaldehyde in these systems. The current situation does not warrant any further research at this current time.

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