

1 **Supplemental Information**

2 **Evidence for Reproductive Health Effects Following Exposures to Hydraulic Fracturing**
3 **Chemical Mixtures**

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12 **Abbreviated Title:** unconventional oil and gas and reproduction

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38 **Table S1. Chemicals used in UOG HF Fluid**

Compound Type	Toxicity	Volatility	Biodegradability	Bioaccumulation
Gelling and Foaming Agents				
Guar (Economides and Nolte, 1989, Dantas et al., 2005)	Non-toxic (Fisher, 2014e)	Not Found	Readily biodegradable (Lester et al., 2014, Fujioka et al., 2009)	Not found
Carboxymethyl guar (CMG) (Economides and Nolte, 1989, Dantas et al., 2005)	Not Found	Not Found	Readily biodegradable (Lester et al., 2014, Fujioka et al., 2009)	Not found
Hydroxypropyl guar (HPG) (Economides and Nolte, 1989, Dantas et al., 2005)	Non-toxic (Ashland, 2018)	Not Found	Readily biodegradable (Lester et al., 2014, Fujioka et al., 2009)	Not found
Carboxymethyl hydroxypropyl guar (CMHPG) (US EPA, 2004b)	Not Found	Not Found	Readily biodegradable (Lester et al., 2014, Fujioka et al., 2009)	Not found
Hydroxyethyl cellulose (HEC) (US EPA, 2004b)	Non-toxic (Yillong Chemical, 2016)	Not Found	Readily biodegradable (Lester et al., 2014, Fujioka et al., 2009)	Not found
Hydroxypropyl cellulose (HPC) (Economides and Nolte, 1989)	Non-toxic (Echemi, 2019b)	Not Found	Readily biodegradable (Lester et al., 2014, Fujioka et al., 2009)	Not found
Carboxymethyl hydroxyethyl cellulose (CMHEC) (Economides and Nolte, 1989)	Non-toxic (Echemi, 2019a)	Not Found	Readily biodegradable (Lester et al., 2014, Fujioka et al., 2009)	Not found
Adipic acid (US EPA, 2004b)	Non-toxic (Kennedy, 2002)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Moderately hydrophilic, moderate soil motility but low bioaccumulation risk (Hansch et

al., 1995).

Fumaric acid (US EPA, 2004b)	Non-toxic (Carl, 2022b)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Moderately hydrophilic, moderate soil motility but low bioaccumulation risk (Hansch et al., 1995).
Diethanolamine (US EPA, 2004b)	GHS Category 2 Acute Oral Toxicity (Sigma, 2024c)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995).
2-butoxyethanol (US EPA, 2004b)	GHS Category 4 - Oral & Respiratory Toxicity (Chemos, 2019)	Semi-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Moderately hydrophilic, low bioaccumulation potential (Hansch et al., 1995).
Ethanol (US EPA, 2004b)	Non-toxic (Chemos, 2020)	Semi-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995).
Isopropanol (US EPA, 2004a)	GHS Category 3 STOT SE (Fisher, 2015c)	Semi-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Moderately hydrophilic, low bioaccumulation potential (Hansch et al., 1995).
Ethylene glycol (US EPA, 2004b)	GHS Category 4 Acute Oral Toxicity; GHS Category 3 STOT SE; GHS Category 2 STOT RE (ThermoFisher, 2021g)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995).
Polyglycol ethers (US EPA, 2004b)	Various	Various	Various	Various

Crosslinkers

Sodium tetraborate (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	GHS Category 2 Reproductive Toxicity; GHS Category 3 STOT SE (ClearTech, 2015)	Non-volatile (Sigma, 2017)	Not biodegradable (Stringfellow et al., 2014, OECD, 1994)	Low concentrations are used (US EPA, 2004a) Low bioaccumulation potential (ClearTech, 2015)
Monoethanolamine (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	GHS Category 4 Acute Oral Toxicity; GHS Category 4 Acute Respiratory Toxicity; GHS Category 3 STOT SE (Nouryon, 2019)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Low concentrations are used (US EPA, 2004a). Hydrophilic, low soil absorption, likely to reach groundwater but low bioaccumulation risk (Hansch

					et al., 1995)
Monoethylamine (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	GHS Category 4 Acute Oral Toxicity; GHS Category 4 Acute Respiratory Toxicity; GHS Category 3 STOT SE (Sigma, 2024d)	Volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)		Low concentrations are used (US EPA, 2004a). Hydrophilic, low soil absorption, likely to reach groundwater but low bioaccumulation risk (Arkema, 2014)
Aluminum compounds (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	Various	Various	Various		Various
Titanium compounds (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	Various	Various	Various		Various
Zirconium nitrate (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	Non-toxic (Chemical Book, 2023b)	Not Found	Inorganic		Not Found
Zirconium sulfate (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	Non-toxic (LTS, 2019)	Not Found	Inorganic		Not Found
Zirconium lactate (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	Not Found	Not Found	Inorganic		Not Found
Triethanolamine zirconate (US EPA, 2004b, FracFocus, 2013, Economides and Nolte, 1989)	GHS Category 3 STOT SE (Gelest, 2016)	Not Found	Inorganic		Not Found

Ammonium chloride (US EPA, 2004a)	GHS Category 4 Acute Oral Toxicity (Fisher, 2015b)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Low concentrations are used (US EPA, 2004a) Not expected to be persistent or an environmental hazard (Stringfellow et al., 2014)
Ethylene glycol (US EPA, 2004a)	<i>(see Gelling and Foaming Agents)</i>			
Potassium metaborate (US EPA, 2004a)	GHS Category 2 Reproductive Toxicity (ThermoFisher, 2020b)	Not Found	Not biodegradable (Stringfellow et al., 2014, OECD, 1994)	Not Found
Breakers				
Hemicellulases (Halliburton, 2012)	GHS Category 1 Respiratory sensitization (ECHA n.d.)	Not Found	Readily biodegradable (ERC, 2017)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (E.H.S. Support, 2021a)
Calcium chloride (FracFocus, 2013)	Non-toxic (ThermoFisher, 2023a)	Not Found	Inorganic	Ubiquitous in the environment, not expected to bioaccumulate (ECHA, 2023f)
Sodium chloride (FracFocus, 2013)	Non-toxic (ThermoFisher, 2023d)	Non-Volatile (ThermoFisher, 2023d)	Inorganic	Ubiquitous in the environment, not an environmental hazard (E.H.S. Support, 2021c)
Ammonium sulfate (US EPA, 2004a)	GHS Category 3 acute oral toxicity; GHS Category 3 acute respiratory toxicity; GHS Category 3 STOT SE (Fisher, 2014c)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Ubiqumica, 2018)	Used in low concentrations and common in the environment (Stringfellow et al., 2014) Hydrophilic, low bioaccumulation potential (Ubiqumica, 2018)
Ammonium (US EPA, 2004a)	GHS Category 3 STOT SE; GHS Category 1 Acute aquatic toxicity (Fisher, 2014b)	Volatile (NIST, 2023)	Readily biodegradable (Stringfellow et al., 2014)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Linde, 2015)
Potassium (Coveney et al., 2000)	GHS Category 3 STOT SE (ThermoFisher, 2020c)	Non-volatile (ThermoFisher, 2020c)	Inorganic	Ubiquitous in the environment, not expected to be a hazard (Stringfellow et al., 2014, Johnson et al., 2022)
Sodium peroxydisulfate (Coveney et al., 2000)	GHS Category 4 Acute oral toxicity; GHS Category 1 Respiratory sensitization; GHS	Non-volatile (Ataman, 2020)	Inorganic	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Ataman, 2020)

Category 3 STOT SE
(ThermoFisher, 2021k)

Calcium peroxide (Economides and Nolte, 1989)	GHS Category 3 STOT SE (ThermoFisher, 2020a)	Non-volatile (Carl Roth, 2022a)	Inorganic	Not expected to bioaccumulate (Solvay, 2013a)
Magnesium peroxide (FracFocus, 2013)	Non-toxic (Sigma, 2024f)	Non-volatile (Sigma, 2024f)	Inorganic	Not expected to bioaccumulate (Solvay, 2013b)
Magnesium oxide (FracFocus, 2013)	Non-toxic (Fisher, 2014f)	Non-volatile (Fisher, 2014f)	Inorganic	Not expected to be an environmental hazard, sometimes used in bioremediation (E.H.S. Support, 2021b)
Glycol ethers (US EPA, 2004a)	Various	Various	Various	Various
Copper compounds (US EPA, 2004a)	Various	Various	Various	Various
pH adjusters				
Acetic acid (US EPA, 2004b, FracFocus, 2013)	Non-toxic (ThermoFisher, 2021c)	Volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995)
Sodium hydroxide (FracFocus, 2013)	Non-toxic (Fisher, 2014h)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Inorganic	Ubiquitous in the environment, will not bioaccumulate (JRC, 2008)
Sodium carbonate (FracFocus, 2013)	Non-toxic (ThermoFisher, 2021j)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Inorganic	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Ciner, 2019)
Fumaric acid (US EPA, 2004b)	(see Gelling and Foaming agents)			
Biocides				
Didecyl dimethyl ammonium chloride (DDAC) (Nishihara et al., 2000)	GHS Category 4 Acute Oral Toxicity; GHS Category 1 Chronic Aquatic Hazard (Sigma, 2023)	Non-volatile (Luz et al., 2020)	Potentially biodegradable (Stringfellow et al., 2014, OECD, 1994, EHS, 2021c)	Moderately hydrophilic, low bioaccumulation potential (EHS, 2021c)

Alkyl dimethyl benzyl ammonium chloride (ADBAC) (Gartiser and Urich, 2009)	GHS Category 4 Acute Oral Toxicity; GHS Category 1 Acute Aquatic Hazard; GHS Category 1 Chronic Aquatic Hazard (Carl Roth, 2020)	Non-volatile (Luz et al., 2020)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Carl Roth, 2020)
Glutaraldehyde (FracFocus, 2013)	GHS Category 3 Acute Oral Toxicity; GHS Category 3 Acute Respiratory Toxicity; GHS Category 3 STOT SE; GHS Category 1 Acute Aquatic Hazard; GHS Category 2 Chronic Aquatic Hazard (Sigma, 2024e)	Low volatility (Bovallius and Anäs, 1977)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Leung, 2001)
Tetrakis hydroxymethyl phosphonium sulfate (THPS) (FracFocus, 2013)	GHS Category 3 Acute Oral Toxicity; GHS Category 3 Acute Respiratory Toxicity; GHS Category 2 Reproductive Toxicity (S.M.C. Global, 2020)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Meylan and Howard, 1995)
Tributyl tetradecyl phosphonium chloride (TTPC) (Halliburton, 2012)	GHS Category 4 Acute Oral Toxicity (Echemi, 2019c)	Not Found	Not Found	Moderately hydrophilic, low bioaccumulation potential (UNEP, 2000)
2,2-dibromo-3-nitripropionamide (DBNPA) (US EPA, 2004b)	Non-Toxic (I.R.O. Group n.d.)	Semi-volatile (ECHA, 2019)	Biodegradable (Stringfellow et al., 2014, OECD, 1994)	Non-bioaccumulative (I.R.O Group n.d.)
Ammonium chloride	(see Crosslinkers above)			
1-Bromo-3-chloro-5,5-dimethylhydantoin (Gartiser and Urich, 2009)	GHS Category 4 Acute Oral toxicity; GHS Category 1 Acute Aquatic Hazard (Molekula, 2019)	Non-volatile (PubChem, 2024)	Not Found	Not Found
Corrosion Inhibitors				
Acetaldehyde (FracFocus, 2013)	GHS Category 2 Carcinogen (Fisher, 2015a)	Volatile (Watts, 1998, Stringfellow et al.,	Readily biodegradable (Stringfellow et al.,	Hydrophilic, low bioaccumulation potential, likely to reach

		2014)	2014, OECD, 1994)	groundwater (US EPA, 2002)
Acetone (US EPA, 2004b)	GHS Category 3 STOT SE (NHSGGC, 2015)	Volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995)
Ethyl methyl derivatives (US EPA, 2004b)	Various	Various	Various	Various
Formic acid (US EPA, 2004b, FracFocus, 2013)	GHS Category 4 Acute Oral Toxicity; GHS Category 3 Acute Inhalation Toxicity (ThermoFisher, 2009)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995)
n,n-dimethyl formamide (Arthur et al., 2009)	GHS Category 4 Acute Inhalation Toxicity; GHS Category 4 Dermal Toxicity; GHS Category 1B Reproductive Toxicity (Sigma, 2024g)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995)
Propargyl alcohol (US EPA, 2004b)	GHS Category 3 Acute Oral Toxicity; GHS Category 2 Acute Inhalation Toxicity; GHS Category 2 Acute Dermal Toxicity; GHS Category 1A Carcinogenicity; GHS Category 3 STOT SE; GHS Category 2 STOT RE (ThermoFisher, 2010b)	Semi-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995)
Pyridinium (US EPA, 2004b)	Not Found	Not Found	Not Found	Not Found
Thiourea (US EPA, 2004b)	GHS Category 4 Acute Oral Toxicity; GHS Category 1B Carcinogenicity; GHS Category 2 Reproductive Toxicity (ThermoFisher, 20211)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Inherently biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Govers et al., 1986)
Isopropanol (US EPA, 2004b, FracFocus, 2013)		(see Gelling and Foaming agents above)		

Scale Inhibitors

Phosphonic acid salts (FracFocus, 2013)	Various	Various	Various	Various
Sodium polycarboxylate (FracFocus, 2013)	Non-Toxic (Dow, 2020b)	Non-volatile (Dow, 2020b)	Not Found	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Dow, 2020b)
Copolymers of acrylamide and sodium acrylate (FracFocus, 2013)	Various	Various	Various	Various

Iron Control

Thioglycolic acid (FracFocus, 2013)	GHS Category 3 Acute Oral Toxicity; GHS Acute Dermal Toxicity; GHS Category 4 Acute Inhalation Toxicity; GHS Category 3 STOT SE (ThermoFisher, 2021h)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Inherently biodegradable (Stringfellow et al., 2014, OECD, 1994)	Moderately hydrophilic, low bioaccumulation potential (Hansch et al., 1995)
Citric acid (FracFocus, 2013)	Non-toxic (Fisher, 2014d)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Avdeef, 2001)
Acetic acid (US EPA, 2004b, FracFocus, 2013)	(see pH Adjusters)			
Sodium erythorbate (FracFocus, 2013)	Non-toxic (Parchem, 2015)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Biodegradable (ECHA, 2021b).	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (ECHA, 2021b)

Clay Stabilizers

Choline chloride (FracFocus, 2013)	Non-toxic (ThermoFisher, 2021e)	Non-volatile (Watts, 1998, Stringfellow et al., 2014)	Readily biodegradable (OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (OECD, 2004)
Tetramethyl ammonium chloride (FracFocus, 2013)	GHS Category 2 Acute Oral Toxicity; GHS Category 3 Acute Dermal Toxicity; GHS Category 1 STOT SE (Carl Roth, 2024)	Non-volatile (Watts, 1998)	Not biodegradable (Stringfellow et al., 2014, OECD, 1994)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (ECHA, 2024)
Potassium chloride (US	GHS Category 5 Acute Oral	Not Found	Inorganic	Hydrophilic, low bioaccumulation

EPA, 2004b) Toxicity (Fisher, 2014g) potential, likely to reach groundwater (OECD, 2001)

Sodium chloride (FracFocus, 2013) (See Breakers Above)

Surfactants

Sodium lauryl sulfate (FracFocus, 2013)	GHS Category 4 Acute Oral Toxicity (ThermoFisher, 2023e)	Not Found	Readily biodegradable (Stringfellow et al., 2014, OECD, 1994)	Moderately hydrophilic, low bioaccumulation potential (Meylan and Howard, 1995)
Dimethyl dihydrogenated tallow ammonium chloride (Miller, 2007)	GHS Category 5 Acute Oral Toxicity; GHS Category 1 Dermal Toxicity; GHS Category 1 Aquatic hazard (Chem Service, 2015)	Non-volatile (SDA, 1996)	Not readily biodegradable (JRC, 2009)	Moderately hydrophilic, low bioaccumulation potential (Leal et al., 1994)

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40 Volatility was determined by Henry’s constant (K_H): Volatile ($K_H \geq 1 \times 10^{-5} \text{ atm m}^3 \text{ mol}^{-1}$), Semi-Volatile ($1 \times 10^{-5} \text{ atm m}^3 \text{ mol}^{-1} > K_H \geq 3 \times 10^{-7} \text{ atm}$
 41 $\text{m}^3 \text{ mol}^{-1}$), Non-volatile ($K_H < 3 \times 10^{-7} \text{ atm m}^3 \text{ mol}^{-1}$) (Stringfellow et al., 2014). Biodegradability was classified according to Organization for
 42 Economic Cooperation and Development (OECD) “Guidelines for the Testing of Chemicals” (OECD, 1994). Hydrophilicity was determined by
 43 octanol-water partition coefficients (K_{OW}): Hydrophilic ($\log K_{OW} < 0$), Moderately hydrophilic/ non-bioaccumulative ($0 < \log K_{OW} < 4.5$),
 44 hydrophobic/bioaccumulation risk ($4.5 < \log K_{OW}$) (ECHA, 2023h).
 45 Not found = no bioaccumulation data found for this chemical.
 46 Various = several compounds within this category have varying properties and no data was found to indicate all compounds had the same
 47 properties (i.e., there are no data to show every "copper compound" is hydrophilic or hydrophobic). "Various" does not infer that the SDS had
 48 various toxicities listed; if there were various toxicities listed, they are all included in the table.

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51 **Table S2. Chemicals used in both UOG and Conventional oil and gas development**

Compound Type	Toxicity	Volatility	Biodegradability	Bioaccumulation
<i>Cutting Deposit Removal</i>				
Barium sulphate (Fink, 2012, Burrafato and Carminati, 2005)	Non-toxic (ThermoFisher, 2021d)	Non-volatile (ECHA, 2023i)	Inorganic	Not expected to bioaccumulate (EHS, 2021a)
<i>Drilling Equipment Removal</i>				
1:3 mixture of nitric and hydrochloric acids with sodium nitrate and monoethanolamine (Onojake and Waka, 2021)	Not Found	Not Found	Not Found	Not Found
<i>Gas Hydrate Inhibitors</i>				
Polyethylene oxide (Kannan and Punase, 2009)	Non-toxic (ThermoFisher, 2021i)	Not Found	Biodegradable (Silva et al., 2018)	Not Found
Alkylated ammonium (Kannan and Punase, 2009)	Not Found	Volatile (Lendvay et al., 2021)	Not Found	Not Found
Phosphonium compounds (Kannan and Punase, 2009)	Various	Various	Various	Various
Sulfonium compounds (Kannan and Punase, 2009)	Various	Various	Various	Various
Amino acids (Kannan and Punase, 2009)	Various	Non-Volatile (Štejfa et al., 2020)	Various	Various
Amino alcohols (Kannan and Punase, 2009)	Various	Various	Various	Various
WBM Specific				
<i>Shale Stabilization</i>				
Potassium chloride (Onojake and Waka, 2021)	GHS Category 5 Acute Oral Toxicity (Fisher, 2014g)	Not Found	Inorganic	Hydrophilic, low bioaccumulation potential, likely to reach groundwater

(OECD, 2001)

Potassium acetate (Onojake and Waka, 2021)	Non-Toxic (ThermoFisher, 2023b)	Not Found	Inorganic	Not Found
Potassium carbonate (Onojake and Waka, 2021, FracFocus, 2013)	GHS Category 3 STOT SE (Sigma, 2024i)	Not Found	Inorganic	Not expected to bioaccumulate (Armand, 2023)
Potassium hydroxide (US EPA, 2004b, Onojake and Waka, 2021, FracFocus, 2013)	GHS Category 4 Acute oral toxicity; GHS Category 3 STOT SE (ThermoFisher, 2023c)	Non-volatile (Mallinkrodt, 2000)	Inorganic	Environmental persistence is unlikely, bioaccumulation potential unknown (ThermoFisher, 2023c)
Potassium salt of partially hydrolyzed polyacrylamide (PHPA) (Onojake and Waka, 2021)	Not Found	Not Found	Not Found	Not Found
<i>Viscosity Control</i>				
Xanthan gum (Onojake and Waka, 2021)	Non-toxic (Fisher, 2008)	Non-volatile (Chemistry Connection, 2015)	Readily biodegradable (Parchem, 2017)	Not expected to bioaccumulate (Parchem, 2017)
Polyacrylamide (PHPA)* (Patel and Muller, 2001, Kaufman et al., 2008, FracFocus, 2013)	Non-toxic (Bore, 2018) Exposure to UV radiation can degrade into acrylamide, a known human carcinogen, mutagen, and teratogen (Wen et al., 2010, Bao et al., 2010)	Non-volatile (Chemistry Connection, 2024b)	Biodegradable (Xiong et al., 2018) but has persisted over 2 months in tap water (Brown et al., 1980)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Chemistry Connection, 2024b)
Acrylamide copolymer* (Patel and Muller, 2001)	Various	Various	Various	Various
<i>Controlling Fluid Loss</i>				
Polyanionic cellulose (PAC) (Onojake and Waka, 2021)	Non-toxic (Dupont, 2020a)	Not Found	Not Found	Not Found
Carboxymethyl starch (Onojake and Waka, 2021)	Not Found	Not Found	Slightly to moderately biodegradable (Bading et al., 2024)	Not expected to bioaccumulate (EHS, 2021b)
Hydroxypropyl starch	Not Found	Not Found	Non-biodegradable (Bading	Not Found

(Onojake and Waka, 2021)			et al., 2024)	
Carboxymethyl cellulose* (CMC) (Patel and Muller, 2001, Onojake and Waka, 2021)	Non-Toxic (USK, 2007)	Not Found	Biodegradable (Dupont, 2020b)	Not expected to bioaccumulate (Dupont, 2020b)
Polypropylene glycol (PPG)* (Patel and Muller, 2001)	GHS Category 4 Acute Oral Toxicity; GHS Category 4 Acute Inhalation Toxicity (Chemi, 2019)	Volatile (Burkholder et al., 2020b)	Various (Zgola-Grzeskowiak et al., 2007)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995)
<i>Variable Density Fluids</i>				
Styrene and divinylbenzene copolymer (Ravi et al., 2009)	Not Found	Not Found	Not Found	Not Found
Styrene and acrylonitrile copolymer (Ravi et al., 2009)	Not Found	Not Found	Not Found	Not Found
Styrene terpolymer (Ravi et al., 2009)	Not Found	Not Found	Not Found	Not Found
Vinylidene chloride (Ravi et al., 2009)	GHS Category 4 Acute Oral Toxicity; GHS Category 4 Acute Inhalation Toxicity; GHS Category 2 Carcinogenicity; GHS Category 2 STOT RE; GHS Category 2 Acute Aquatic Hazard; GHS Category 3 Chronic Aquatic Hazard (Sigma, 2024j)	Volatile (Chemical Book, 2023a)	Non-biodegradable (Inchem, 2003)	Moderately hydrophilic, low bioaccumulation potential (Hansch et al., 1995)
Acrylonitrile (Ravi et al., 2009)	GHS Category 3 Acute Oral Toxicity; GHS Category 3 Acute Dermal Toxicity; GHS Category 3 Acute Inhalation Toxicity; GHS Category 1B Carcinogenicity; GHS Category 2 Reproductive Toxicity; GHS Category 3 STOT SE (ThermoFisher, 2022)	Volatile (Duchowicz et al., 2020)	Non-biodegradable (OECD, 1998)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (HNS, 2024)

Lubrication

Glycol (Onojake and Waka, 2021)	Various	Various	Various	Various
Glycerol (Onojake and Waka, 2021)	Non-Toxic (Sigma, 2014a)	Semi-Volatile (Burkholder et al., 2020b)	Readily Biodegradable (FDA, 2017)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (OECD, 2002)
Anionic fluids (Onojake and Waka, 2021)	Various	Various	Various	Various
Cationic fluids (Onojake and Waka, 2021)	Various	Various	Various	Various

OBM Specific*Viscosity Control*

Ethylenepropylene elastomers (Jones, 1999, Ashjian et al., 1996)	Various	Various	Various	Various
Polyolefins (PAOs) (Jones, 1999, Ashjian et al., 1996)	Various	Various	Various	Various
Calcium bentonites (Kondo and Sawada, 1996)	Various	Various	Various	Various

Corrosion Control

Hydrazine (Sikora, 1994)	GHS Category 3 Acute Oral Toxicity; GHS Category 2 Acute Inhalation Toxicity; GHS Category 3 Acute Dermal Toxicity; GHS Category 1B Carcinogenicity; GHS Category 1 Acute Aquatic Hazard; GHS Category 1 Chronic Aquatic Hazard (Sigma, 2014b)	Volatile (NLM, 2015)	Not Found	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995)
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Dispersal Control

Alkylsilanes (Kondo and Sawada,	Various	Various	Various	Various
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1996)				
Phosphonates (Kondo and Sawada, 1996)	Various	Various	Various	Various
<i>Surfactants</i>				
Alkylpolyglucosides (APGs) (Nicora and McGregor, 1998)	Various	Various	Various	Various
<i>Additives</i>				
Ammonia (Natural Gas) (Onojake and Waka, 2021)	GHS Category 1 Acute Aquatic Hazard; GHS Category 3 STOT SE (Fisher, 2014b)	Volatile (Burkholder et al., 2020b)	Readily biodegradable (ECHA, 2023d)	Ubiquitous in the environment, not expected to bioaccumulate (ECHA, 2023d)
Hydrogen fluoride (Natural Gas) (Onojake and Waka, 2021)	GHS Category 3 Acute Inhalation Toxicity; GHS Category 1 STOT SE (Airgas, 2018)	Volatile (Hayer et al., 2022)	Inorganic	Not Found
Carbon monoxide (Natural Gas) (Onojake and Waka, 2021)	GHS Category 3 Acute Inhalation Toxicity; GHS Category 1 Reproductive Toxicity; GHS Category 1 STOT RE (Airgas, 2020)	Semi-volatile (Burkholder et al., 2020a)	Inorganic	Does not bioaccumulate (NLM n.d.)
Methanol (Us, 2004b, Onojake and Waka, 2021)	GHS Category 3 Acute Oral Toxicity; GHS Category 3 Acute Inhalation Toxicity; GHS Category 3 Acute Dermal Toxicity; Category 1 STOT SE (Fisher, 2015d)	Volatile (Burkholder et al., 2020b)	Readily biodegradable (ECHA, 2021a)	Hydrophilic, low bioaccumulation potential, likely to reach groundwater (Hansch et al., 1995, ECHA, 2021a)
Glycol (Onojake and Waka, 2021)	(see Lubrication Above)			
Diethylene glycol (Kannan and Punase, 2009)	GHS Category 4 Acute Oral Toxicity; GHS Category 2 STOT RE (ThermoFisher, 2021f)	Volatile (Dupeux et al., 2022)	Readily biodegradable (ECHA, 2023c)	Not expected to bioaccumulate (ECHA, 2023c)

Odorizers

Ethylmarcaptan (Fink, 2012)	GHS Category 4 Acute Oral Toxicity; GHS Category 4 Inhalation Toxicity; GHS Category 1 Acute Aquatic Hazard; GHS Category 1 Chronic Aquatic Hazard (ECHA, 2023g)	Volatile (Burkholder et al., 2020b)	Not readily biodegradable (ECHA, 2023g)	Moderately hydrophilic, low bioaccumulation potential (ECHA, 2023g)
Butane-1-thiol (Onojake and Waka, 2021)	GHS Category 4 Acute Oral Toxicity; GHS Category 4 Inhalation Toxicity; GHS Category 3 STAT SE (ThermoFisher, 2021a)	Volatile (ChemEurope, 2024)	Readily biodegradable (OECD, 2010)	Moderately hydrophilic, low bioaccumulation potential (Chemistry Book, 2024a)
2-methylpropane-2-thiol (Onojake and Waka, 2021)	Non-Toxic (ThermoFisher, 2021b)	Volatile (NLM, 2015)	Not readily biodegradable (Sigma, 2022)	Not expected to bioaccumulate (Sigma, 2022)
Diethyl sulfide (Onojake and Waka, 2021)	GHS Category 3 STOT SE (ThermoFisher, 2024b)	Volatile (Burkholder et al., 2020b)	Not readily biodegradable (Chevron, 2018)	Moderately hydrophilic, low bioaccumulation potential (Hansch et al., 1995)
Ethyl propyl sulfide (Onojake and Waka, 2021)	Non-Toxic (TCI, 2018)	Volatile (Gharagheizi et al., 2012)	Not readily biodegradable (Morgott et al., 2014)	Not Found
Diethyl disulphide (Onojake and Waka, 2021)	GHS Category 3 Acute Oral Toxicity; GHS Category 3 Inhalation Toxicity; GHS Category 2 Reproductive Toxicity; GHS Category 3 STOT SE; GHS Category 2 Acute Aquatic Hazard; GHS Category 2 Chronic Aquatic Hazard (Chevron, 2019)	Volatile (Wong and Wang, 1997)	Not readily biodegradable (EFSA et al., 2019)	Moderately hydrophilic, low bioaccumulation potential (Hansch et al., 1995)
Mixture of ethylmercaptan, propylmercaptan and butylmercaptans (Onojake and Waka, 2021)	Not Found	Not Found	Not Found	Not Found

Surfactants

Cetyltrimethyl ammonium chloride (Rose et al., 1988)	GHS Category 1 Acute Aquatic Hazard; GHS Category 1 Chronic Aquatic Hazard (Sigma, 2020)	Non-volatile (EPA, 2024)	Readily biodegradable (ECHA, 2024)	Moderately hydrophilic, low bioaccumulation potential (Hansch et al., 1995)
Dodecyl diphenyl oxide disulfonate (Rose et al., 1988)	Non-Toxic (Dow, 2020a)	Non-volatile (Dow, 2020a)	Biodegradable (Dow, 2020a)	Not Found
Soya bis (2-hydroxyethyl)amine (Rose et al., 1988)	Non-Toxic (Sigma, 2024b)	Non-volatile (SCB, 2010)	Inherently biodegradable (ECHA, 2023b)	Not Found
<i>Crude Oil Treatment</i>				
Sodium hydroxide with sodium bicarbonate or sodium (Padron, 1996, Onojake and Waka, 2021)	Not Found	Not Found	Not Found	Not Found
Aluminium nitrate (Rodriguez et al., 1990)	Non-toxic (Fisher, 2014a)	Not Found	Inorganic	Not Found
<i>Chemical Inhibitors (film formers)</i>				
2-phenyl-1H-benzimidazole (Onojake and Waka, 2021)	GHS Category 4 Acute Oral Toxicity; GHS Category 3 STOT SE (ThermoFisher, 2024a)	Not Found	Not Found	Not Found
2-methyl-1,3-benzothiazol-1-ium (Onojake and Waka, 2021)	Non-toxic (ThermoFisher, 2012)	Not Found	Not Found	Not Found
1H-benzotriazole (Onojake and Waka, 2021)	GHS Category 4 Acute Oral Toxicity; GHS Category 2 Acute Aquatic Hazard; GHS Category 2 Chronic Aquatic Hazard (Sigma, 2024a)	Volatile (NLM, 2015)	Not readily biodegradable (ECHA, 2023e)	Moderately hydrophilic, low bioaccumulation potential (KWR, 2009)
1,3-dimethylthiourea (Onojake and Waka, 2021)	GHS Category 3 Acute Oral Toxicity (ThermoFisher, 2010a)	Not Found	Not readily biodegradable (ECHA, 2023a)	Low bioaccumulation potential (ECHA, 2023a)
<i>Corrosion Inhibitors</i>				
Phosphates (Onojake and Waka, 2021)	Various	Various	Various	Various
Polyphosphates (Onojake and Waka, 2021)	Various	Various	Various	Various

Tungsten (Onojake and Waka, 2021)			Inorganic	Found to bioaccumulate (US EPA, 2017, Kennedy et al., 2012)
Silicates (Onojake and Waka, 2021)	Various	Various	Inorganic	Various
Chromates (Onojake and Waka, 2021)	Various	Various	Various	Various
meta-, ortho-, and pyrovanadates (Onojake and Waka, 2021)	Various	Various	Various	Various
Phosphate esters (Onojake and Waka, 2021)	Various	Various	Various	Various
Sulphur compounds (Onojake and Waka, 2021)	Various	Various	Various	Various
Nitrogenous compounds (Onojake and Waka, 2021)	Various	Various	Various	Various
Quaternary ammonium salts and betains (Onojake and Waka, 2021)	Various	Various	Various	Various
Amidoamines (Onojake and Waka, 2021)	Various	Various	Various	Various
Imidazolines (Onojake and Waka, 2021)	Various	Various	Various	Various
Polyhydroxy and ethoxylated amines/amidoamines (Onojake and Waka, 2021)	Various	Various	Various	Various
<i>Wax inhibitors</i>				
Alkyl sulfonates (Onojake and Waka, 2021)	Various	Various	Various	Various
Alkyl aryl sulfonates (Onojake and Waka, 2021)	Various	Various	Various	Various
Fatty amine ethoxylates (Onojake and Waka, 2021)	Various	Various	Various	Various
<i>Scale Inhibitors</i>				
Polymetaphosphates (Onojake and Waka, 2021)	Various	Various	Various	Various
Phosphate salts	Various	Various	Various	Various

(Onojake and Waka, 2021)

Polyacrylic acid (PAA) (Onojake and Waka, 2021)	Non-toxic (Sigma, 2024h)	Non-volatile (Chemistry Book, 2024c)	Biodegradable (ECCC, 2018)	Moderately hydrophilic, low bioaccumulation potential (Chemistry Book, 2024c)
Phosphinocarboxylic acid (Onojake and Waka, 2021)	GHS Category 5 Acute Oral Toxicity; GHS Category 5 Acute Inhalation Toxicity; GHS Category 2 STOT RE (North, 2018)	Not Found	Not readily biodegradable (North, 2018)	Not Found
Sulfonated polymers (Onojake and Waka, 2021)	Various	Various	Various	Various
Phosphonates (Onojake and Waka, 2021)	Various	Various	Various	Various

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53 * fundamental to all WBM (Patel and Muller, 2001).

54 Volatility was determined by Henry's constant (K_H): Volatile ($K_H \geq 1 \times 10^{-5} \text{ atm m}^3 \text{ mol}^{-1}$), Semi-Volatile ($1 \times 10^{-5} \text{ atm m}^3 \text{ mol}^{-1} > K_H \geq 3 \times 10^{-7} \text{ atm}$
55 $\text{m}^3 \text{ mol}^{-1}$), Non-volatile ($K_H < 3 \times 10^{-7} \text{ atm m}^3 \text{ mol}^{-1}$) (Stringfellow et al., 2014). Biodegradability was classified according to Organization for
56 Economic Cooperation and Development (OECD) "Guidelines for the Testing of Chemicals" (Oecd, 1994). Hydrophilicity was determined by
57 octanol-water partition coefficients (K_{OW}): Hydrophilic ($\log K_{OW} < 0$), Moderately hydrophilic/ non-bioaccumulative ($0 < \log K_{OW} < 4.5$),
58 hydrophobic/bioaccumulation risk ($4.5 < \log K_{OW}$) (Echa, 2023h).
59 Not found = no bioaccumulation data found for this chemical.
60 Various = several compounds within this category have varying properties and no data was found to indicate all compounds had the same
61 properties (i.e., there are no data to show every "copper compound" is hydrophilic or hydrophobic). "Various" does not infer that the SDS had
62 various toxicities listed; if there were various toxicities listed, they are all included in the table.

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Thermofisher Scientific 2021i Poly(ethylene oxide) MSDS.

Thermofisher Scientific 2021j Sodium Carbonate - SDS.

Thermofisher Scientific 2021k Sodium peroxydisulfate - SDS.

Thermofisher Scientific 2021l Thiourea MSDS.

Thermofisher Scientific 2022 Acrylonitrile.

Thermofisher Scientific 2023a Calcium chloride - SDS.

Thermofisher Scientific 2023b Potassium Acetate MSDS.

Thermofisher Scientific 2023c Potassium Hydroxide - SDS.

Thermofisher Scientific 2023d Sodium Chloride - SDS.

Thermofisher Scientific 2023e Sodium Lauryl Sulfate MSDS.

Thermofisher Scientific 2024a 2-Phenylbenzimidazole MSDS.

Thermofisher Scientific 2024b Diethyl sulfide MSDS.

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