FEASIBILITY OF ENVIRONMENTALLY FRIENDLY SOLVENT IN BITUMEN RECOVERY THROUGH SOLVENT-STEAM PROCESSES

A Thesis

by

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Submitted to the Office of Graduate and Professional Studies of
Texas A&M University
in partial fulfilment of the requirements for the degree of

MASTER OF SCIENCE

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August 2018

Major Subject: Petroleum Engineering

ABSTRACT

Steam flooding is the most widely used and reliable thermal enhanced oil recovery (EOR) process to recover bitumen. However, the excessive water required to generate steam causes environmental concerns. Thus, a noble idea to reduce the sole dependency on steam alone is to co-inject solvent with steam to improve miscibility aside from the oil displacement mechanisms from steam itself. However, the usage of industrial grade solvents are toxic, hence difficult to handle. These chemicals will cause long term health issues as well as environmental pollution. Thus, the aim of this research is to investigate the feasibility of a plant-based environmentally friendly solvent to replace the toxic industrial grade solvents as well as reduce the dependency on steam alone.

Eight core flooding experiments were conducted on a Canadian bitumen by varying propane, hexane, toluene, benzoyl peroxide, MS environmentally friendly solvent, and steam. Results obtained indicated good oil recoveries through solvent-steam processes especially using the MS solvent. The produced and residual oil were analyzed through asphaltenes separation which showed that the MS solvent produced more of the asphaltene in the produced oil. Meanwhile, the other solvents precipitated more asphaltenes in the residual oil on the spent rock since they are asphaltene precipitants except for toluene.

Polar asphaltene should react with polar liquid water to form emulsion based on literature. However, the asphaltene content in produced oil did not correlate with the emulsion severity during investigation. Thus, control experiments involving individual SARA fractions were conducted to understand the role of each fraction in emulsion formation. Results showed that the mutual interaction between aromatics and resins induced the formation of emulsion before being stabilized by the asphaltenes. At the same time, it was found that emulsion formation intensifies during steam

temperature and exist as foam before condensing into more stable water droplets at a lower temperature.

These results meant that the MS environmentally friendly solvent could potentially replace the toxic chemicals during solvent-steam processes to mitigate the environmental footprint. Other than that, the role of asphaltene as an emulsion stabilizer instead of as an emulsion inducer will alter emulsion treatment and inhibition chemicals by targeting the deasphalted oil instead to improve the oil quality by removing the emulsion. This behavior of asphaltene will also shed light onto the fundamentals of asphaltene which still remains to be a complex molecule to understand.

DEDICATION

I dedicate my thesis to my loving and supportive parents, Ng Chee Seng and Wee Siew Chen. Their unconditional love and continuous support made it possible for me to achieve this.

ACKNOWLEDGEMENTS

First and foremost, I would like to thank my advisor, Dr. Berna Hascakir, for believing in me when I was still an undergraduate and her willingness to guide and help me throughout my research and graduate education. Her trust made me who I am as a graduate student today.

I am also thankful to my committee members, Dr. Ibere Alves, Dr. Rashid Hasan, and Dr. Debjyoti Banerjee for their invaluable guidance and support throughout this research.

I sincerely appreciate the members of the Heavy Oil, Oil Shales, Oil Sands, and Carbonate Analysis and Recovery Methods (HOCAM) research group for their help, feedback and support in my research. In particular, I would like to thank Elizabeth Seber and Lifu Zhang for their help with lab measurements. I am also grateful to Dr. Taniya Kar for guiding me throughout the steam flooding process which was a continuation of her steam flooding research.

A big heartfelt appreciation to my friends, petroleum engineering faculties, and acquaintance who make me felt at home at Texas A&M University. Finally, I thank my family and friends for bringing out the best in me.

NOMENCLATURE

API	American Petroleum Institute
ASTM	American Standard for Testing and Materials
BP	Benzoyl peroxide
BTEX	Benzene, Toluene, Ethylbenzene, Xylene
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
C3	Propane
C6	n-Hexane
cP	Centipoise
DES	Deep Eutectic Solvents
EOR	Enhanced Oil Recovery
ID	Internal diameter
MS	Ethicalchem MS environmentally friendly solvent
SAGD	Steam Assisted Gravity Drainage
SARA	Saturate, Aromatics, Resins, and Asphaltenes
SOR	Steam-oil ratio
St	Steam
TGA/DSC	ThermoGravimetric Analysis/ Differential Scanning Calorimetry
Tol	Toluene
TPH	Total Petroleum Hydrocarbon
vol%	Volume percent
wt%	Weight percent

CONTRIBUTORS AND FUNDING SOURCES

Contributors

This work was supervised by a thesis committee consisting of Professor Berna Hascakir [advisor] and Professor Ibere Alves of the Department of Petroleum Engineering [Home Department] and Professor A. Rashid Hasan of the Department of Petroleum Engineering [Home Department] and Professor Debjyoti Banerjee of the Department of Mechanical Engineering [Outside Department].

All work conducted for the thesis was completed by the student independently.

Funding Sources

There are no outside funding contributions to acknowledge related to the research and compilation of this document.

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CHAPTER I

INTRODUCTION

Energy demand is growing with the increased in human population through the increased in per capita energy usage. Based on the most recent 2018 World Energy Outlook Report by the U.S. Energy Information Administration (EIA), it was reported that energy demand will rise at a rate of 0.7% per annum from 2018 until 2050. Furthermore, the main source of energy that will meet this growth demand comes from the petroleum industry (EIA 2018). With this projection, the demand for a continuous and adequate supply of petroleum is important and need to be ascertained of.

For a long while since the early discovery of petroleum, most of the petroleum sources have been from conventional reservoirs called ‘super giants’ where oil and gas production had been straightforward and economically viable at low oil prices (Hirsch 2005, Höök et al. 2009). However, these reserves are fast depleting and, thus, the need to revert to unconventional reservoirs to sustain this energy demand (Owen et al. 2010). Amongst the unconventional resources, bitumen, heavy and extra heavy oil account for about 55% of the oil reserves worldwide with an estimated three fold rise in production in 2035 compared to 2010 (Hama 2014, IEA 2013, Meyer and Attanasi 2004).

There are several definitions used to categorize and distinguish between these unconventional fluids. The most commonly used and accepted definition categorized bitumen as crude with viscosity above 10,000 cP regardless of its API gravity (Meyer and De Witt 1990). This means that bitumen could potentially have either a high or low API gravity. On the other hand, extra heavy oil has a viscosity below 10,000 cP and an API gravity of less than 10 °API while heavy oil has a viscosity below 10,000 cP and an API gravity of 10-22.3 °API. Light oil also has a viscosity below 10,000 cP but an API gravity greater than 22.3 °API. (Meyer et al. 2007). Due to the high viscosity and low API gravity nature of these unconventional fluids, effective recovery of these resources through primary depletion and secondary recovery techniques such as water flooding is not possible (Meyer and Attanasi 2004, Nasr and Ayodele 2005). Thus, thermal recovery processes which utilize heat to reduce the crude's viscosity to allow better flow are applied (Prats 1982). Among the thermal recovery processes, steam flooding proves to be the most promising and reliable process (Memarzadeh and Rahnema 2015, Morrow et al. 2014, Willman et al. 1961). Because it has the ability to alter the reservoir rock wettability to water-wet, it improves the oil relative permeability (Kar et al. 2015, Morte and Hascakir 2016, Stape and Hascakir 2016). Moreover, the high heat content of steam which is around 1,192 Btu/lb makes the oil displacement more efficient by increasing the oil mobility compared to other water injection methods (Johansen 1979, Willman et al. 1961).

As a result, field scale projects had been attempted and the first attempt on steam flooding was conducted by Worthington Corp. and Forest Oil Corp. in 1953 in Parker Pool, Pennsylvania. It was an air-steam flooding which proves to be successful (Walter 1957). Meanwhile, the first officially reported steam flood project in the world was in Schoonebeek, Netherlands in 1960 while the first project in the U.S. is in East Coalinga, California in 1963 with both projects proving to be successful mainly due to lowered oil viscosity and gas cap expansion which maintained the additional reservoir pressure (Ali and Meldau 1979, Blevins et al. 1984). In 1984, Blevins and his colleague reported that the first few unsuccessful projects were in Triumph, Shamburgh, and Franklin Harvey Pool, Pennsylvania and El Dorado, Kansas in 1965. The reasons for these failures were due to thief zones (zones with high permeabilities) which caused low oil displacement efficiencies due to steam channelling created by the steam fingers (Dehghani and Ehrlich 1998, Doujuan et al. 2004).

Despite those early setbacks, steam flooding is still widely practiced because of its effective oil displacement mechanisms. The heat content in steam enables the contacted crude in the reservoir to swell which reduces its overall density. This in turn will reduce its viscosity to allow better flow (Al Adasani and Bai 2011, Yitang et al. 2008). Hence, thermal expansion of the oil, reduction in oil viscosity, and steam distillation are the three main oil displacement mechanisms observed in steam injection processes (Green and Willhite 1998, Prats 1982, Willman et al. 1961). However, the most prominent and unique mechanism associated with steam flooding is the steam distillation mechanism. When steam contacts the crude, it will swell as described earlier and, at the same time, vaporizing the lighter crude fraction. These light components such as short chain hydrocarbons will distillate and flow along with the steam bank until it condenses at lower temperatures nearer to the producers (Mango 1997, Thompson 1983).

However, this mechanism may lead to the formation of emulsions due to the polar-polar interactions between the water and polar components of crude oil. Steam which will condense at lower temperature into liquid phase will interact with the produced oil to form severe emulsion (Chung and Butler 1988). Furthermore, this emulsion will increase the overall produced fluid’s viscosity and requires more surface processing of produced oil to meet industrial standards (Dealy 1979, Mao and Marsden 1977, Steinborn and Flock 1983). Due to its high polarity, asphaltenes had been blamed for interacting with polar liquid water to form water-in-oil emulsions (Kilpatrick 2012, Punase and Hascakir 2016b, Punase et al. 2016, Xia et al. 2004, Yarranton et al. 2000) . Besides asphaltenes, resins are also polar (Swanson 1942) while aromatics and saturates may also have some polar functional groups in their structures (Prakoso et al. 2016). Apart from emulsion formation, pure steam at high temperature of around 370 °C may cause the release of highly corrosive gases such as CO_2 and H_2S (Akstinat 1983).

Besides the concerns on the produced oil quality, the steam generation process itself requires huge amount of fresh water and it also releases huge volume of CO_2 due to hydrocarbon fuel consumption to heat water to generate steam. These drawbacks will then lead to environmental issues. (Yang and Gates 2009). To streamline the numerical quantity of fresh water needed, the steam-oil ratio (SOR) which is the amount of steam required to produce one barrel of oil is the industry accepted unit for comparison. As of 2006 in California, the SOR for a steam flood project ranges from 1.06 to 168 (Brandt and Unnasch 2010). In the worst case, this means that 168 barrels of cold water equivalent of steam is required to produce just one barrel of oil. In 2004, Law compared three Steam Assisted Gravity Drainage (SAGD) processes to three steam flooding processes in Canada in terms of water usage to produce one barrel of oil. He found that even with the more efficient SAGD process (Butler 1982), at least one barrel of water is necessary to produce one barrel of oil which, when upscaled to the full field size, will still require a huge amount of water. At the same time, the most efficient steam flooding investigated required at least four times that amount (Law 2004). This excessive amount of water usage will lead to increase in water production which is highly contaminated with sulfur, nitrates, particulates, and heavy metals (Sarathi and Olsen 1992, Ali and Hascakir 2015, Gu et al. 2015, Satter 1965). A separate three steam process sites in Canada were tested to further consolidate this theory and it was found that all three sites had elevated pollutants ranging from high total dissolved solids (TDS) to high heavy metal contents which exceeded the level set by the Canadian Council of Ministers of the Environment (Donaldson et al. 1985, Jamaluddin 1994). Additionally, Pod One and Algar, two separate steam process fields operated by Connacher Oil in Canada released 192,000 tonnes of

CO_2e and 118,000 tonnes of CO_2e of greenhouse gases (GHG) respectively (Hulley et al. 2012). To put these figures into perspective, Pod One's GHG emission is equivalent to those released by 41,000 passenger vehicles driven per year while Algar's is equivalent to those released by 25,000 passenger vehicles driven per year.

With such huge conundrums on the environmental footprint and excessive fresh water usage associated with steam flooding, steam flooding application are getting limited. However, considering that steam flooding is still the most reliable of all thermal recovery processes, a more efficient process such as solvent-steam co-injection process can be an improved alternative. This alternative will add the miscibility mechanism contributed by the solvent which will also reduce viscosity addition to steam. Solvent that is co-injected will reduce the interfacial tension between two fluids: in this case, the interfacial tension between vapor/steam and crude (Dong et al. 2009, Wagner and Leach 1966). A reduction in the interfacial tension, physically, will decrease the capillary force (the force which traps liquid in tight pore throats) which will allow more crude to be produced. The reduction in capillary forces, numerically, will increase the capillary number (viscous force per capillary force) which indicates better EOR prospect (Ali 1974, Marciales and Babadagli 2016, Naderi and Babadagli 2016). The reduction in interfacial tension may also lead to the breaking of emulsion (Taylor 1934) since emulsion formation is also a surface related phenomenon. The solvents are able to reduce the interfacial tension between water-oil to breakdown this emulsion (Kar and Hascakir 2015, 2016).

This combined fluid injection process was first tested in the laboratory by Farouq Ali in 1965 where he co-injected an alcohol slug with steam. He reported that this co-injection managed to increase oil recovery by an additional 12% compared to just steam alone. Mainly, he attributed this success to the combined effects of lowering interfacial tension by the solvent and the aforementioned steam process' oil displacement mechanisms (Farouq 1965). Farouq Ali continued with his laboratory experiments on solvent-steam process in 1976 when he varied his solvent options to be co-injected with steam. The solvents tested were synthetic crude, mobil solvent, and naphtha which all showed improved oil recovery. However, he established that the lowest solvent-bitumen ratio was 0.24 which means that he required 6 volume units of solvent to produce 25 volume units of bitumen which was uneconomical during the time of investigation (Ali and Abad 1976). However, if the solvents can also be produced then, they could be reinjected. Much of the obstacle with solvent-steam co-injection had been the price of the solvent itself. Although it is undeniable that this hybrid process improves oil recovery, the cost of purchasing the solvent was not compensated enough by the increased in production (Doscher et al. 1979). Redford and Mckay improved on Farouq Ali's work by investigating more solvents and their effect on the oil recovery. Their experiments agreed with Farouq Ali's work in terms of solvents being able to enhance the oil recovery (Redford and McKay 1980). However, the real novelty in their research is in the early contribution towards the acknowledgement of solvent effects on asphaltene deposition in the reservoir which will be discussed later on.

On a field scale, the early application of solvent with steam was observed in the Athabasca tar sand where Shell Canada injected steam and a solvent option of either toluene, benzene, naphtha, or carbon tetrachloride solution to drain the bitumen. It was a success with a reported additional recovery of 38% (Hernández and Ali 1972). This was followed by another application where solvent is co-injected with steam through a solvent assisted cyclic steam stimulation process which was later patented by Exxon in 1985 (Islip and Shu 1985). Investigation into this hybrid process only took off when the SAGD process was introduced in 1982 by Roger Butler and later improved by Nasr and his colleagues through the Expanding Solvent – SAGD (ES-SAGD) process

(Nasr et al. 2003) where pilot tests were carried out in Alberta, Canada. With the ability to reduce the solvent volume and improved in process efficiencies (Mukhametshina et al. 2016, Mukhametshina and Hascakir 2014, Kar et al. 2014, Unal et al. 2015), solvent-steam co-injection is getting the industry's attention as one of the best thermal recovery methods to extract bitumen. Also, the idea of reinjection of produced solvents is making this process more effective.

However, the usage of solvent poses a few concerns as well. The industrial-grade solvents are highly toxic and poses as health hazards which causes handling problems (Kelland 2014, Morrow et al. 2014, Mukhametshina and Hascakir 2014). The usage of these chemicals will also increase the total petroleum hydrocarbon (TPH) contaminants which are measurable amount of petroleum-based hydrocarbon in an environmental media that can be dispersed through air or liquid (Adeniyi and Afolabi 2002, Hutcheson et al. 1996, Saari et al. 2007). Among the most detrimental TPHs are Benzene, Toluene, Ethylbenzene, Xylene (BTEX) group of chemicals which is poisonous and will cause permanent damage to the central nervous system (Janks and Cadena 1991, Todd et al. 1999).

Furthermore, as reported earlier through Redford & McKay's research in 1980, solvent types will affect the deposition of asphaltenes in the reservoir. Asphaltenes is one of the crude fractions alongside saturates, aromatics, and resins (Mullins and Sheu 2013, Mullins et al. 2007). Structurally, it consists of complex aliphatic hydrocarbon molecules that are attached to aromatics, and naphthenic rings which contains heteroatoms such as sulfur, nitrogen, oxygen, and metals (Prakoso et al. 2017, Punase et al. 2017, Yarranton et al. 2007, Yen et al. 1961). Asphaltenes react to different types of solvents differently (Demir et al. 2016, Coelho et al. 2016, Hascakir 2016, Punase and Hascakir 2016a). It is insoluble in paraffinic solvents such as pentane and hexane but soluble in aromatics solvent such as toluene and benzene (Mannistu et al. 1997, Mitchell and

Speight 1973, Wang and Buckley 2003). Furthermore, the solubility power of paraffinic solvents increases with carbon number which means that higher carbon number alkanes will more likely keep asphaltenes molecules in solution (Fuhr et al. 1991, Mullins 2008). Thus, depending on the solvents selected, more asphaltene could either be deposited in the reservoir or carried along in the produced oil (Gaspar et al. 2012, Kharrat et al. 2007, Leontaritis et al. 1994). Due to the environmental and asphaltene related problems, alternative solvents which can replace these toxic chemicals can be implemented.

Environmentally friendly solvents had been widely used in the oil and gas industry for many purposes ranging from well stimulation to clean up and by-product disposal (Akinlua et al. 2015, Ituen et al. 2016, Martínez-Palou and Sánche 2011). However, the usage of environmentally friendly solvent in a solvent-steam process is relatively new with few researches being conducted after the widespread of ES-SAGD process. One of the latest research was conducted by Petcavich and his colleague in 2013 on a green solvent which comprise of water-based fluid with surfactants. Results showed that the green solvent was promising when flooded through Berea sandstone with recovery as high as 94% in the lab (Petcavich et al. 2013). Later in 2014, Deep Eutectic Solvents (DES) were investigated by Mohsenzadeh and his colleague. DES is a mixture fluid where two cheap and environmentally safe fluids are mixed through hydrogen bond interactions to produce a new eutectic mixture with a lowered boiling point. This green chemical showed mix results with lowering the oil-wet level of the rock while increasing the interfacial tension (Mohsenzadeh et al. 2015). Unfortunately, there are no environmentally friendly solvent that has been tested in the field to date. This shows that there is a lot of potential within this research focus to create a suitable green solvent for solvent-steam field application.

Thus, the focus of this research is to investigate the oil recovery performance of a Canadian bitumen based on steam, solvent, and solvent-steam processes. The solvents tested comprise of the industrial grade chemicals of paraffinic and aromatic solvents as well as a plant-based environmentally friendly solvent. Besides that, the produced oil quality is also investigated to compare the asphaltene deposition tendencies and the severity of emulsion formed especially in the steam related processes. Eventually, the relationship between asphaltenes and emulsion formation is investigated.

CHAPTER II

EXPERIMENTAL MATERIALS AND PROCEDURE

In this study, recovery potential of the Canadian bitumen with solvent and steam injection methods were tested. Physical properties of the bitumen are listed in Table 1. The Canadian bitumen sample has an API gravity less than 10 and the viscosity is 290,500 cP at room temperature. It has 19.0 wt% of saturates, 20.9 wt% of aromatics, 35.7 wt% of resins, and 24.4 wt% of asphaltenes. To determine SARA, ASTM D2007-11 method was followed. Hence, n-pentane insoluble fraction of crudes was named asphaltenes.

Table 1 – The physical characteristics of bitumen used in this study

Oil Type	API Gravity	Viscosity (cP)	SARA Weight Fraction (wt%) (ASTM D2007-11)			
			Saturates	Aromatics	Resins	Asphaltenes
Canadian Bitumen	9.6	290,500	19.0	20.9	35.7	24.4

Eight core flooding experiments were conducted with bitumen. Among the eight experiments conducted, one was steam flooding (E1), three were solvent flooding (E2, E4, E8), and four were solvent – steam flooding (E3, E5, E6, E7). Table 2 shows the experimental conditions for all eight core flooding experiments. In solvent-steam flooding experiments, five different solvents were tested: n-Hexane (C6), propane (C3), toluene, Benzoyl Peroxide (BP), and a plant-based environmentally friendly solvent (MS).

Table 2 – Injected fluid type, injection rate, and total experiment time summary for all eight core flooding experiments

Experiments		Injected Fluid Type	Injection Rate (ml/min CWE)	Experiment Time (min)
Number	**Hydrocarbon Type**			
E1	Bitumen	Steam	18	240
E2	Bitumen	Propane	2	240
E3	Bitumen	Steam - Propane	18 : 2	240
E4	Bitumen	n-Hexane	2	240
E5	Bitumen	Steam – n-Hexane	18 : 2	160ǂ
E6	Bitumen	Steam – Propane – MS*	18 : 2 : 2	234
E7	Bitumen	Steam – Propane – BP**	18 : 2 : 2	140ǂǂ
E8	Bitumen	Toluene	2	240

CWE : Cold water equivalent; * MS is the environmentally friendly solvent; **Benzoyl peroxide (BP) is in solid phase and dissolved in a mixture of the ratio 0.25 g BP : 1ml dichloromethane : 6ml n-Hexane; ǂ Early termination due to minor vapor phase n-Hexane leak in the separator; ǂǂ Early termination due to possible plugs associated with BP and/or BP-asphaltene precipitation

n-Hexane and propane were selected due to their wide usage within the petroleum industry (Allen and Tate 1974, Whorton and Kieschnick 1950). Besides that, toluene is tested because it is a strong and effective crude solvent (Pisio and Kirkvold 1977, Tellez et al. 2002). Benzoyl peroxide is tested to investigate the behavior and performance of a solid solvent compared to a gaseous and a liquid solvent. Lastly, the MS environmentally friendly solvent is tested for its feasibility to replace the toxic solvent in terms of oil recovery and produced oil quality. More detailed properties of solvents are given in the appendix (Figure E-1 through E-7). Among the solvents tested, all the solvents are asphaltene precipitants except for toluene (Yen et al. 1961). This way the role of asphaltenes on the recovery characteristics of bitumen was also investigated.

The eight core flooding experiments were conducted using 100% 20 – 40 mesh size Ottawa Sand. For the Ottawa Sand packs, 39.1% porosity were achieved. The pore space was saturated with 84 vol% bitumen (S_{oi}) and 16 vol% distilled water (S_{wi}) (Bayliss and Levinson 1976, Hamm and Ong 1995). Prepared reservoir rock-fluid mixtures were then packed into a 20 cm length by 5.36 cm ID core holder and is placed into the experimental set-up as shown in Figure 1.

Steam generator was fed by distilled water tank which was pumped through a 1,000 ml TELEDYNE ISCO model 1000D syringe pump. The secondary water pump (500 ml TELEDYNE ISCO model LC-5000 syringe pump) is only used during intervals when the primary water pump had to be refilled. The steam generator generates heat up to 220 °C to convert the liquid phase distilled water into vapor phase. 18 ml/min steam was injected in cold water equivalent into the core holder continuously.

For solvent and solvent-steam flooding, both liquid and gas solvent were injected at a rate of 2 ml/min at room condition. The liquid solvent was injected by a BECKMAN model 100A continuous pump while the gas solvent was directly injected from the gas cylinders by using a mass flowmeter. A thermocouple was inserted into the core holder to record the core's temperature throughout the experiment every 2 seconds. The backpressure was maintained at 75 psi. Nitrogen gas was used to maintain 75 psi backpressure (Coelho 2016, Kar 2015, 2017, Mukhametshina 2013, Stape 2016). Experiment time was decided according to cumulative oil rate of the base experiments (steam injection experiment with Canadian bitumen (E1)). Accordingly, for comparison purposes, all experiments conducted with bitumen took 240 minutes.

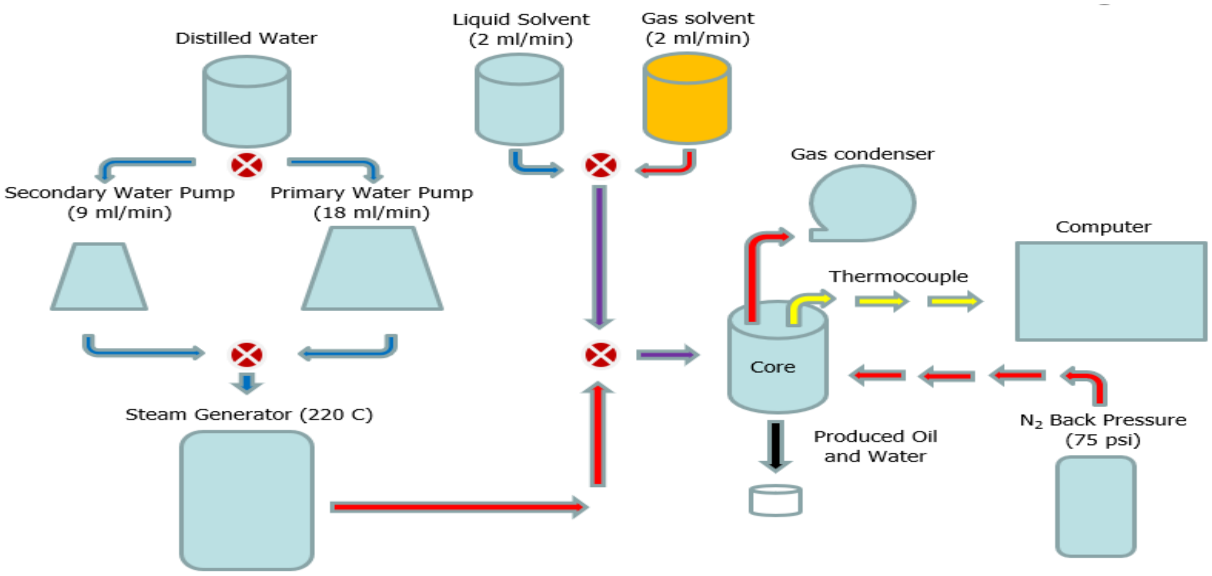


Figure 1 – Experimental set up for core flooding

At the end of each experiment, produced oil samples were first analysed through microscopic images to determine the presence and type of emulsions. The produced oil samples' viscosity then, was measured using a Brookfield DV III Ulta rheometer (ASTM 2015). Shear rate against shear stress were plotted and fitted with a Power-law model (Goodeve 1939).

Spent rock and produced oil samples from each experiment were analysed using NETZSCH thermogravimetric and differential scanning calorimetry (TGA/DSC) to determine their components through evaporation and burning (Kar 2015, 2017, Kar and Hascakir 2015). During these analyses, the samples were heated from room temperature to 900 °C under air injection at a rate of 50 ml/min. The TGA measures the weight loss of the sample with increased in temperature, hence, were used to determine the amount of residual oil and residual solvent in spent rock and water content in produced oil (Chen et al. 2012, Kar and Hascakir 2015, Kar et al.

2016). DSC measures heat flow with increase in temperature. Water and solvent evaporations are endothermic reaction and the combustion of oil is an exothermic reaction (Roos and Karel 1990, Shkadinskii et al. 1971). It should be noted that while the valleys indicate the exothermic reactions in the DSC curves, the peaks show endothermic reactions. Thus, DSC curves are used to determine the temperature values where water and solvent were evaporated and oil was combusted from either the spent rock or produced fluids.

In the microscopic images of produced oil samples, emulsions were detected. Asphaltenes due to their polar nature are blamed for causing emulsions (Kilpatrick 2012, Punase and Hascakir 2016b, Punase et al. 2016, Xia et al. 2004, Yarranton et al. 2000). Hence, the amount of asphaltenes were separated and the impact of the amount of asphaltenes on the emulsion severity in the produced oil was discussed. Asphaltenes were also separated from the spent rock to investigate the precipitation tendency of asphaltene with different solvent used in the flooding experiments and asphaltenes' potential to plug the pores.

Due to the various combination of solvents, water and crude in the flooding experiments, the produced oil quality in terms of emulsion severity varies. Thus, additional control experiments were conducted to understand better the role of each component towards the formation of emulsion in the produced oil. For simplicity, the crude was fractionated into its Saturates, Aromatics, Resins, and Asphaltenes fractions (SARA) using the widely used ASTM D2007-11 method. Asphaltenes were precipitated using n-pentane. Then, the deasphalted oil was charged through a 2-section column: the upper column consists of 100g of attapulgus clay while the lower column consists of 50g of attapulgus clay and 200g of silica gel. The attapulgus clay will absorb the resins while the silica gel will absorb the aromatics. Thus, the filtrate will be saturates (Andersen and Speight 1992, ASTM 2011). To investigate further the role of asphaltenes and the polar fractions of the crude, individual crude fractions and their combinations were placed on microscopic slides and exposed to either liquid water at room temperature or steam (100 °C) for 10 minutes. Microscopic images of the fractions (40X magnification) were taken before and after the 10 minute exposure to steam or water to observe for the formed emulsions (if any).

At the same time, a separate set of bottle test were conducted as control experiments to further investigate the findings from the flooding experiments and microscopic slide control experiments. Specifically, these bottle tests were conducted to understand if the continuous phase is water or oil in emulsion as well as understanding the role of the solvents towards the emulsification mechanism. Five test tubes were filled with bitumen in which four of them were added with water and solvent: water and MS solvent, water and benzoyl peroxide solvent (0.25g Bp + 1ml DCM + 5 ml C6), water and toluene, and water and n-hexane in fixed ratios. Then, the test tubes were shaken in a 72 °F water bath in a 5 minutes interval for 15 minutes. Microscopic images (40X magnification) of each distinctive liquid layers formed in the test tubes after the shaking were taken immediately to observe for emulsion (if any). This set of five test tubes were replicated at 158 °F and 210 °F to simulate hot water and steam conditions respectively. For these two temperatures, additional microscopic images were taken after 30 minutes to allow sufficient cooling of the liquid to observe for stabilized emulsion.

CHAPTER III

EXPERIMENTAL RESULTS AND DISCUSSION

III.1 Canadian Bitumen Core Flooding Experiments

In this section, eight core flooding experimental results are discussed; one steam (E1), three solvent (E2, E4, E8), and four solvent-steam (E3, E5, E6, E7) flooding experiments.

The produced oil quality is first discussed with viscosity measurements by using Brookfield DV III Ultra rheometer. Due to the non-Newtonian characteristic of bitumen and heavy oil (Dealy 1979, Van der Poel 1958), their dynamic viscosities were measured for varying shear stresses and shear rates and the obtained data were fitted to Power Law trend. Data obtained for every produced oil at three different temperatures (30°C, 40°C, 50°C) is given in the appendix (Table B-1) and the equation for power law fluids is given below.

$\sigma = K\gamma^n$ ………………………………………………………………………...……….Eq^{n}1

The Power Law model represented by the equation above generally describes the rheological behavior of crude. σ represents the shear stress (dyne/cm^2), K is the flow consistency index, γ is shear rate (1/sec), and n is the flow behaviour index. For most of the cases, the value of n is less than one which indicates the shear-thinning property of the initial and produced crudes (Al Fariss and Pinder 1987, Hasan et al. 2010). In general, all the cases fit the Power Law model with R^2-value close to 1. The n-value for E8 (0.9659 at 30°C) in which toluene was injected was closest to 1 (Newtonian fluid). Its n-value increased compared to the initial bitumen sample's n-value (0.9435 at 30°C). This means the produced oil in E8 is least likely to be affected by temperature and shear rate since a Newtonian fluid's rheological property is independent of both of those parameters (Rutgers 1962). On the other end, the n-value for E6 in which the environmentally friendly solvent was co-injected with propane and steam yielded the lowest n-value (0.0455 at 30°C). The produced oil from E6, hence, shows the most evident shear thinning characteristic. Based on Rutgers in 1962, a shear thinning fluid's viscosity decreases with the increased in shear rate. Thus, in terms of operational advantage, the high flowrate in pipeline (Baker 1953) will most likely help reduce the produced oil (through co-injection of MS solvent, propane, and steam) viscosity.

Apparent viscosity can be obtained through the ratio of $\sigma/\ \gamma$ (Green and Willhite 1998). In terms of viscosity reduction, E6 with the environmentally friendly solvent was able to achieve 17,838 cP. Compared to the viscosity of the initial bitumen of 290,500 cP, this large reduction in viscosity (94%) is one of the reason for the good performance in oil recovery. Since the crude became less viscous, its mobility was enhanced and it was produced easier (Prats 1982). In general, the solvent -steam processes all manage to reduce the displaced oil's viscosity more than steam or solvent-only. As described by Farouq Ali in 1965, the solvent injected decreases the interfacial tension of the crude through the miscibility process. The decrease in interfacial tension breaks the rigid structure of the oil droplet to flow better. At the same time, he also highlighted that steam process has steam distillation, dilution, and viscosity reduction through heat oil displacement mechanisms which mutually combine with the solvent's lowering of the interfacial tension and decreasing the oil viscosity more than either steam only or solvent only could. Hence, the viscosity of the oil from solvent-steam processes has lower viscosity.

Next, the produced oil quality is discussed with API gravity measured by transferring the oil to a graduated cylinder and kept in the oven overnight at 65 °C which allowed the separation of produced oil from water and solvents. Then, the mass and volume of the produced oil were recorded to obtain the specific gravity (SG) at standard conditions (15 °C and 1 atm). The data were converted to API gravity by using Eq^n 2 below and tabulated in Table B-2. Note that the initial bitumen has 9.6 °API (Table 1).

$$°API = \frac{141.5}{SG} - 131.5 \text{……………………………………………………………..………..Eq}^n\text{ 2}$$

Accordingly, E2 yielded the greatest API gravity (109.4 °API) which means that it has the lowest density. This is because C3 is a good miscible gas which is able to reduce the interfacial tension of the crude and causes the crude to swell (C. Yang & Gu, 2006). The next best performer is E6 (91.4 °API) with the environmentally friendly solvent. This positive result along with the reduced in viscosity show that the produced oil in E6 is upgraded in better quality than the initial bitumen.

The produced oil is further analysed for the recovery performances. Figure 2 shows the cumulative produced liquid for E1 to E8 obtained through core flood experiments. Produced liquid collected immediately from the separator was a mixture of produced oil, water, and solvent. The produced liquid comprised of produced oil, produced water, and solvent. From the figure, E2 (C3) and E4 (C6) which are solvent-only experiments, expectedly, have the least amount of produced liquid simply because in those experiments only solvents were injected at 2ml/min rate for about 240 minutes (Table 2). The lack of steam injection reduced the size of the injected fluid bank (solvent only) to push the oil out. Thus, the low cumulative produced liquids which are produced oil mainly were observed in both experiments. However, E8, in which toluene was injected alone, has one of the greatest cumulative produced liquid amount due to the strong solvent power of toluene (McLean and Kilpatrick 1997b, Mitchell and Speight 1973). Thus, it is able to have a high sweep efficiency which produces high volume of oil (S_{oi}). For those experiments involving steam, E6 (steam – C3 - MS) produced the greatest amount of liquid at the end of 240 minutes. Note that MS is the environmentally friendly solvent in which steam and propane were co-injected with it.

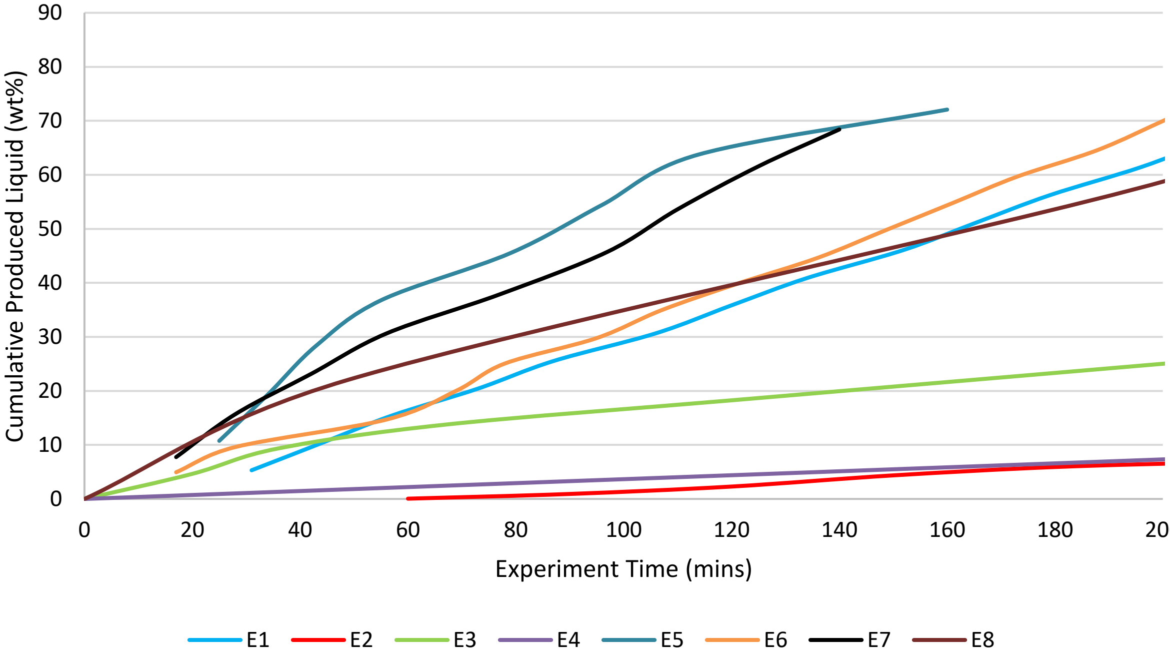


Figure 2 – Cumulative produced liquids which include steam and/or solvent and oil

In Figure 2, produced liquids are reported which also include the total produced water and/or solvents. These samples upon production were kept in the oven for 30 to 90 days to evaporate the water and solvent at 65 °C temperature. The weight loss of the water and solvent were recorded in time until no significant weight loss was observed which will, then, indicate the total weight of produced oil. Figure 3 was constructed to investigate the produced oil samples alone. Figure 3 shows the cumulative produced oil for E1 to E8.

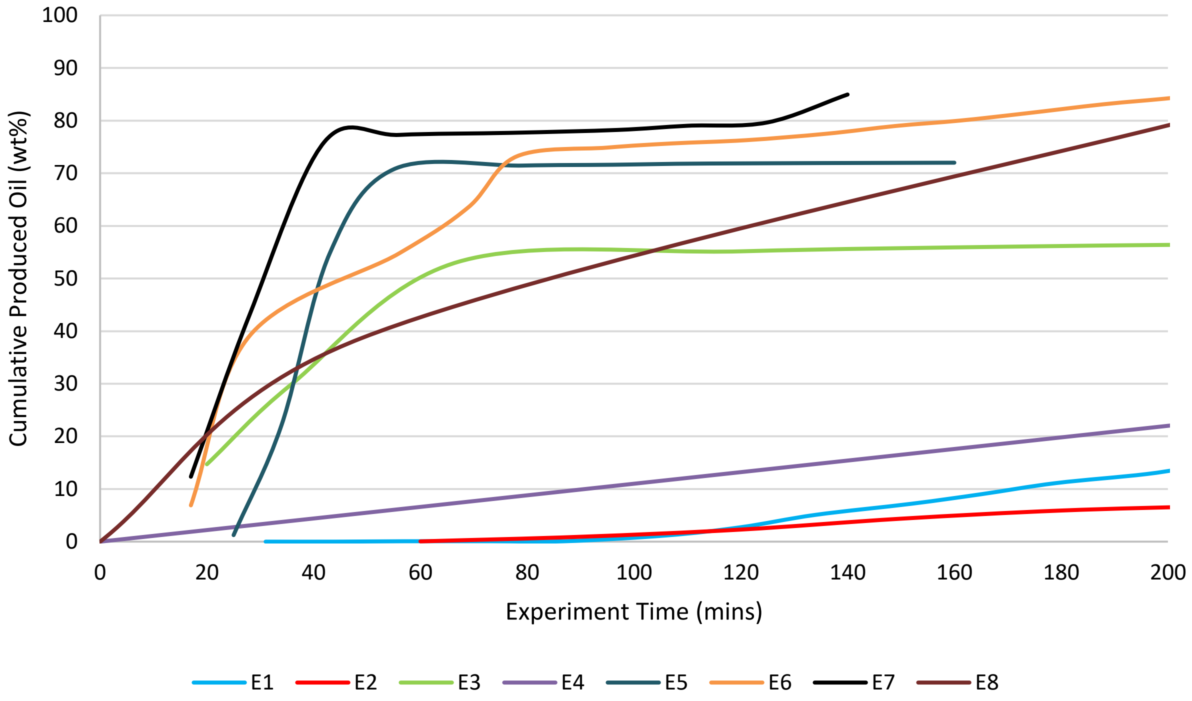


Figure 3 – Cumulative produced oil recovery from all bitumen experiments (E1 through E8)

The lowest oil recovery was obtained in E1 in which steam was injected alone. The low recoveries in E2 and E4 in which asphaltene insoluble solvents were injected only are confirmed through this figure with both having among the lowest produced oil. E2, especially, performs the worst. This is because the vapor phase of C3 gives a poor solvent front in E2 where viscous fingering occurs and not sweeping the crude efficiently (Caudle and Dyes 1958). Propane-bitumen has a larger two-phase envelope compare to n-hexane-bitumen on the Pressure-Temperature graph (McCain 1990). This means that there is a wider range of temperature and pressure conditions where liquid-vapor two phase exist for propane-bitumen. This is a disadvantage in terms of achieving miscibility which can only occur when both fluid is in single phase (either liquid or gas). Thus, n-hexane-bitumen will more likely achieve miscibility which lowers interfacial tension to produce the crude. Moreover, C3 precipitates more asphaltenes than C6 (Fuhr et al. 1991, Mullins 2008), hence, C3 leaves behind more hydrocarbons which reduces the overall recovery. Similar impact is observed when steam is co-injected with the same solvents. Hence, E5 (steam – n-hexane) recovered more oil than E3 (steam – propane).

Among all flooding experiments, E6 in which the MS environmentally friendly solvent was co-injected with propane and steam resulted in the greatest oil recovery (88 wt%). The oil recovery was also greater than E8 in which toluene, a strong crude solvent, was injected. All solvent-steam results confirm that the co-injection of steam with solvent increases oil production due to the combined oil displacement mechanisms from steam such as steam distillation and from solvent such as reduction in interfacial tension (Farouq 1965, Mohammadzadeh et al. 2010, Mukhametshina and Hascakir 2014, Mukhametshina et al. 2016, Mukhametshina et al. 2014).

Based on Figure 2, the greatest production is obtained with E5 in which steam and n-hexane were co-injected together at around 160 minutes compared to other experiments at the same time. However, this experiment carried more water and/or solvent than E6 as shown in Figure 3 where E6 produced greater amount of oil than E5. Undoubtedly, the solvent-steam experiments (E5, E6, E7) have greater amount of water and/or solvent produced than steam only or solvent only experiments. From a positive standpoint, this means that the injected steam which later condensed into liquid water and the injected solvent could be retrieved and reinjected. Hence, not only does solvent-steam processes increase oil recovery, they could also improve the project’s economic by reducing the amount of water and solvent needed to be purchased for each injection cycle (Boyer et al. 1983, McCants 1992). Nevertheless, it could also be a concern in terms of the produced oil quality. Great amount of water and/or solvent would possibly lead to severe emulsion formation in the produced oil which requires extensive and costly surface processing to remove the emulsion.

Thus, the quality of the produced oil is investigated later in the chapter to determine if the produced water and/solvent will be an advantage.

Next, the mass balance for the flooding experiments is as tabulated in Table 3. The mass in includes oil (S_{oi}) and water (S_{wi}) which were initially packed during the core sample preparation and the injected steam (18 ml/min) and liquid solvent (2 ml/min). The mass out includes the amount of produced oil (Figure 3) and the amount of produced and vented water/solvent. Produced water/solvent were determined by keeping the produced liquids in the oven at 65 °C and the weight recorded until no significant weight changes were observed (complete water/solvent evaporation). The vented water/solvent is the amount of vapor that did not condense into liquid and separated by venting during production. Besides that, the oil in spent rock (S_{or}) and the water in spent rock (S_{wr}) were determined through TGA/DSC analysis (Kar 2015, 2017, Kar and Hascakir 2015).

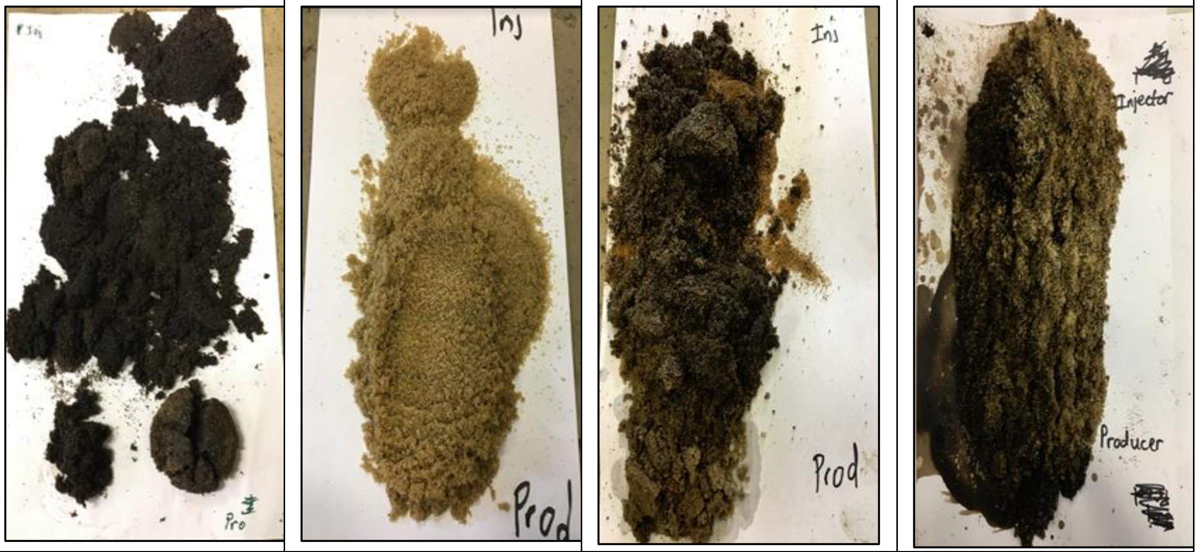
Table 3 – Mass balance between packed and injected liquid, and produced, vented and residual liquid

Exp	Mass In (g)				Mass Out (g)				
	S_{oi}	S_{wi}	Injected Steam	Injected Solvent	Produced Oil	Solvent + Water		S_{or}	S_{wr}
						Produced	Vented		
E1	127.7	22.5	4320	NA	68.0	3407.3	933.8	59.7	1.4
E2	128.0	24.4	NA	NA	37.8	NA	23.4	90.2	1.0
E3	128.3	24.4	4032	NA	103.8	1404.6	2649.8	24.5	2.0
E4	128.3	24.5	NA	480	52.7	21.7	481.1	75.6	1.7
E5	128.7	24.5	2880	320	112.6	1661.2	1559.2	16.1	4.1
E6	127.6	24.5	4212	468	121.0	4011.1	690.3	6.6	3.1
E7	126.4	24.3	2520	280	91.5	1910.9	910.0	34.9	3.4
E8	126.7	24.2	NA	480	101.5	365.8	135.5	25.2	2.9

S_{oi} : Initial oil saturation packed into core; S_{wi} : Initial water saturation packed into core; S_{or} : Residual oil saturation in spent rock; S_{wr} : Residual water saturation in spent rock; NA : Not applicable

At the end of each experiment, first visual inspection was done on the spent rock samples (Figure 4). In these pictures, the injection point for the steam/solvent is at the top while the production point is the bottom.

E1	E2	E3	E4
(A) Steam	(B) Propane	(C) Steam + Propane	(D) n-Hexane



E5	E6	E7	E8
(E) Steam + n-Hexane	(F) Steam + n-Hexane + MS environmentally friendly solvent	(G) Steam + Propane + Benzoyl Peroxide	(H) Toluene

Figure 4 – Post-mortem pictures of spent rock samples obtained at the end of each experiment

The consolidation of the spent rock observed in Figure 4-A might be due to asphaltenes which precipitated and acts as cementing material to bind the sand grains together. Hence, both residual oil and their asphaltene contents were measured and reported in Table 4. TGA/DSC (Figure A-29 through A-58) was used to determine the residual oil (Kar 2015, 2017, Kar and Hascakir 2015). During air injection from room temperature to 900 °C at a rate of 50 ml/min, DSC curves were generated and observed for endothermic (evaporation) and exothermic (combustion of oil) peaks which corresponded to a weight loss in the TGA curves. These weight losses belong to water, solvent, and oil which gave the weight percentage of each component within the spent rock. At the same time, the spent rock was analyzed by washing with, first, n-pentane to determine the asphaltene content (ASTM 2011).

Table 4 – Initial oil and asphaltene, and residual oil and asphaltene content in spent rock for bitumen samples

	Oil in 100g initial oil+water+sand pack (g)	Volume of initial oil (vol%)	Initial asphaltene (g)	Initial asphaltene (wt%)
Initial oil-sand mixture	17.3	84.00	24.4	24.4
Experiments	Residual oil in 100g spent rock (g)	Volume of residual oil (vol%)	Asphaltenes in residual oil (g)	Asphaltenes in residual oil (wt%)
E1	10.4	50.50	2.76	26.57
E2	12.2	59.24	2.32	19.04
E3	3.3	16.02	0.93	28.1
E4	6.8	33.02	1.42	20.92
E5	2.7	13.11	0.63	23.42
E6	0.2	0.97	0.06	27.74
E7	0.3	1.46	0.07	23.79
E8	1.4	6.80	0.42	30.2

Residual oil and their asphaltene contents are reported and compared to the initial oil and asphaltene content from the oil-sand mixture in Table 4. The weight loss data obtained from the TGA curve is in weight percent (wt%) which was converted into volume percent (vol%). Since the initial oil-sand mixture has 17.3 g of initial oil which corresponds to 84 vol%, the weight percent (wt%) of residual oil from each experiment's spent rock was, hence, normalized to 17.3 g based on the initial oil-sand mixture to obtain the corresponding volume percent (vol%).

Accordingly, E1 has the greatest amount of asphaltene (in gram) in the residual oil left on the spent rock. This explains the dark color and consolidation of the spent rock for E1. Besides the asphaltene amount, E1 also has the second greatest residual oil amount (50.50 vol%) which contributed to the consolidation of the spent rock and its dark color. Meanwhile, E2 has lower asphaltene deposited than E1 but it has the highest residual oil (59.24 vol%). The dark color in the post mortem indicates that not only asphaltenes but also the resins are on the spent rock. Hence, the asphaltene-resins mutual interaction prevented the asphaltene agglomerations which indirectly favors the existence of open oil pathways within the spent rock. However, the presence of steam increases the asphaltene precipitation for E3 (28.1 wt%). Since the residual oil decreased significantly for E3 (16.02 vol%), the precipitated asphaltene did not cause cementation (Figure 4).

Other than that, E6 has the least amount of asphaltenes in the residual oil which explains the light and clear color of the spent rock which is similar to the initial Ottawa Sand color. As indicated earlier, all the solvents tested were asphaltene insoluble solvents except for toluene. In other words, asphaltene would most likely precipitate when contacted with these solvents except for toluene. BP, MS, C6, and C3, consequently, observed higher asphaltene content in the residual oil on the spent rock. It shall be noted that only MS solvent in E6 precipitates very little asphaltene. C3 precipitated the highest amount of asphaltene. This is because C3 is a paraffinic solvent with straight chain n-alkane molecules. This chemical characteristic causes C3 to have very low asphaltene solubility power (higher carbon number, higher asphaltene solubility power). Consequently, more asphaltene destabilized and induced higher asphaltene precipitation on the spent rock (Andersen and Speight 1992, Mullins 2008).

Then, the residual oil (vol%) reported in Table 4 was used to construct Figure 5 and Eq^n 3 was used for the calculation. Sweep efficiencies were determined for the samples collected from both the injection and production points of spent rock samples. The sweep efficiency is calculated based on the equation as shown below with S_{oi} being the initial oil saturation and S_{or} being the residual oil saturation:

$$Sweep\ efficiency, vol\% = \frac{S_{oi}-S_{or}}{S_{oi}} \text{...Eq}^n\ 3$$

The calculated sweep efficiencies are summarized in Figure 5.

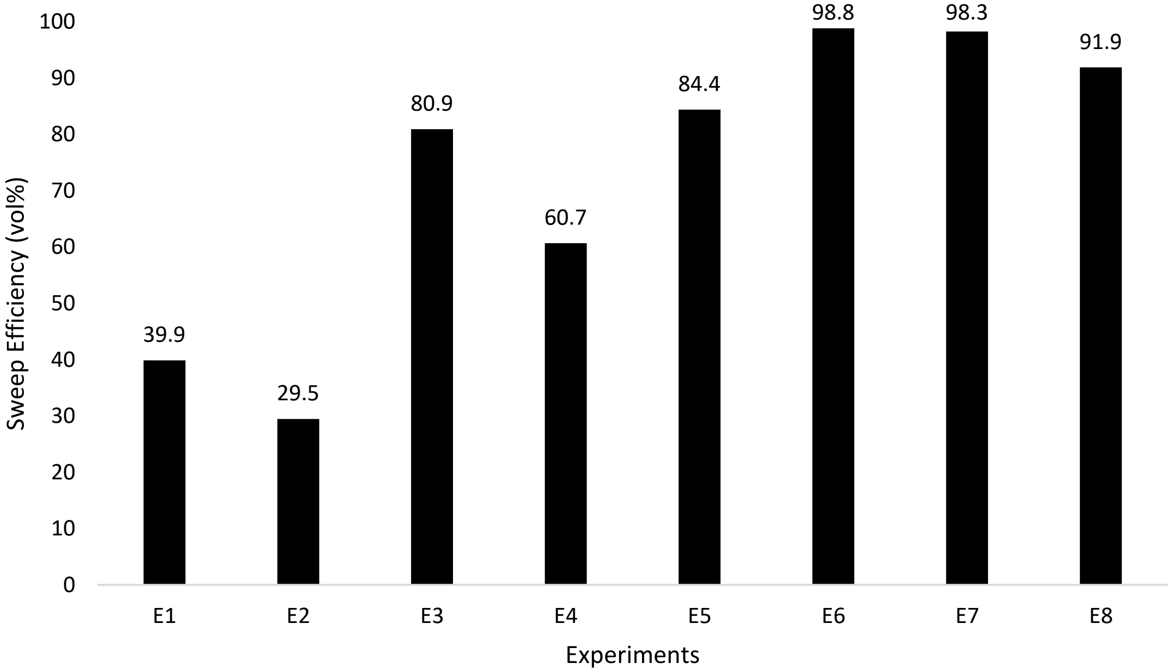


Figure 5 – Sweep efficiencies of the spent rock from the bitumen core flooding experiments

The sweep efficiency values match the trend observed for the cumulative produced oil trend (Figure 3). E6 which contains the MS environmentally friendly solvent is proven to have the greatest sweep efficiency. Besides that, all the solvent-steam experiments have greater sweep efficiencies than either steam-only (E1) or solvent-only (E2 and E4) experiments. The sweep efficiencies are reflected through the degree of consolidation of the spent rock as well. Since E6 has the greatest sweep efficiency, most of the oil along with the asphaltenes had been displaced, leaving behind an unconsolidated spent rock which appears the cleanest among all. Corresponding low amount of asphaltenes caused the sand grains to be not cemented and became loose thus not retaining the shape of the cylindrical core holder. Only E1 which was injected with steam only retained the shape of the cylindrical core. This is due to its high asphaltene deposition (2.76 g) which binds the sand grains together (Table 4). The solvent-steam related experiments which had high sweep efficiencies, in general, had low asphaltene contents.

The oil recovery performance of the MS environmentally friendly solvent is encouraging. Its result is better than toluene's which is a very strong but toxic solvent (Kelland 2014, Morrow et al. 2014, Mukhametshina and Hascakir 2014). BP which has a peroxide functional group is equally toxic since it is carcinogenic when exposed for a long period of time (Kurokawa et al. 1990). The paraffinic solvents such as C3 and C6 which are widely used in the industry prove to be harmful to the human nervous system at high concentration and when exposed for a long period of time as well (Ferguson 1939). In the light of these health and environmental concerns, MS could be a suitable alternative to replace these solvents. Furthermore, the solvent price which had been an issue since it was first highlighted by Farouq Ali in 1976 can be mitigated with the usage of the MS solvent (Figure D-1) because its manufacturing ingredient which largely comprise of corn is economical since corn is abundant in the United States and its production is supported by the government (Edwards 2018, Serra et al. 2011).

With the advantages seen in the oil recovery through the co-injection of solvent and steam especially with the MS solvent, it is equally important to analyse the produced oil quality in terms of emulsion severity. This is because produced oil with severe emulsion will require expensive and time-consuming surface processing (Martínez-Palou et al. 2013).

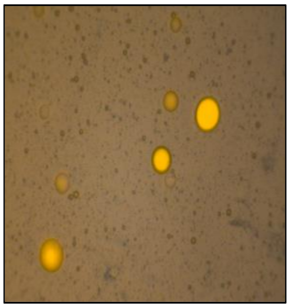
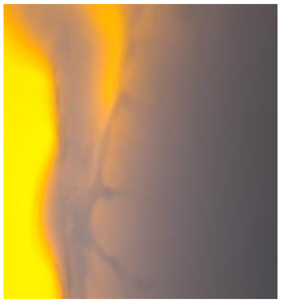
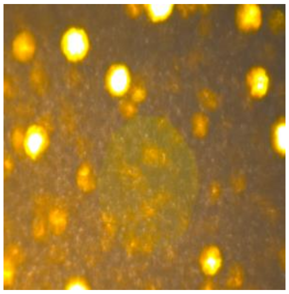
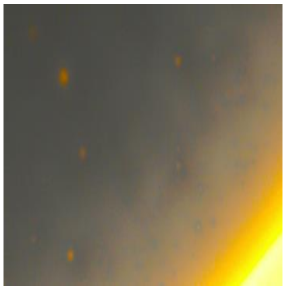
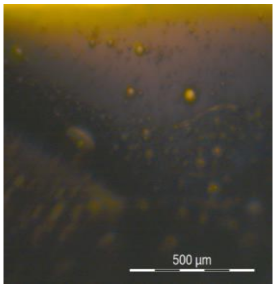
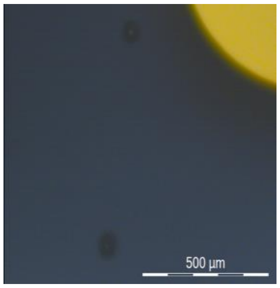
			
E1	E2	E3	E4
(A) Steam	(B) Propane	(C) Steam + Propane	(D) n-Hexane
			
E5	E6	E7	E8
(E) Steam + n-Hexane	(F) Steam + Propane + MS environmental friendly solvent	(G) Steam + Propane + Benzoyl Peroxide	(H) Toluene

Figure 6 – Microscopic images of produced oil (40X magnification)

Figure 6 shows the microscopic images of the produced oil for all experiments. A droplet of the produced oil was immediately dripped after it was produced onto the microscopic slide and observed under 40X magnification for the emulsion formed. Emulsions in E3 and E5 are severe. E3 has small droplets of emulsions. The small sizes of the emulsions were stable, hence, will be difficult to coalesce to be removed. E5 has triple emulsion (oil-in-water-in-oil) and they exist in various sizes which will be difficult to breakdown and remove. For the solvent-only experiments (E2, E4, E8), non-severe to no emulsion were observed as expected since water injection was not involved in these experiments. Promisingly, E6 which has the MS environmentally friendly solvent has non-severe emulsion as well.

After microscopy analysis, produced oil samples were subjected to TGA/DSC to determine water content shown. TGA/DSC results are shown in the appendix (Figure A-1 through A-28) and ASTM D2007-11 was used to determine the asphaltene content of oil samples (ASTM 2011). Table 5 summarizes the water, solvent, and n-C5 insoluble asphaltenes content in produced oil for E1 to E8.

Table 5 – Water, solvent and n-C5 insoluble asphaltene content of produced oil samples from E1 through E8

Experiments	Water and/or Solvent (wt%)	n-C5 insoluble asphaltene content (wt%)
E1	3	41.1
E2	0	36.9
E3	12	80.4
E4	2	66.9
E5	9	81.4
E6	1	98.6
E7	0	97.6
E8	7	90.7

The severity of the emulsion observed in Figure 6 corresponds to the water and/or solvent content in the produced oil. E2, E4, and E8 have only initial water content which resulted in non-severe to no emulsion in the produced oil. Since E3 and E5 have the greatest water and/or solvent content, they lead to severe emulsion in the produced oil as seen in Figure 6. E6 in which MS was co-injected with propane and steam has very little water and/or solvent and consequently has non-severe emulsion. Earlier in the literature, asphaltene is known as the most polar crude fraction, hence, its predicted interaction with polar liquid water to form emulsion (Kilpatrick 2012, Punase and Hascakir 2016b, Punase et al. 2016, Xia et al. 2004, Yarranton et al. 2000). However, asphaltene content shown in Table 5 indicates no distinctive correlation between asphaltene content and the emulsion severity (emulsion amount, droplet size and dispersion) observed in Figure 6. For example, E6 has the greatest amount of asphaltene in the produced oil (98.6 wt%)

but the water amount in oil is almost zero. At the same time, E3 and E5 which have lower amount of asphaltene in the produced oil both showed greater amount of water than in E6. This means that asphaltene content is not directly correlated to the emulsion severity in produced oil. However, it should be noted that asphaltenes are not the only fraction of crude oil with polarity. Resins also are reported as polar and the other crude fractions may also have polar functional groups in their structures (Kar and Hascakir 2015, Prakoso et al. 2016). The main causes of emulsion is discussed later with control experiments' results.

III.2 Asphaltene and Emulsion Relationship

In this section, the relationship between asphaltene and emulsion will be discussed. An asphaltene molecule consists of complex aliphatic hydrocarbon molecules with aromatic rings as well as having naphthenic rings with heteroatoms such as sulfur, nitrogen, oxygen, and metals (Creek et al. 2009, Prakoso et al. 2016, Thomas et al. 1995). There are very limited studies on asphaltene molecular structure due to its complexity (Schuler et al. 2015).

Asphaltene is one of the heaviest fraction of the crude oil and it has the greatest polarity. However, it is known that due to its high polarity, a polar-polar interaction between asphaltene and liquid water is predicted to form and stabilize the emulsion (Auflem 2002, Czarnecki et al. 2012, Spiecker et al. 2003). To predict the emulsion formation better, the role of asphaltene fraction is investigated previously (McLean and Kilpatrick 1997a, Xia et al. 2004). The microscopic images of the produced oil in Section 3.1 (Figure 6) show non-severe to severe emulsion formation for different solvents that were tested. However, no direct relationship between the amount of asphaltene and water in produced oil was observed.

Hence, we normalize the asphaltenes for 100g of asphaltene in the produced oil from the total between the produced oil asphaltene and the asphaltene deposited on the spent rock. Figure 7 shows the asphaltene distribution between those deposited on the spent rock and those found in the produced oil for E1 to E8 which had been normalized to represent the 100% distribution of asphaltene from the initial bitumen. Normalized values were presented instead of actual weight (gram) because easier and direct comparison can be made between experiments.

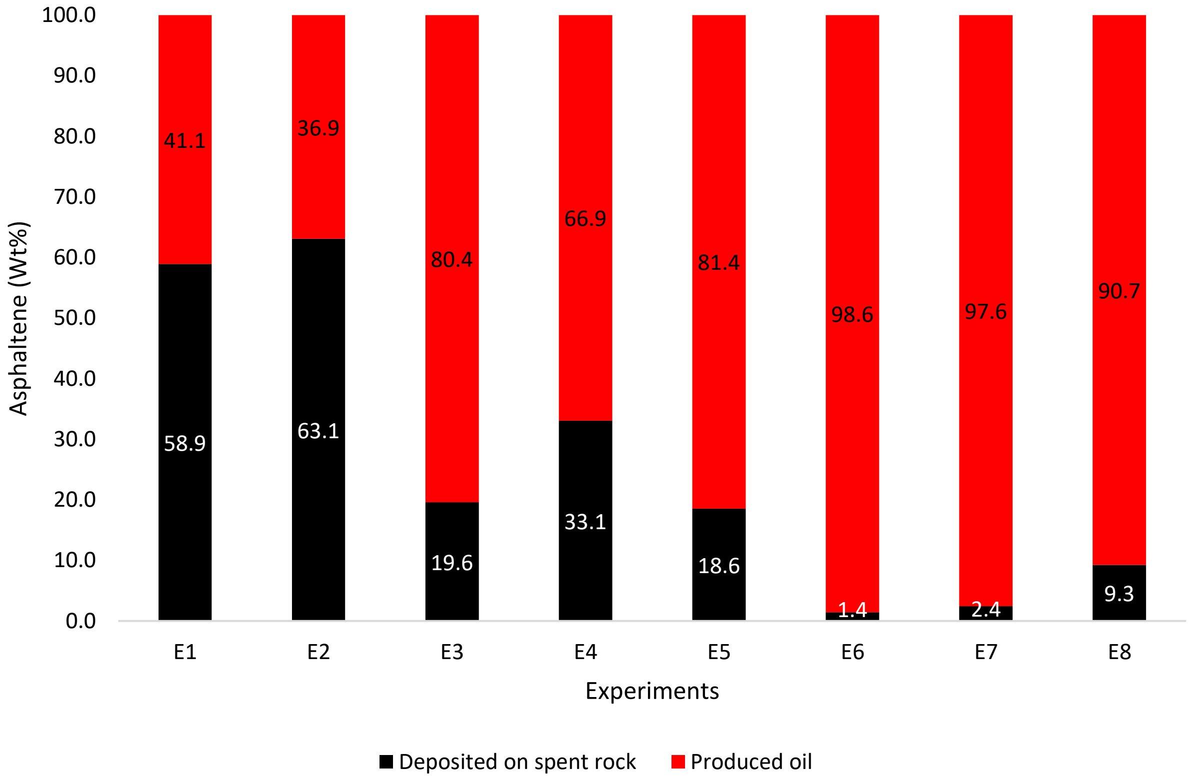


Figure 7 – Normalized asphaltene amount in produced oil and deposited on spent rock based on initial asphaltene present in bitumen

E6 (steam – C3 – MS) has the least amount of asphaltene deposited on the spent rock and in turn, has the highest asphaltene content in the produced oil. This is due to the longer carbon chain which results in very little asphaltene deposition on the spent rock (Yang and Kilpatrick 2005).

Saturated solvents (C3 and C6) have increasing asphaltene solubility power as the carbon number increases (Fuhr et al. 1991, Mullins 2008). For example, heptane (C7) will have a higher asphaltene solubility power than butane (C4) since C7's carbon number is greater than C4's. From this figure, E2 (C3) deposits more asphaltene with 63.1 wt% on the spent rock compared to E4 (C6) with 33.1 wt%. This result agrees with the solubility nature of alkane solvents. To further proof the accuracy of this data set, similar observation is made for the solvent -steam cases. E3 (steam -C3) has 19.6 wt% asphaltene deposited on the spent rock while E5 (steam – C6) has 18.6 wt% asphaltene deposited on the spent rock. This result confirms the accuracy and reliability of the ASTM method to separate n-alkane insoluble asphaltenes.

E7 has the second greatest asphaltene content. As reported in Table 2, E7 was also terminated earlier due to pressure increase caused by plug occurring in the production pipeline. It was suspected that asphaltene deposition caused it. However, the control experiment conducted on BP and bitumen asphaltene under microscope revealed that BP forms some crystalline structure and bind more the asphaltene clusters which helps to form bigger chunks of asphaltenes (Figure 8). If this happens in the reservoir in the field scale, it may caused pore plugging and reduction in permeability significantly.

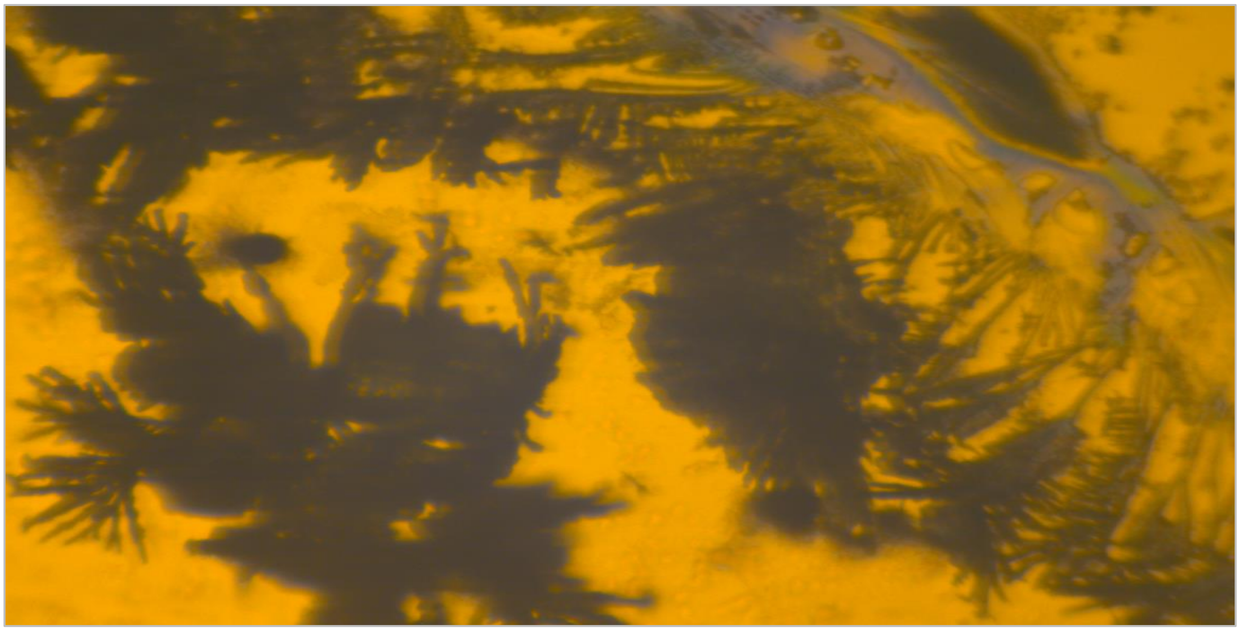


Figure 8 – Control experiment to understand BP interaction with n-C5 insoluble asphaltenes

In general, the experiments show that the co-injection of solvent and steam reduces the deposition of asphaltene on the spent rock. In other words, a solvent-steam process will produce more asphaltene in the produced oil. Thus, according to Mullins and colleagues in 2008, the produced oil with high asphaltene contents should have correspondingly severe emulsion. However, no direct correlation between asphaltene content in produced oil and the severity of the emulsion formed could be established. To investigate this, control experiments were conducted to understand the potential emulsion contribution by the other crude fractions.

III.3 Explanation on Emulsion Formation Mechanism Through Control Experiments

In all steam experiments, emulsification is observed once the steam temperature (100 °C) is reached within the core as shown in the appendix (Figure C-1 through C-5). To better understand the emulsification mechanism, control experiments were conducted on crude oil and their fractions. Crude oil and its SARA fractions were exposed to liquid and vapor water. Microscopic images were taken before and after the interaction (Figure 9).

Prakoso and friends in 2015 conducted research on identifying the polarity of the crude fractions using zeta potential and dielectric measurements. From their research aromatics which was widely expected to be non-polar actually showed slight polarity which could be due to impurities such as metals and heteroatoms (Prakoso et al. 2016). At the same time, they also proved that the saturates fraction has slightly polar functional groups in their molecular structure while asphaltene has the highest polarity followed by the resin fractions. With these findings, the control experiments were conducted.

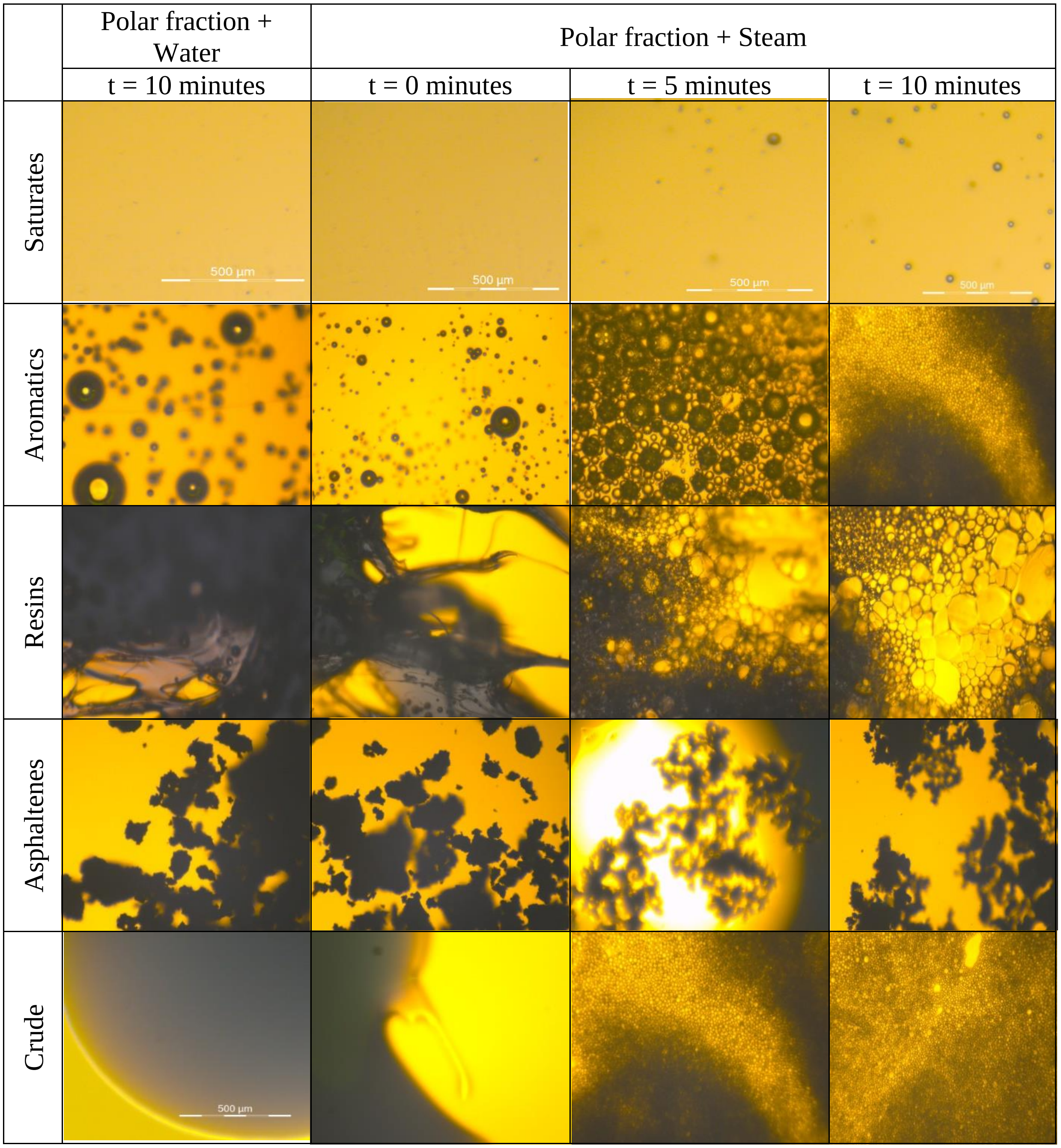


Figure 9 – Microscopic images for crude fraction interaction with water and steam (40X magnification) (use the scale for every image given in the saturates image)

Figure 9 shows that the saturates fraction is non-polar since no reaction occurred when saturates were reacted with liquid water after 10 minutes. This means that the slight polar functional group discovered by Prakoso and friends in 2015 were insufficient to give an overall polarity to the saturates fraction. For the reaction with steam, non-severe emulsion formed. However, for the aromatics fraction, it behaved slightly polar as claimed by Prakoso and friends since some of the emulsion got larger after being exposed to liquid water after 10 minutes. This might indicate the presence of a polar-polar interaction between the aromatics fraction and liquid water. Other than that, severe emulsion is clearly seen when all the fractions including the crude is exposed to steam. The resins fraction also produces severe emulsion with large bubbles while the asphaltene, surprisingly, does not show any distinctive water bubbles. Instead, the asphaltene seems to aggregate and form clusters. Finally, the crude has severe emulsion and it is important to note that the emulsion appears to be foamy. Similar foamy emulsions is not seen when the crude is exposed to liquid water. This result might indicate that the emulsion formed at the steam stage exist as foam before condensing at a lower temperature to form stable water-in-oil emulsions.

It is obvious from Figure 9 that aromatics and resins have critical role on emulsion formation, hence the mutual interaction of the fractions with asphaltenes was further investigated under the microscope and this interaction is reported in Figure 10 below.

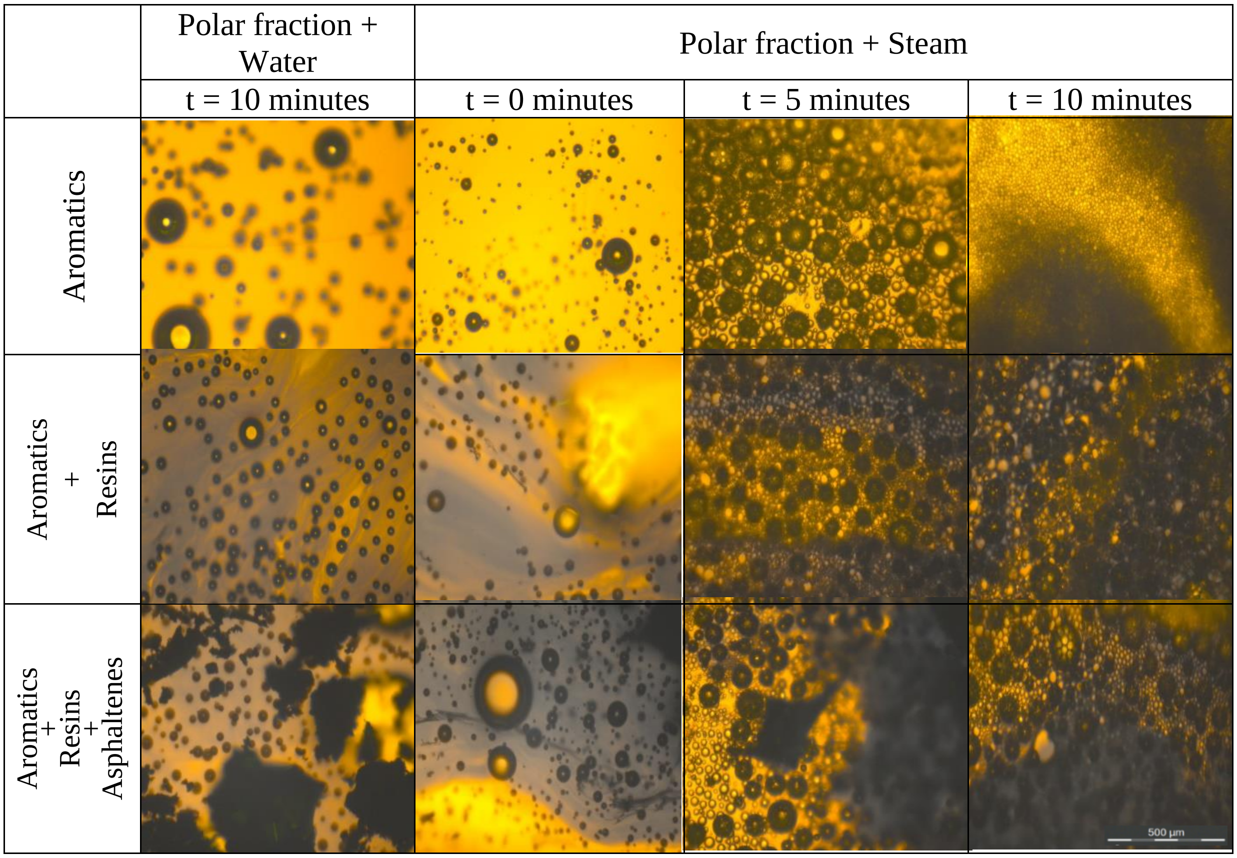


Figure 10 – Microscopic images for aromatic, resin and asphaltene interaction with water and steam (40X magnification) (use the scale for every image given in the aromatics + resins + asphaltenes reaction with steam after 10 minutes image)

Figure 10 shows that the addition of resins onto aromatics forms a more complex and severe emulsion. Their mutual interaction forms smaller and more number of emulsions compare to just aromatics alone. However, when asphaltene is added to the asphaltene – resin combination, the emulsion seems to be more dispersed with more triple emulsions. This could indicate that the mutual interaction between the aromatics and resin fractions induces severe emulsion before being stabilized by the asphaltenes. This finding shows that asphaltene is not the main fraction which was widely blamed for inducing emulsion but rather, it stabilizes the already formed emulsions from the mutual interaction between resins and aromatics. This will explain the earlier results where higher asphaltene content in produced oil does not necessarily cause more emulsion since asphaltene does not form the emulsion in the first place.

III.4 Explanation on Emulsion Formation Mechanism Through Bottle Test

A separate set of bottle test were conducted as control experiments to further investigate the findings from the flooding experiments and microscopic slide control experiments. Specifically, these bottle tests were conducted to understand if the continuous phase is water or oil in emulsion. Table 6 shows the composition for each of the bottle test and the specific ratio while Figure 11 shows the bottle test with the temperature ranges and composition.

Five test tubes were filled with bitumen in which four of them were added with water and MS solvent, water and benzoyl peroxide solvent (0.25g Bp + 1ml DCM + 5 ml C6), water and toluene, and water and n-hexane respectively in fixed ratios as shown in Table 6. Then, the test tubes were shaken in a 72 °F water bath in a 5 minutes interval for 15 minutes to generate the emulsion (if any). Microscopic images of each distinctive liquid layers in the test tubes were taken immediately to observe for emulsion. This set of five test tubes were replicated for 158 °F and 210 °F to simulate hot water and steam condition respectively. For these two temperatures, additional microscopic images were taken after 30 minutes to allow sufficient cooling of the liquid to observe for stabilized emulsion. The test tubes are as shown in Figure 11.

Table 6 – Mixture composition and ratios for bottle test

Content	Description	Ratio (ml:ml)
OW	Oil + Water	3:7
OW + MS	Oil + Water + Ethicalchem MS	3:5:2
OW + BP	Oil + Water + Benzoyl Peroxide (0.25g BP + 1ml DCM + 5ml C6)	3:5:2
OW + Tol	Oil + Water + Toluene	3:5:2
OW + C6	Oil + Water + n-Hexane	3:5:2

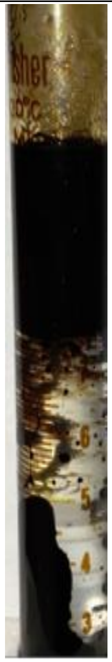
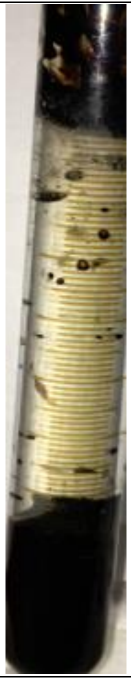
Bottle 1	Bottle 2	Bottle 3	Bottle 4	Bottle 5	Bottle 6	Bottle 7	Bottle 8
72 °F	72 °F	72 °F	72 °F	72 °F	158 °F	158 °F	158 °F
OW+MS	OW+BP	OW+Tol	OW+C6	OW	OW+MS	OW+BP	OW+Tol
							
Bottle 9	Bottle 10	Bottle 11	Bottle 12	Bottle 13	Bottle 14	Bottle 15	
158 °F	158 °F	210 °F	210 °F	210 °F	210 °F	210 °F	
OW+C6	OW	OW+MS	OW+BP	OW+Tol	OW+C6	OW	
							

Figure 11 – Test tubes to observe for emulsion formation at 72 °F, 158 °F, and 210 °F with different solvents

For the first set of experiments conducted at room temperature 72°F, the test tube with the mixture ratio as shown in Table 6 were shaken within a 5 minute interval for 15 minutes and the emulsion formed was observed under the microscope as seen in Figure 12.

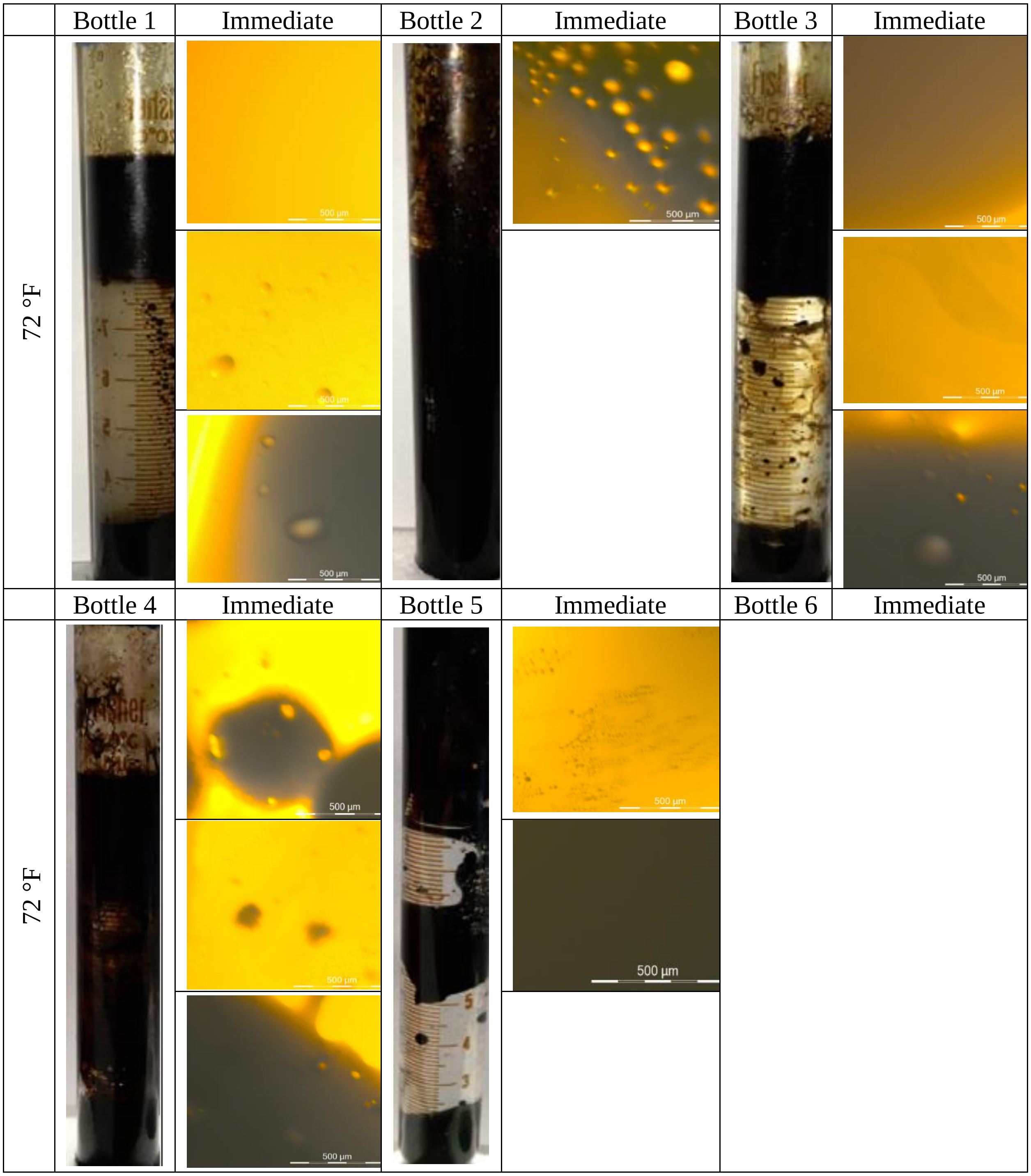


Figure 12 - Bottle test at 72°F (40X magnification microscopic images)

The number of microscopic images represents the number of distinctive layers formed after shaking in the test tubes while the location of the microscopic images represent the sequence of the layer. Severe emulsion is observed in bottle 2 which consisted of BP and in bottle 4 which consisted of C6. Based on the proposed emulsion formation mechanism, there shouldn't be any severe emulsion forming at room temperature since most of the emulsion formation occurs at steam temperature. However, BP and C6 show that severe emulsion could formed even at room temperature depending on the solvent used. In bottle 2, a single homogenous mixture was obtained after shaking and the emulsion observed appears to be water-in-oil where oil is the continuous phase. On the other hand, there were three layers formed in bottle 4. In the top and bottom layers, water bubbles appear to exist within a continuous oil phase which means that the emulsion formed is water-in-oil emulsion. The other bottle tests behave accordingly with very little to no emulsion forming.

Figure 13 shows the bottle test experiment conducted at 158 °F to simulate hot water temperature. Similar procedures were done as with the room temperature test. For this hot water test, additional microscopic images were taken after 30 minutes to ensure the mixture had cooled down.

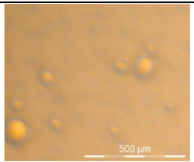
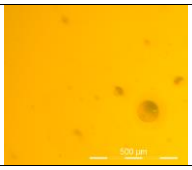
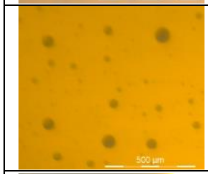
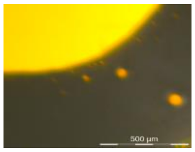
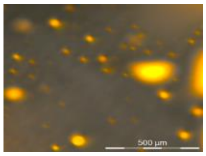
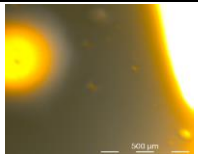
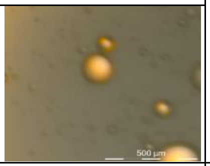
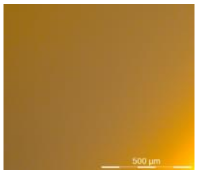
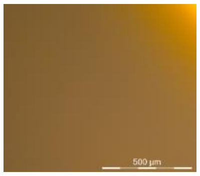
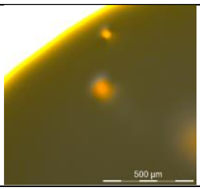
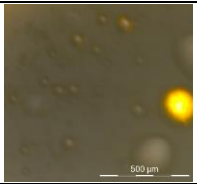
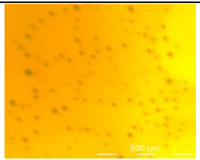
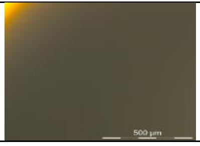
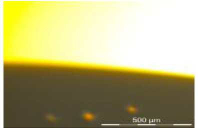
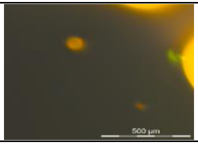
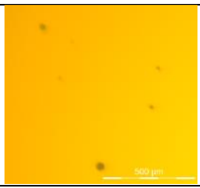
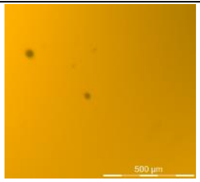
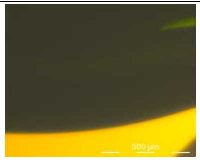
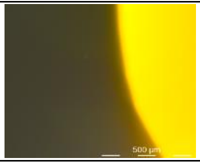
	Bottle 6	Immediate	After 30 Minutes	Bottle 7	Immediate	After 30 Minutes
158 °F						
						
						
	Bottle 8	Immediate	After 30 Minutes	Bottle 9	Immediate	After 30 Minutes
158 °F						
						
						
	Bottle 10	Immediate	After 30 Minutes			
158 °F						
						

Figure 13 – Bottle test at 158°F (40X magnification microscopic images)

In general, the emulsion formed were more severe compared to those formed at room temperature. This observation supports the earlier finding where an increase in temperature will lead to more severe emulsion. The immediate images were taken at 158 °F and show that all the bottles had emulsions. However, once they cooled to room temperature, the ‘After 30 Minutes’ images showed reduction in emulsion severity except for bottle 7 (BP) and bottle 9 (C6). Both BP and C6 once again had the most severe emulsion which remained stable and severe even after cooling. This characteristic agrees with the initial room temperature test where both of these solvents produced severe emulsion. Both bottle 7 and 9 also produced water-in-oil emulsions. Bottle 6 which has the MS solvent initially has emulsion which disappeared after cooling. This means that the emulsion formed is not stable and would be easy to remove.

Figure 14 shows the bottle test conducted at 210 °F to simulate steam temperature. The microscopic images show more severe emulsion than those at 72 °F and 158°F. Throughout the previous two temperature stages, there were minor emulsion observed for the MS solvent (bottle 1 and 6). However, at steam temperature, almost no emulsion is observed which proves that MS is a capable solvent with low emulsion formation at steam temperature. At the same time, bottle 15 (BP) and bottle 17 (C6) still have the most severe emulsion. All the emulsions observed were water-in-oil emulsions.

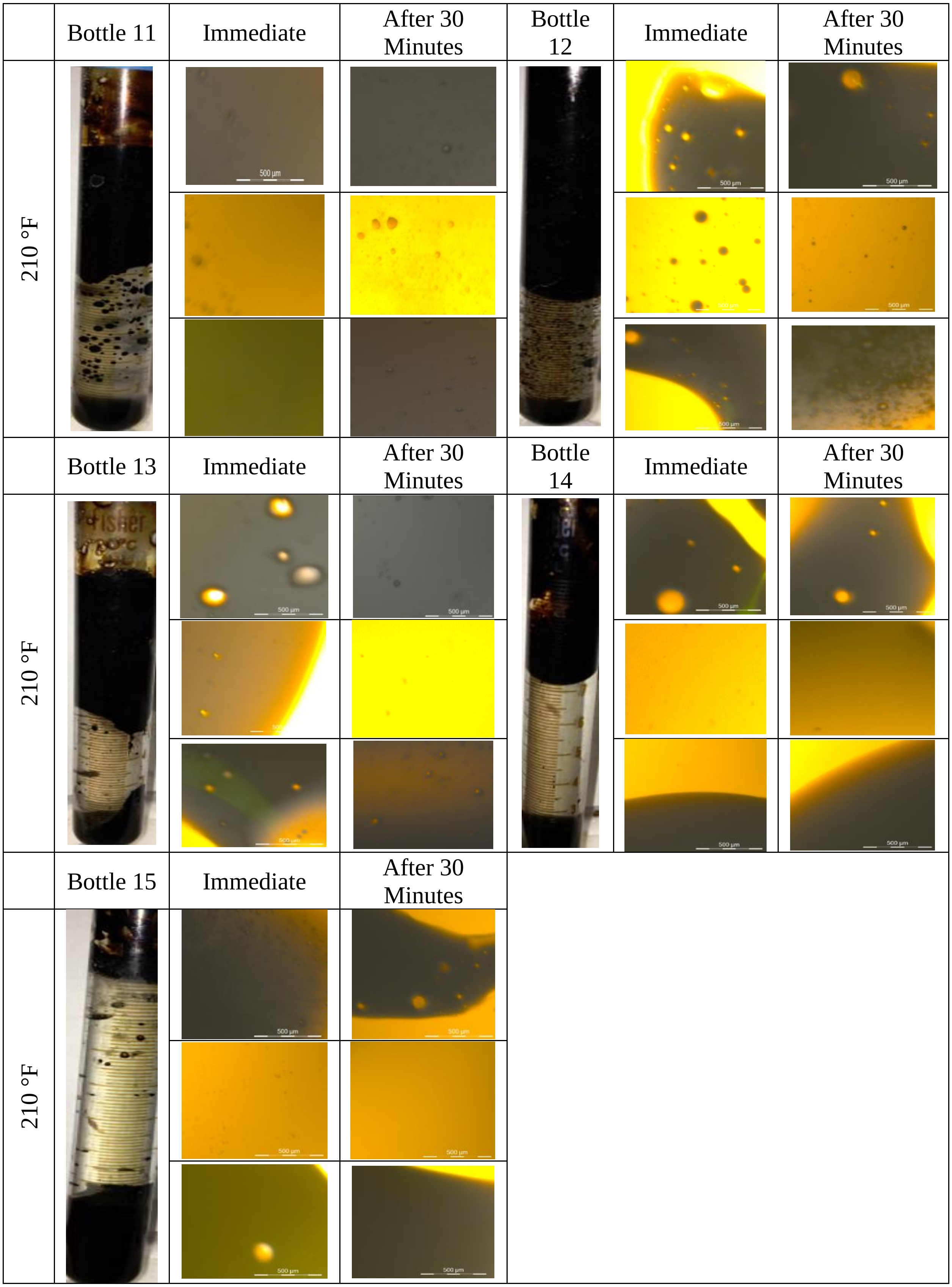


Figure 14 - Bottle test at 210°F (40X magnification microscopic images)

CHAPTER IV

CONCLUSIONS

Core flood experimental investigation were conducted on Canadian bitumen sample (E1 to E8). The purpose is to compare the steam, solvent, and solvent-steam performances in terms of oil recovery, water production, and emulsion severity in the produced oil. An environmentally friendly solvent, MS, and a solid phase solvent, BP, were also investigated. From the investigations, they show that a solvent-steam process will increase oil recovery as compared to either steam-only or solvent-only processes excluding toluene. The combined oil displacement mechanisms in a solvent-steam process is able to increase oil production. Among the solvent-steam processes, the MS solvent had the best oil recovery performance which indicates its suitability to replace current toxic solvents such as alkanes and aromatics solvents. Meanwhile, BP is not recommended for flooding application since BP precipitates and interact with the produced oil, especially with the asphaltenes, to form complex crystalline structure which plugged the pipelines.

High asphaltene content in spent rock caused the spent rock to be consolidated since it acts as cementing material which binds the sand grains together. Besides that, the high asphaltene content also contributed to the darker color of the spent rock. On the other hand, the high asphaltene content in the produced oil did not correspond with severe emulsion. Instead, emulsion formation was proposed to be caused by the deasphalted oil (oil with no asphaltene) rather than by the asphaltenes itself. This non-conforming asphaltene-emulsion relationship was observed under microscopic images conducted on saturates, aromatics, resins, asphaltenes, and crude control experiments. Severe emulsion formation was observed when the aromatics fraction was exposed to steam and similar observation was also made when the resins fraction was exposed to steam. Meanwhile, no distinctive emulsions existed when asphaltenes was exposed to steam. In the same control experiment, it was found that aromatics might be slightly polar based on the enlarged emulsion when aromatics was reacted with liquid water. This finding supports previous research findings where aromatics were deemed slightly polar through zeta potential and dielectric measurements. The third conclusion from the control experiments is that emulsion formation intensifies during the steam temperature stage and forms foamy bubbles. As temperature decrease, these foamy bubbles will condense and stabilize into water droplets.

Next, bottle test experiments proved that the MS solvent does not generate severe emulsion especially at steam temperature. The emulsion was also unstable and, hence disappear after being cooled. Besides that, the C6 and BP solvents produced severe emulsion throughout the three temperature ranges which signify the unsuitability of these solvents to be used in thermal recovery processes. The emulsions formed were observed to be water-in-oil emulsion. Based on the findings, a better understanding of the emulsification process was achieved and this will allow better design of emulsion treatment and inhibition processes. Instead of targeting asphaltenes, perhaps, more focus should be placed on the deasphalted oil. Finally, the MS environmentally friendly solvent could potentially be a very effective solvent to enhance the recovery of bitumen in a solvent-steam process. Based on current oil prices and sweep efficiencies, E3, E5, E6, E7, and E8 use economically viable oil displacement methods and are recommended for oil recovery. However, due to the environmental impact of the solvents involved, E6 in which the MS solvent was co-injected with steam and propane is the best choice. In terms of solvent prices as well, E6 is favourable as shown in the appendix (Figure D-1).

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APPENDIX A

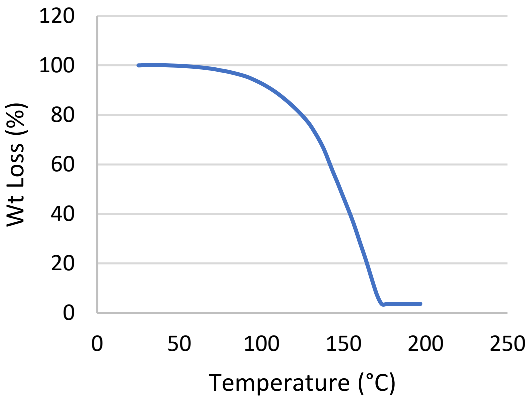


Figure A-1 – TGA for distilled water

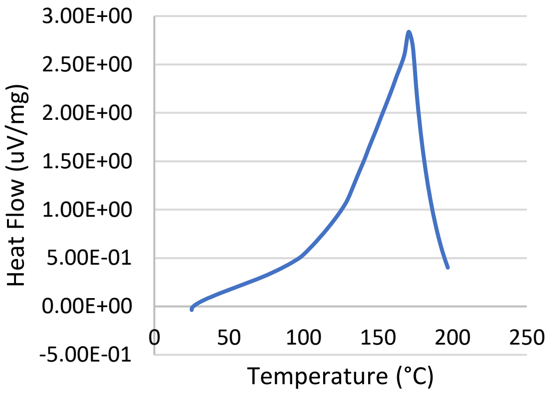


Figure A-2 – DSC for distilled water

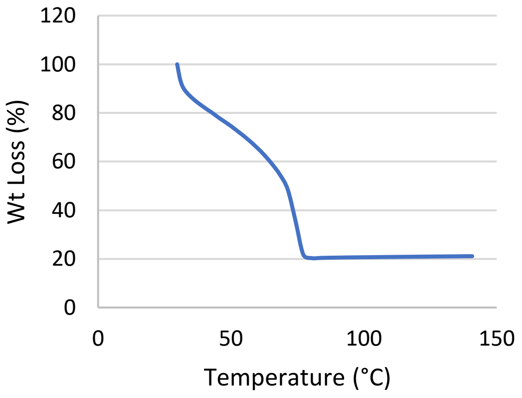
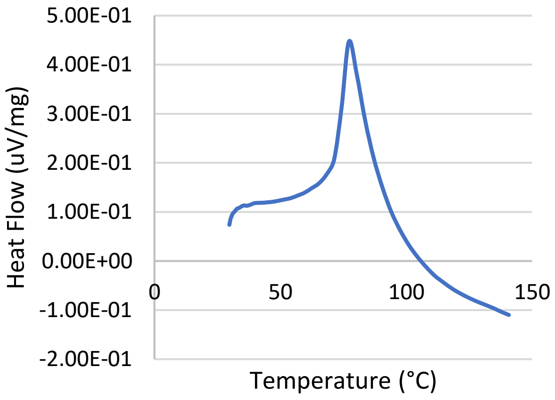


Figure A-3 – TGA for C6



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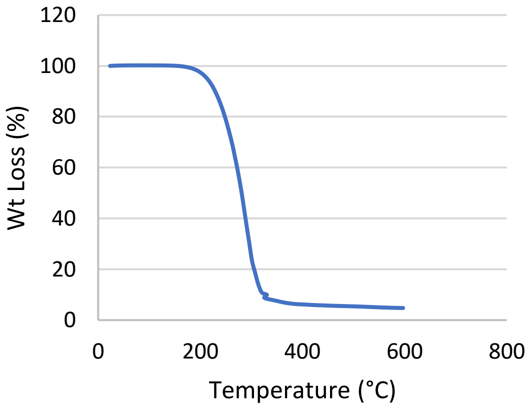
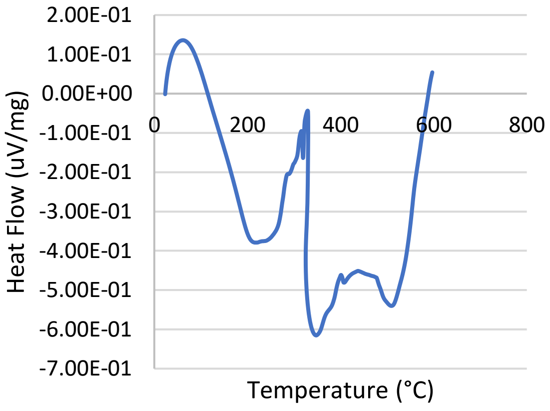


Figure A-5 – TGA for MS solvent



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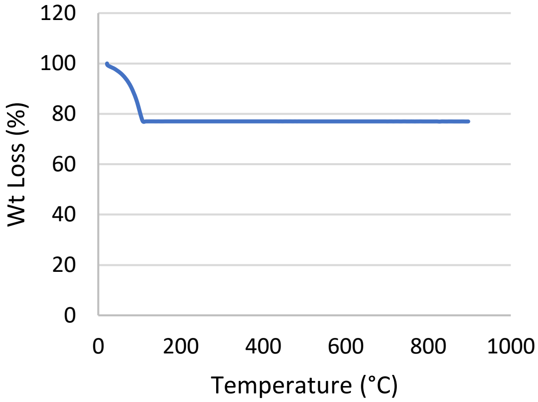
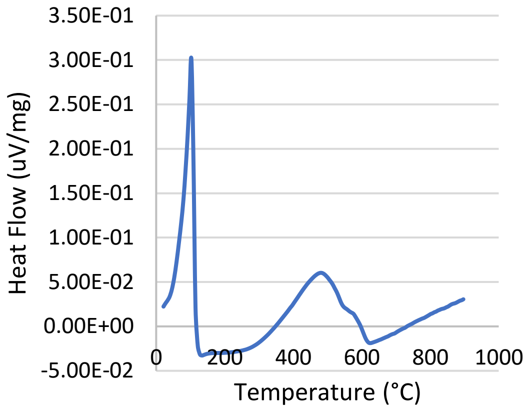


Figure A-7 – TGA for toluene



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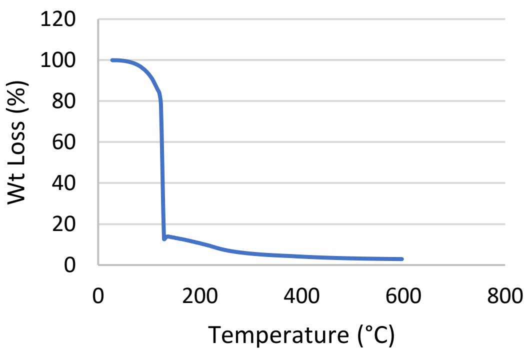
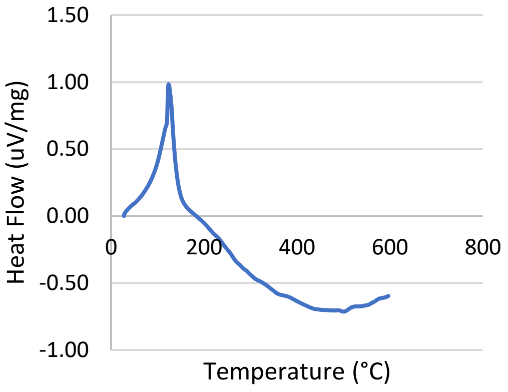


Figure A-9 – TGA for BP



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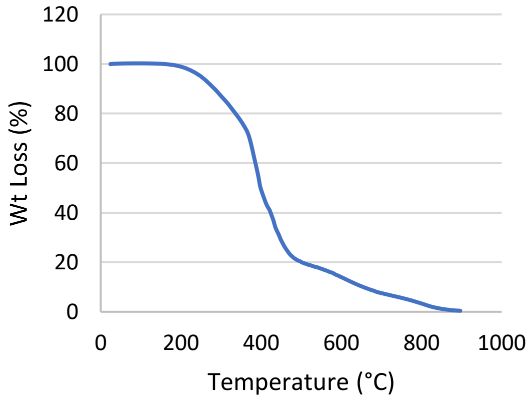
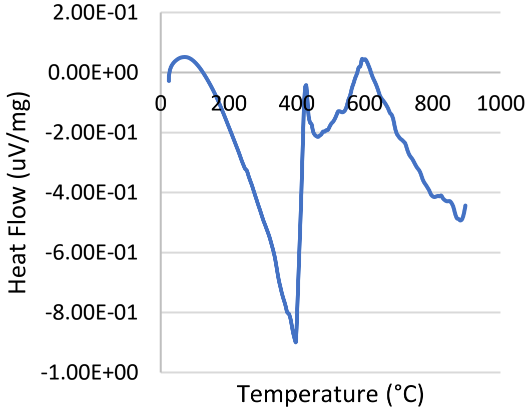


Figure A-11 – TGA for Canadian bitumen



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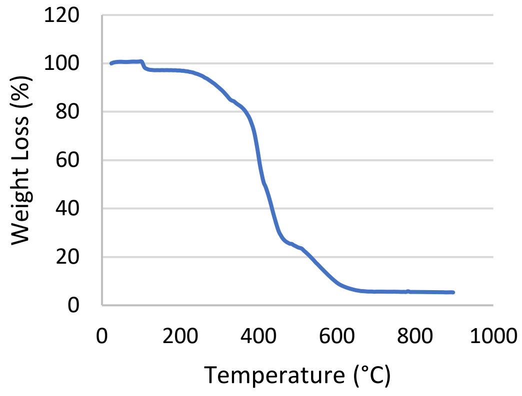
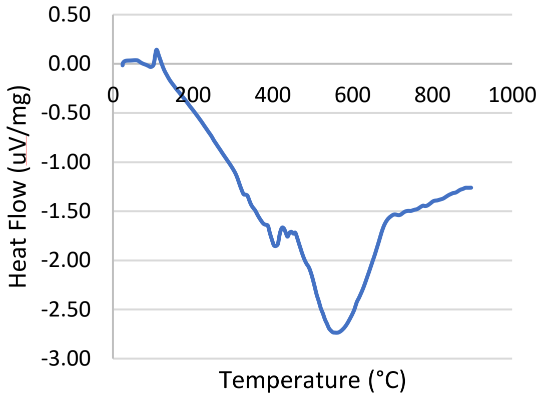


Figure A-13 – TGA for E1



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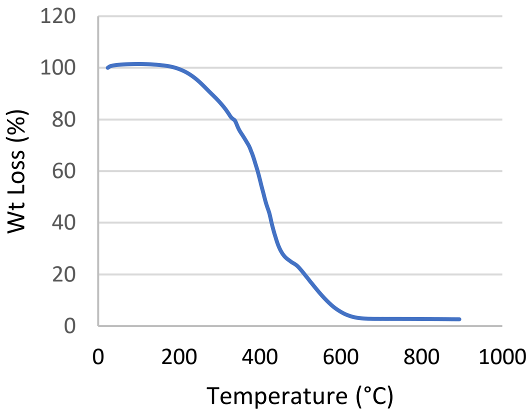
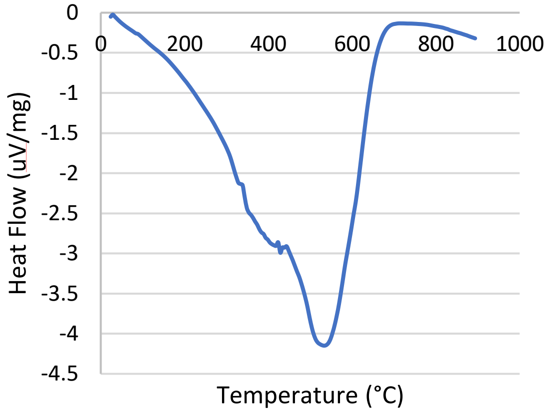


Figure A-15 – TGA for E2



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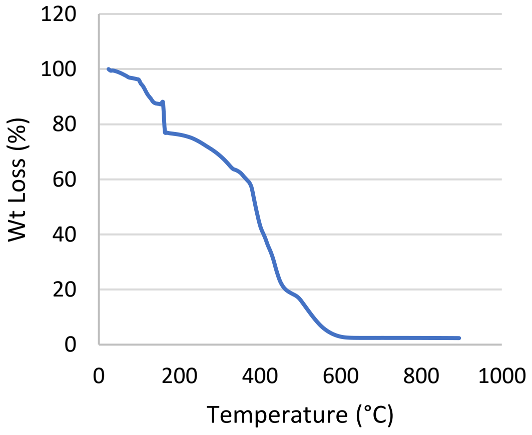

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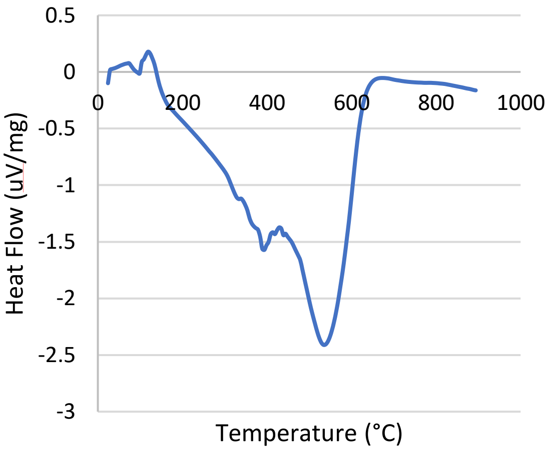

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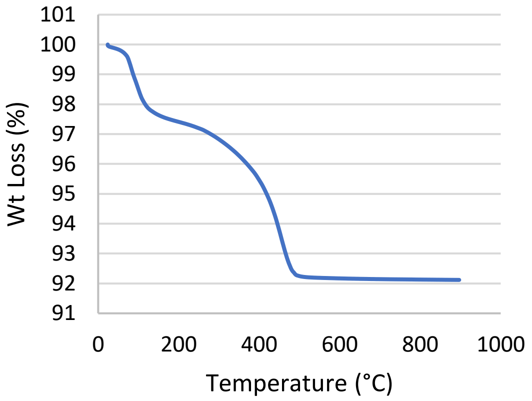


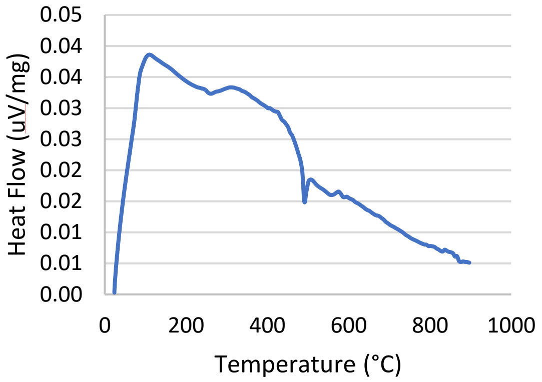
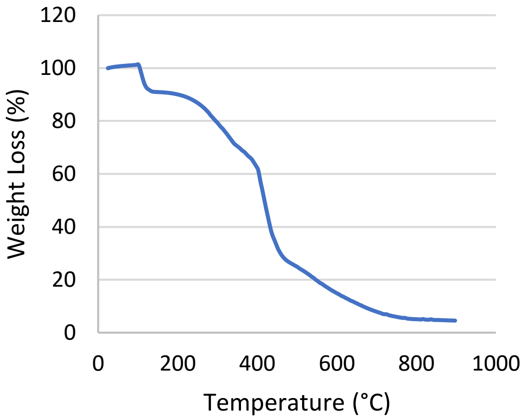


Figure A-19 – TGA for E4	Figure A-20 – DSC for E4



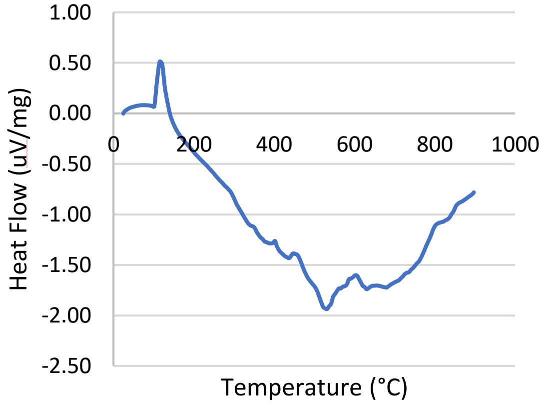
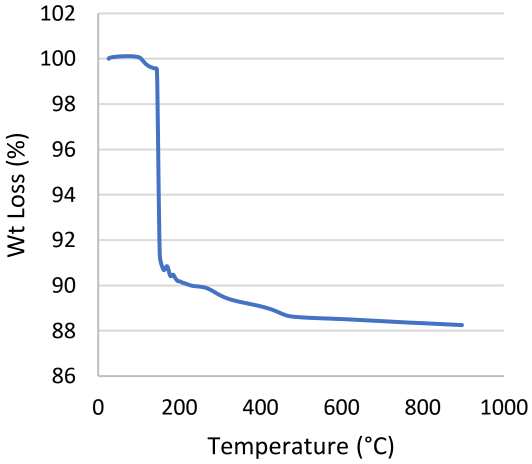


Figure A-21 – TGA for E5	Figure A-22 – DSC for E5



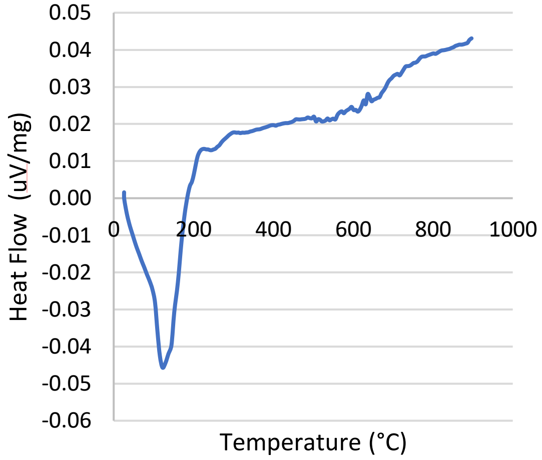
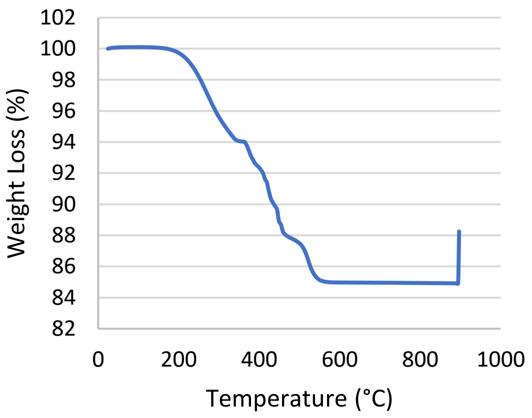


Figure A-23 – TGA for E6	Figure A-24 – DSC for E6



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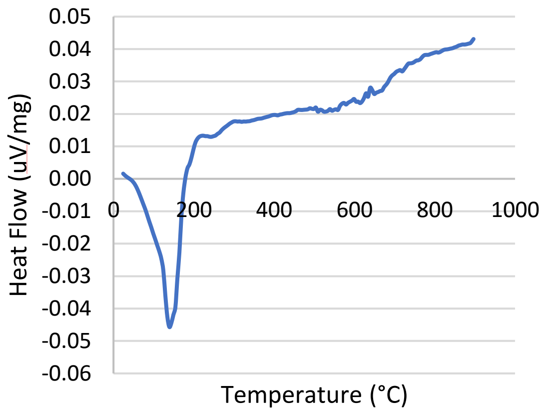

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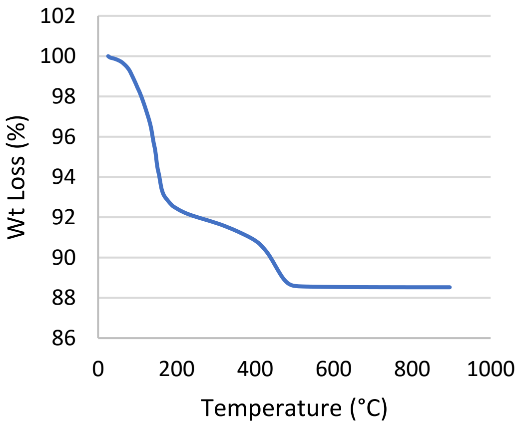

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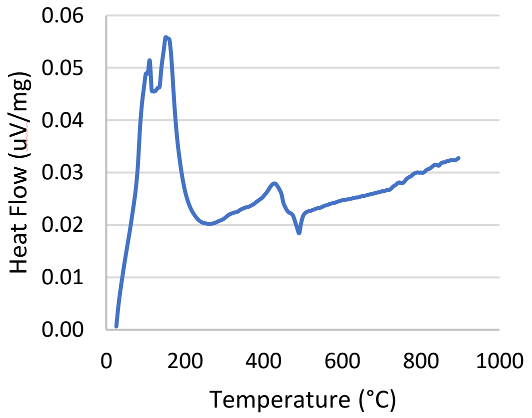

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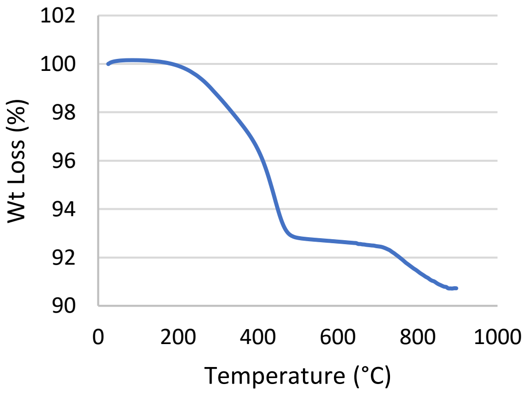


Figure A-29 – TGA for E1 injector portion of spent rock

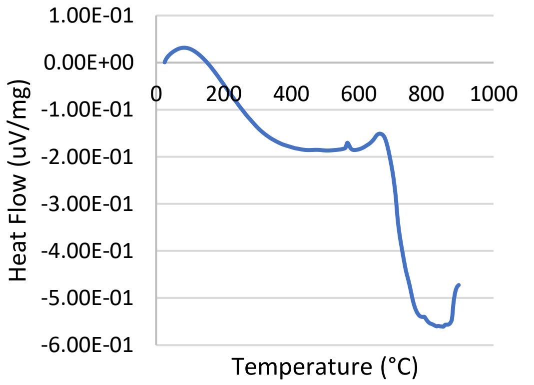


Figure A-30 – DSC for E1 injector portion of spent rock

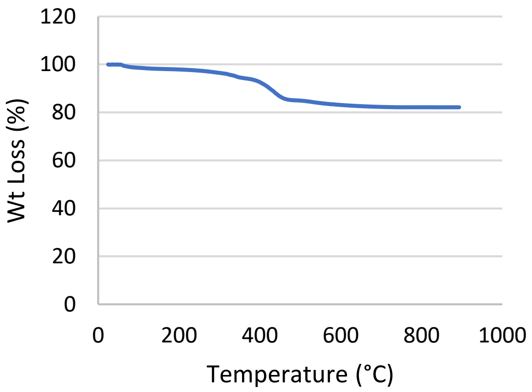
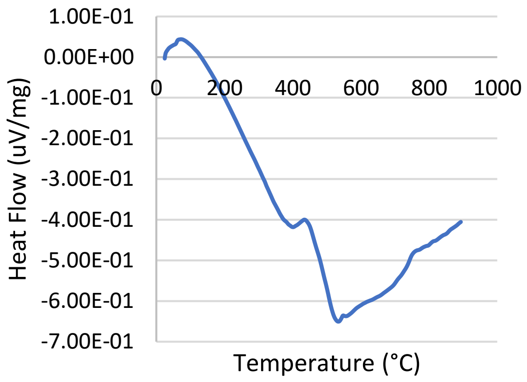


Figure A-31 – TGA for E1 producer portion of spent rock



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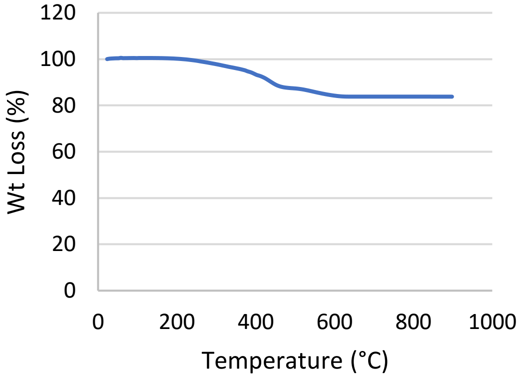


Figure A-33 – TGA for E2 injector portion of spent rock

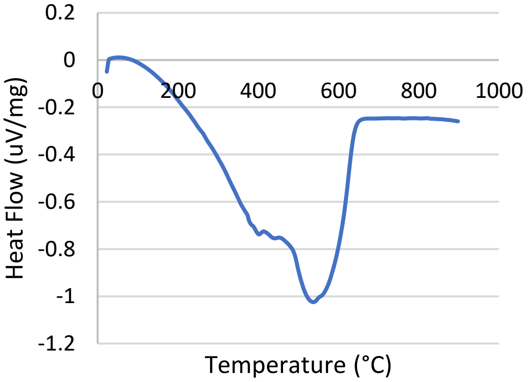


Figure A-34 – DSC for E2 injector portion of spent rock

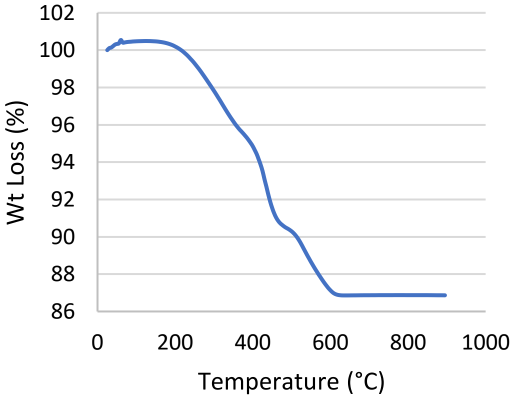


Figure A-35 – TGA for E2 producer portion of spent rock

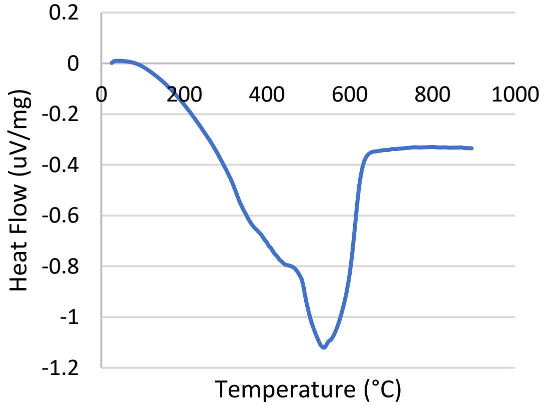
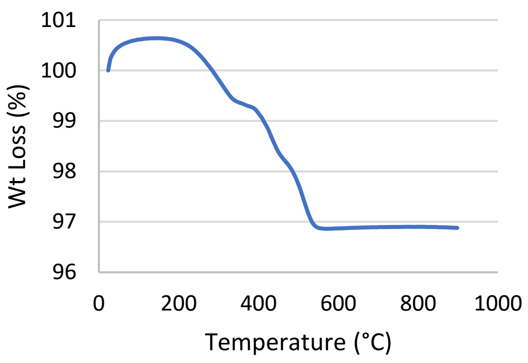


Figure A-36 – DSC for E2 producer portion of spent rock



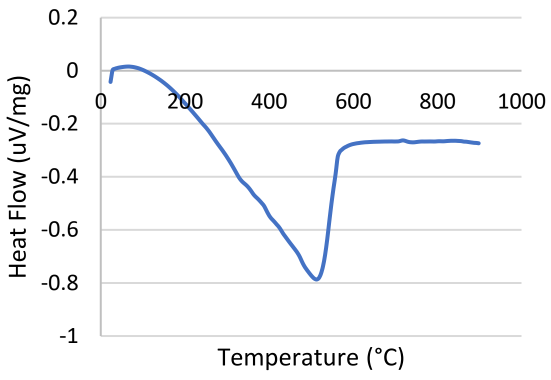
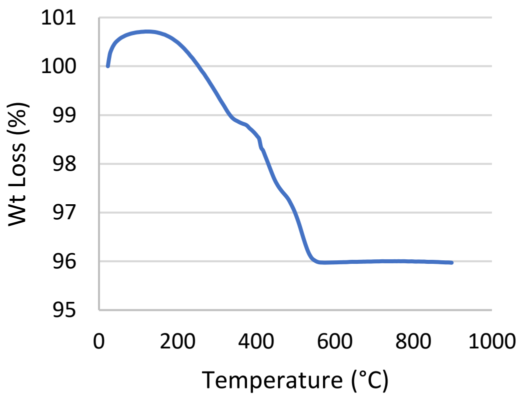


Figure A-37 – TGA for E3 injector portion of spent rock	Figure A-38 – DSC for E3 injector portion of spent rock



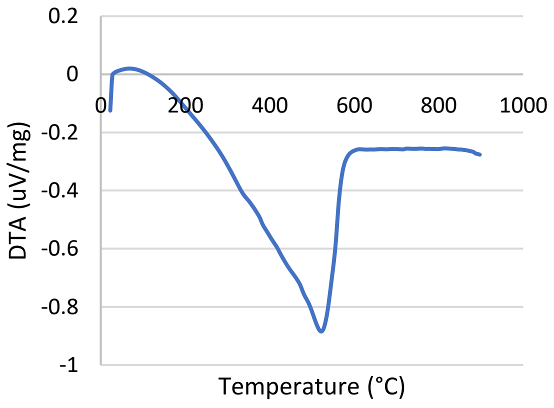
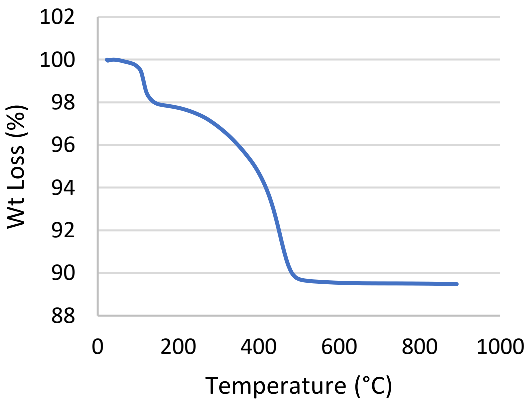


Figure A-39 – TGA for E3 producer portion of spent rock	Figure A-40 – DSC for E3 producer portion of spent rock



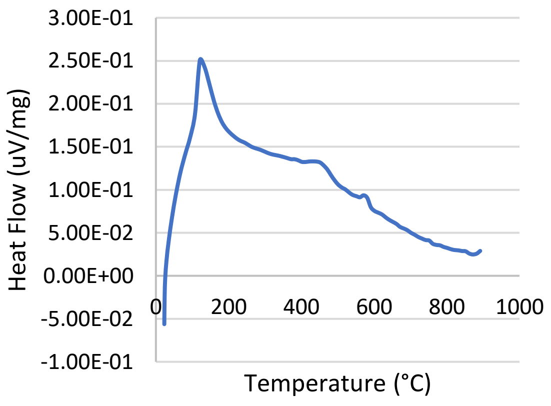


Figure A-41 – TGA for E4 injector portion of spent rock	Figure A-42 – DSC for E4 injector portion of spent rock

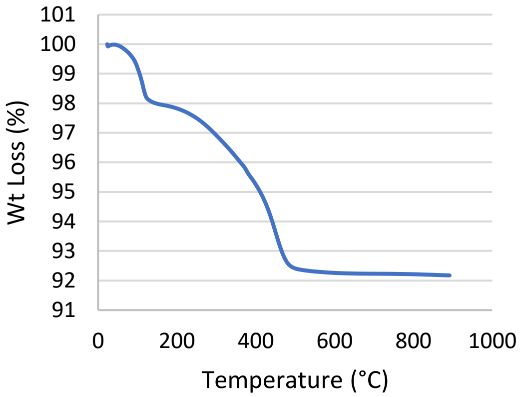


Figure A-43 – TGA for E4 producer portion of spent rock

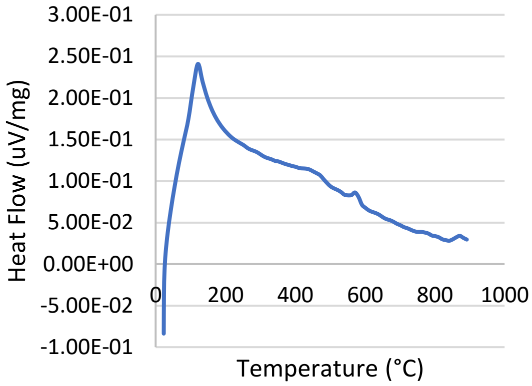


Figure A-44 – DSC for E4 producer portion of spent rock

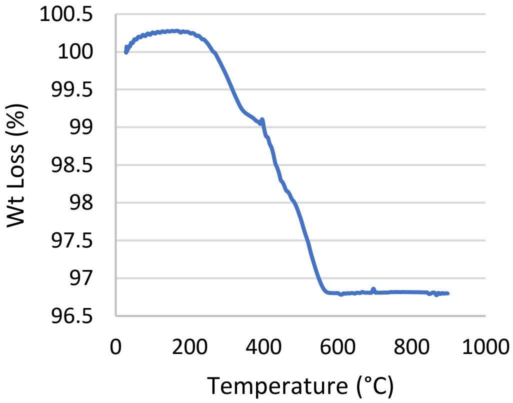


Figure A-45 – TGA for E5 overall portion of spent rock

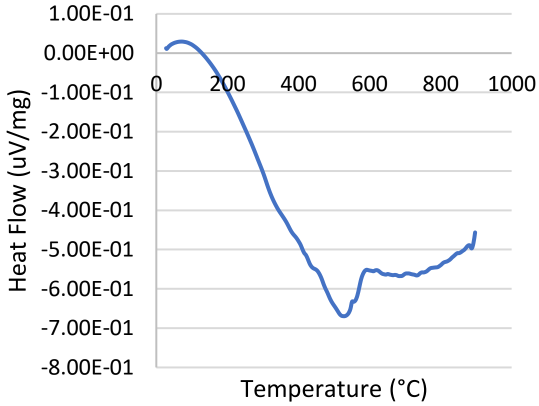


Figure A-46 – DSC for E5 overall portion of spent rock

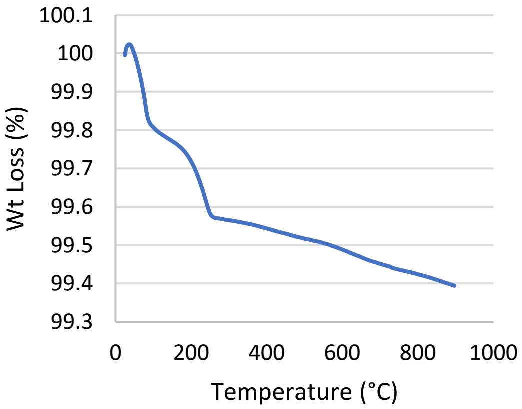


Figure A-47 – TGA for E6 injector portion of spent rock

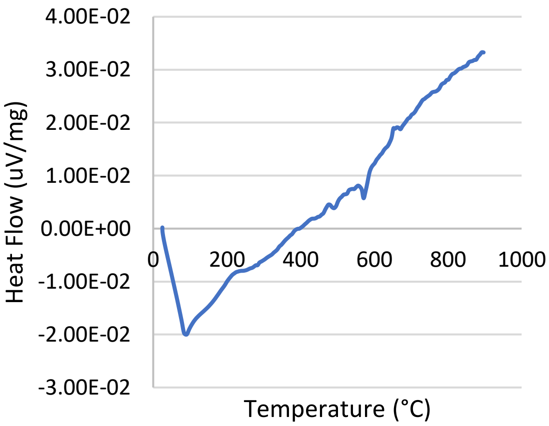


Figure A-48 – DSC for E6 injector portion of spent rock

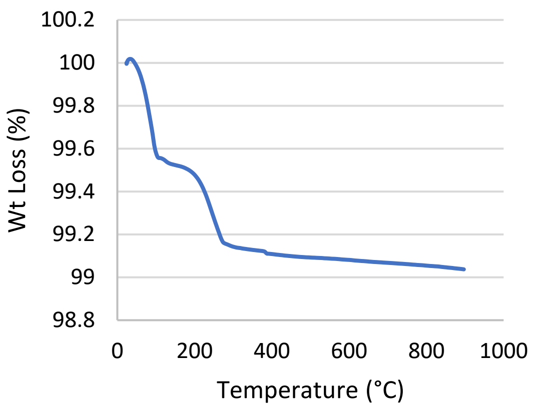


Figure A-49 – TGA for E6 producer portion of spent rock

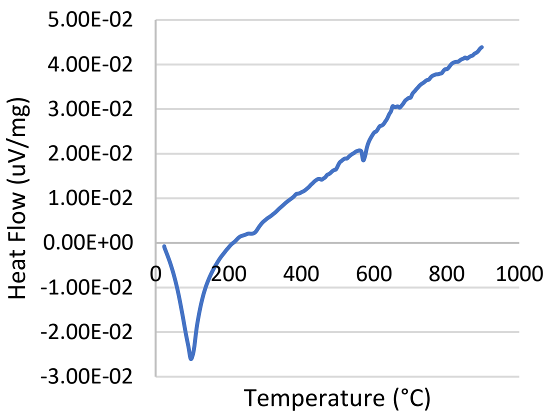


Figure A-50 – DSC for E6 producer portion of spent rock

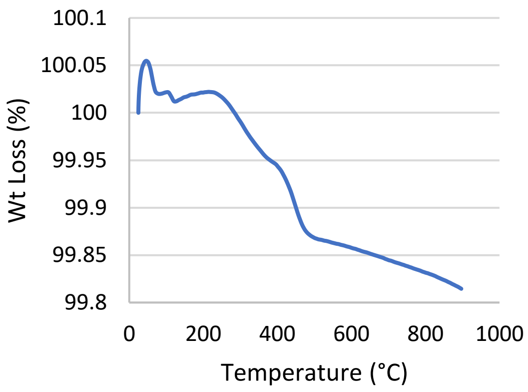


Figure A-51 – TGA for E7 injector portion of spent rock

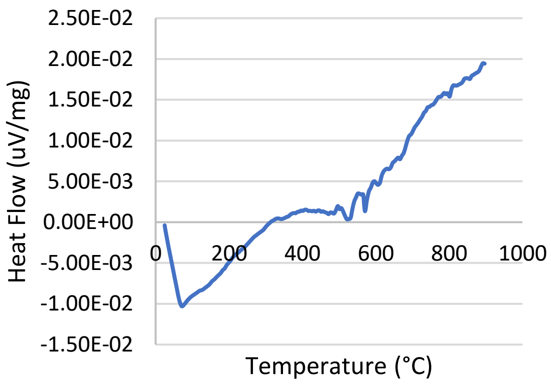


Figure A-52 – DSC for E7 injector portion of spent rock

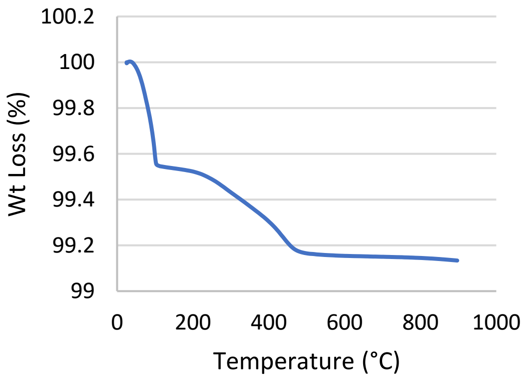


Figure A-53 – TGA for E7 producer portion of spent rock

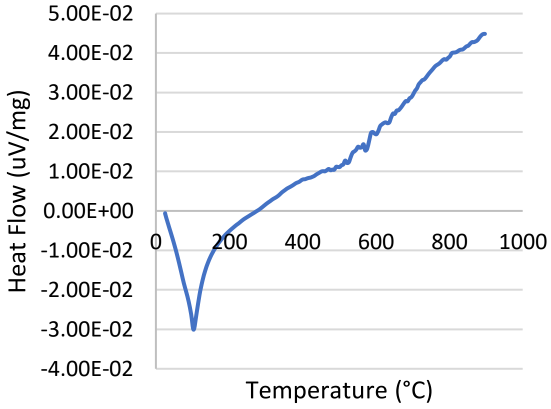


Figure A-54 – DSC for E7 producer portion of spent rock

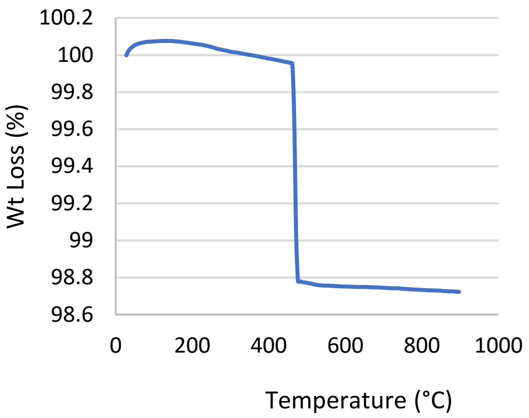


Figure A-55 – TGA for E8 injector portion of spent rock

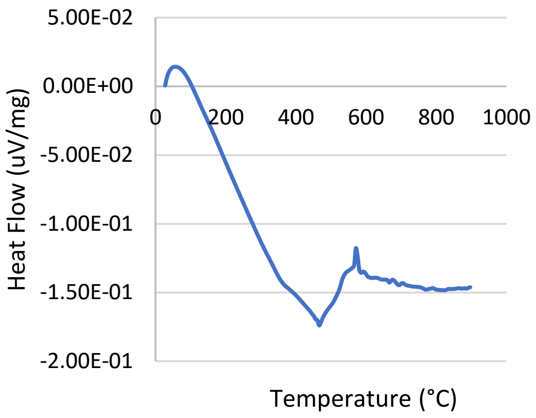


Figure A-56 – DSC for E8 injector portion of spent rock

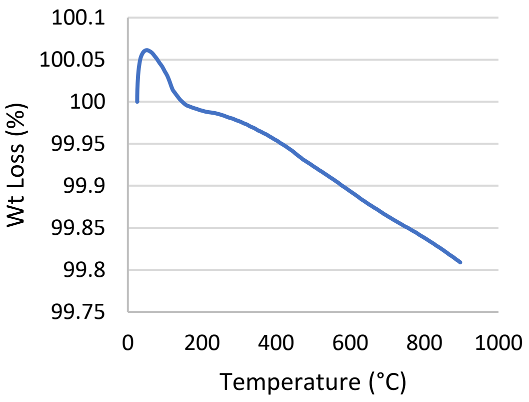


Figure A-57 – TGA for E8 producer portion of spent rock

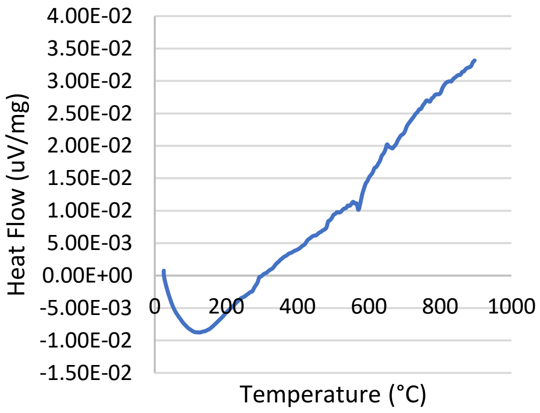


Figure A-58 – DSC for E8 producer portion of spent rock

APPENDIX B

Table B-1 – Rheological model for produced oil in E1 to E8

Experiment	Temperature (°C)	Power Law	R^2	Viscosity $_{@\ 25°C}$ (cP)
Canadian Bitumen	30	$\sigma = 133.95\gamma^{0.9435}$	0.9999	290,500
	40	$\sigma = 33.935\gamma^{0.9738}$	0.9999	
	50	$\sigma = 8.6775\gamma^{1.0574}$	0.9998	
E1	30	$\sigma = 436.8\gamma^{0.6839}$	0.9607	67,555
	40	$\sigma = 170.62\gamma^{0.9106}$	0.9559	
	50	$\sigma = 293.33\gamma^{2.1221}$	0.9999	
E2	30	$\sigma = 865.71\gamma^{0.6375}$	0.9595	118,746
	40	$\sigma = 176.62\gamma^{0.6923}$	0.1912	
	50	$\sigma = 40.223\gamma^{1.0362}$	0.9909	
E3	30	$\sigma = 409.31\gamma^{0.6379}$	0.9865	66,445
	40	$\sigma = 82.323\gamma^{0.8993}$	0.9999	
	50	$\sigma = 17.236\gamma^{0.9221}$	0.9984	
E4	30	$\sigma = 150.66\gamma^{0.2596}$	0.8768	20,866
	40	$\sigma = 88.506\gamma^{0.0427}$	0.9837	
	50	$\sigma = 70.707\gamma^{0.1202}$	0.7756	
E5	30	$\sigma = 918.37\gamma^{0.7344}$	0.8078	173,656
	40	$\sigma = 141.19\gamma^{1.2967}$	0.9979	
	50	$\sigma = 63.639\gamma^{0.988}$	0.9998	
E6	30	$\sigma = 129.72\gamma^{0.0455}$	0.0424	17,838
	40	$\sigma = 52.88\gamma^{0.8749}$	0.776	

	50	$\sigma = 18.678\gamma^{2.3162}$	0.7085	
E7	30	$\sigma = 191.86\gamma^{0.8234}$	0.9651	31,609
	40	$\sigma = 49.783\gamma^{1.0267}$	0.7917	
	50	$\sigma = 42.63\gamma^{3.4259}$	0.7467	
E8	30	$\sigma = 209.49\gamma^{0.9659}$	0.9959	33,706
	40	$\sigma = 58.254\gamma^{1.1447}$	0.612	
	50	$\sigma = 26.439\gamma^{2.1651}$	0.4389	

R^2 represents the fit of the date according to the power law

Table B-2 – API gravity for Canadian bitumen and E1 to E8

Experiment	API gravity (°API)
Bitumen	9.6
E1	87.9
E2	109.4
E3	75.0
E4	67.4
E5	68.7
E6	91.4
E7	63.0
E8	45.7

APPENDIX C

Table C-1 – Water production and temperature profile for E1

Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E1	31	65	5
	44	80	11
	57	80	16
	73	92	21
	87	97	26
	106	95	32
	120	101	37
	134	106	42
	152	103	47
	165	107	52
	179	108	58
	196	108	63
	210	110	68
	225	111	74
	240	108	78

Table C-2 – Water production and temperature profile for E2, E3 and E4

Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E2	60	Not applicable (Conducted at room temperature)	0
	90		0
	120		0
	150		0
	180		0
	210		0
	240		0
Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E3	20	Not available	5
	36		10
	67		14
	120		19
	173		24
	230		29
	240		30
Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E4	0	Not applicable (Conducted at room temperature)	0
	240		4

Table C-3 – Water production and temperature profile for E5

Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E5	25	47	11
	34	120	19
	43	132	27
	55	133	35
	79	127	44
	96	127	53
	114	128	63
	160	128	72

Table C-4 – Water production and temperature profile for E6

Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E6	17	112	5
	28	117	9
	56	117	14
	69	113	19
	78	113	24
	95	105	29
	107	104	34
	121	101	39
	136	98	44
	149	99	49
	161	98	54
	173	98	59
	188	97	64
	201	95	70
	213	96	75
	225	97	80
	234	98	85

Table C-5 – Water production and temperature profile for E7 and E8

Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E7	17	21	8
	28	21	14
	42	160	21
	56	136	29
	77	113	36
	97	114	44
	110	115	52
	125	118	61
	140	107	68
Experiment	Time (mins)	Temperature (°C)	Cumulative solvent + water produced (wt%)
E8	49	Not applicable (Conducted at room temperature)	18
	201		54
	240		73

APPENDIX D

Table D-1 – Price comparisons for the solvents tested in the flooding experiments

Solvents	Prices
Propane	$0.75 / liter
n-Hexane	$ 74.50 / liter
Toluene	$ 37.69 / liter
Benzoyl Peroxide	$ 31.00 / 100g
MS environmentally friendly solvent	$ 0.54 / liter

SAFETY DATA SHEET

Propane

Section 1. Identification

GHS product identifier : Propane

Chemical name : propane

Other means of identification : Propyl hydride; n-Propane; Dimethyl methane; Bottled gas; propane in gaseous state; propane liquefied, n-Propane; Dimethylmethane; Freon 290; Liquefied petroleum gas; Lpg; Propyl hydride; R 290; C3H8; UN 1075; UN 1978; A-108; Hydrocarbon propellant.

Product type : Liquefied gas

Product use : Synthetic/Analytical chemistry.

Synonym : Propyl hydride; n-Propane; Dimethyl methane; Bottled gas; propane in gaseous state; propane liquefied, n-Propane; Dimethylmethane; Freon 290; Liquefied petroleum gas; Lpg; Propyl hydride; R 290; C3H8; UN 1075; UN 1978; A-108; Hydrocarbon propellant.

SDS # : 001045

Supplier's details : Airgas USA, LLC and its affiliates
259 North Radnor-Chester Road
Suite 100
Radnor, PA 19087-5283
1-610-687-5253

24-hour telephone : 1-866-734-3438

Section 2. Hazards identification

OSHA/HCS status : This material is considered hazardous by the OSHA Hazard Communication Standard (29 CFR 1910.1200).

Classification of the substance or mixture : FLAMMABLE GASES - Category 1
GASES UNDER PRESSURE - Liquefied gas

GHS label elements

Hazard pictograms :

Signal word : Danger

Hazard statements : Extremely flammable gas.
May form explosive mixtures with air.
Contains gas under pressure; may explode if heated.
May cause frostbite.
May displace oxygen and cause rapid suffocation.

Precautionary statements

General : Read and follow all Safety Data Sheets (SDS'S) before use. Read label before use. Keep out of reach of children. If medical advice is needed, have product container or label at hand. Close valve after each use and when empty. Use equipment rated for cylinder pressure. Do not open valve until connected to equipment prepared for use. Use a back flow preventative device in the piping. Use only equipment of compatible materials of construction. Always keep container in upright position. Approach suspected leak area with caution.

Prevention : Keep away from heat, hot surfaces, sparks, open flames and other ignition sources. No smoking.

Response : Leaking gas fire: Do not extinguish, unless leak can be stopped safely. Eliminate all ignition sources if safe to do so.

Storage : Protect from sunlight. Store in a well-ventilated place.

Section 2. Hazards identification

Disposal : Not applicable.

Hazards not otherwise classified : Liquid can cause burns similar to frostbite.

Section 3. Composition/information on ingredients

Substance/mixture : Substance

Chemical name : propane

Other means of identification : Propyl hydride; n-Propane; Dimethyl methane; Bottled gas; propane in gaseous state; propane liquefied, n-Propane; Dimethylmethane; Freon 290; Liquefied petroleum gas; Lpg; Propyl hydride; R 290; C3H8; UN 1075; UN 1978; A-108; Hydrocarbon propellant.

Product code : 001045

CAS number/other identifiers

CAS number : 74-98-6

Ingredient name	%	CAS number
Propane	100	74-98-6

Any concentration shown as a range is to protect confidentiality or is due to batch variation.

There are no additional ingredients present which, within the current knowledge of the supplier and in the concentrations applicable, are classified as hazardous to health or the environment and hence require reporting in this section.

Occupational exposure limits, if available, are listed in Section 8.

Section 4. First aid measures

Description of necessary first aid measures

Eye contact : Immediately flush eyes with plenty of water, occasionally lifting the upper and lower eyelids. Check for and remove any contact lenses. Continue to rinse for at least 10 minutes. Get medical attention if irritation occurs.

Inhalation : Remove victim to fresh air and keep at rest in a position comfortable for breathing. If not breathing, if breathing is irregular or if respiratory arrest occurs, provide artificial respiration or oxygen by trained personnel. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation. Get medical attention if adverse health effects persist or are severe. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband.

Skin contact : Wash contaminated skin with soap and water. Remove contaminated clothing and shoes. To avoid the risk of static discharges and gas ignition, soak contaminated clothing thoroughly with water before removing it. Get medical attention if symptoms occur. In case of contact with liquid, warm frozen tissues slowly with lukewarm water and get medical attention. Do not rub affected area. Wash clothing before reuse. Clean shoes thoroughly before reuse.

Ingestion : Remove victim to fresh air and keep at rest in a position comfortable for breathing. Get medical attention if adverse health effects persist or are severe. Ingestion of liquid can cause burns similar to frostbite. If frostbite occurs, get medical attention. Never give anything by mouth to an unconscious person. If unconscious, place in recovery position and get medical attention immediately. Maintain an open airway. Loosen tight clothing such as a collar, tie, belt or waistband. As this product rapidly becomes a gas when released, refer to the inhalation section.

Most important symptoms/effects, acute and delayed

Potential acute health effects

Eye contact : Liquid can cause burns similar to frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Dermal contact with rapidly evaporating liquid could result in freezing of the tissues or frostbite.

Section 4. First aid measures

Frostbite : Try to warm up the frozen tissues and seek medical attention.

Ingestion : Ingestion of liquid can cause burns similar to frostbite.

Over-exposure signs/symptoms

Eye contact : Adverse symptoms may include the following:, frostbite

Inhalation : No specific data.

Skin contact : Adverse symptoms may include the following:, frostbite

Ingestion : Adverse symptoms may include the following:, frostbite

Indication of immediate medical attention and special treatment needed, if necessary

Notes to physician : Treat symptomatically. Contact poison treatment specialist immediately if large quantities have been ingested or inhaled.

Specific treatments : No specific treatment.

Protection of first-aiders : No action shall be taken involving any personal risk or without suitable training. It may be dangerous to the person providing aid to give mouth-to-mouth resuscitation.

See toxicological information (Section 11)

Section 5. Fire-fighting measures

Extinguishing media

Suitable extinguishing media : Use an extinguishing agent suitable for the surrounding fire.

Unsuitable extinguishing media : None known.

Specific hazards arising from the chemical : Contains gas under pressure. Extremely flammable gas. In a fire or if heated, a pressure increase will occur and the container may burst, with the risk of a subsequent explosion. The vapor/gas is heavier than air and will spread along the ground. Gas may accumulate in low or confined areas or travel a considerable distance to a source of ignition and flash back, causing fire or explosion.

Hazardous thermal decomposition products : Decomposition products may include the following materials:
carbon dioxide
carbon monoxide

Special protective actions for fire-fighters : Promptly isolate the scene by removing all persons from the vicinity of the incident if there is a fire. No action shall be taken involving any personal risk or without suitable training. Contact supplier immediately for specialist advice. Move containers from fire area if this can be done without risk. Use water spray to keep fire-exposed containers cool. If involved in fire, shut off flow immediately if it can be done without risk. If this is impossible, withdraw from area and allow fire to burn. Fight fire from protected location or maximum possible distance. Eliminate all ignition sources if safe to do so.

Special protective equipment for fire-fighters : Fire-fighters should wear appropriate protective equipment and self-contained breathing apparatus (SCBA) with a full face-piece operated in positive pressure mode. For incidents involving large quantities, thermally insulated undergarments and thick textile or leather gloves should be worn.

Section 6. Accidental release measures

Personal precautions, protective equipment and emergency procedures

For non-emergency personnel : Accidental releases pose a serious fire or explosion hazard. No action shall be taken involving any personal risk or without suitable training. Evacuate surrounding areas. Keep unnecessary and unprotected personnel from entering. Do not touch or walk through spilled material. Shut off all ignition sources. No flares, smoking or flames in hazard area. Avoid breathing gas. Provide adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Put on appropriate personal protective equipment.

Section 6. Accidental release measures

For emergency responders : If specialized clothing is required to deal with the spillage, take note of any information in Section 8 on suitable and unsuitable materials. See also the information in "For non-emergency personnel".

Environmental precautions : Ensure emergency procedures to deal with accidental gas releases are in place to avoid contamination of the environment. Avoid dispersal of spilled material and runoff and contact with soil, waterways, drains and sewers. Inform the relevant authorities if the product has caused environmental pollution (sewers, waterways, soil or air).

Methods and materials for containment and cleaning up

Small spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment.

Large spill : Immediately contact emergency personnel. Stop leak if without risk. Use spark-proof tools and explosion-proof equipment. Note: see Section 1 for emergency contact information and Section 13 for waste disposal.

Section 7. Handling and storage

Precautions for safe handling

Protective measures : Put on appropriate personal protective equipment (see Section 8). Contains gas under pressure. Do not get in eyes or on skin or clothing. Avoid breathing gas. Use only with adequate ventilation. Wear appropriate respirator when ventilation is inadequate. Do not enter storage areas and confined spaces unless adequately ventilated. Do not puncture or incinerate container. Use equipment rated for cylinder pressure. Close valve after each use and when empty. Protect cylinders from physical damage; do not drag, roll, slide, or drop. Use a suitable hand truck for cylinder movement.
Use only non-sparking tools. Empty containers retain product residue and can be hazardous. Store and use away from heat, sparks, open flame or any other ignition source. Use explosion-proof electrical (ventilating, lighting and material handling) equipment.

Advice on general occupational hygiene : Eating, drinking and smoking should be prohibited in areas where this material is handled, stored and processed. Workers should wash hands and face before eating, drinking and smoking. Remove contaminated clothing and protective equipment before entering eating areas. See also Section 8 for additional information on hygiene measures.

Conditions for safe storage, including any incompatibilities : Store in accordance with local regulations. Store in a segregated and approved area. Store away from direct sunlight in a dry, cool and well-ventilated area, away from incompatible materials (see Section 10). Eliminate all ignition sources. Cylinders should be stored upright, with valve protection cap in place, and firmly secured to prevent falling or being knocked over. Cylinder temperatures should not exceed 52 °C (125 °F). Keep container tightly closed and sealed until ready for use. See Section 10 for incompatible materials before handling or use.

Section 8. Exposure controls/personal protection

Control parameters

Occupational exposure limits

Ingredient name	Exposure limits
Propane	**NIOSH REL (United States, 10/2016).** TWA: 1800 mg/m³ 10 hours. TWA: 1000 ppm 10 hours. **OSHA PEL (United States, 6/2016).** TWA: 1800 mg/m³ 8 hours. TWA: 1000 ppm 8 hours. **OSHA PEL 1989 (United States, 3/1989).** TWA: 1800 mg/m³ 8 hours. TWA: 1000 ppm 8 hours. **ACGIH TLV (United States, 3/2017). Oxygen Depletion [Asphyxiant].**

Section 8. Exposure controls/personal protection

Appropriate engineering controls : Use only with adequate ventilation. Use process enclosures, local exhaust ventilation or other engineering controls to keep worker exposure to airborne contaminants below any recommended or statutory limits. The engineering controls also need to keep gas, vapor or dust concentrations below any lower explosive limits. Use explosion-proof ventilation equipment.

Environmental exposure controls : Emissions from ventilation or work process equipment should be checked to ensure they comply with the requirements of environmental protection legislation. In some cases, fume scrubbers, filters or engineering modifications to the process equipment will be necessary to reduce emissions to acceptable levels.

Individual protection measures

Hygiene measures : Wash hands, forearms and face thoroughly after handling chemical products, before eating, smoking and using the lavatory and at the end of the working period. Appropriate techniques should be used to remove potentially contaminated clothing. Wash contaminated clothing before reusing. Ensure that eyewash stations and safety showers are close to the workstation location.

Eye/face protection : Safety eyewear complying with an approved standard should be used when a risk assessment indicates this is necessary to avoid exposure to liquid splashes, mists, gases or dusts. If contact is possible, the following protection should be worn, unless the assessment indicates a higher degree of protection: safety glasses with side-shields.

Skin protection

Hand protection : Chemical-resistant, impervious gloves complying with an approved standard should be worn at all times when handling chemical products if a risk assessment indicates this is necessary. If contact with the liquid is possible, insulated gloves suitable for low temperatures should be worn. Considering the parameters specified by the glove manufacturer, check during use that the gloves are still retaining their protective properties. It should be noted that the time to breakthrough for any glove material may be different for different glove manufacturers. In the case of mixtures, consisting of several substances, the protection time of the gloves cannot be accurately estimated.

Body protection : Personal protective equipment for the body should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product. When there is a risk of ignition from static electricity, wear anti-static protective clothing. For the greatest protection from static discharges, clothing should include anti-static overalls, boots and gloves.

Other skin protection : Appropriate footwear and any additional skin protection measures should be selected based on the task being performed and the risks involved and should be approved by a specialist before handling this product.

Respiratory protection : Based on the hazard and potential for exposure, select a respirator that meets the appropriate standard or certification. Respirators must be used according to a respiratory protection program to ensure proper fitting, training, and other important aspects of use.

Thermal hazards : If there is a risk of contact with the liquid, all protective equipment worn should be suitable for use with extremely low temperature materials.

Section 9. Physical and chemical properties

Appearance

Physical state : Gas. [Compressed gas.]

Color : Colorless.

Odor : Odorless.BUT MAY HAVE SKUNK ODOR ADDED.

Odor threshold : Not available.

pH : Not available.

Melting point : -187.6°C (-305.7°F)

Boiling point : -161.48°C (-258.7°F)

Section 9. Physical and chemical properties

Critical temperature : 96.55°C (205.8°F)

Flash point : Closed cup: -104°C (-155.2°F)
Open cup: -104°C (-155.2°F)

Evaporation rate : Not available.

Flammability (solid, gas) : Extremely flammable in the presence of the following materials or conditions: open flames, sparks and static discharge and oxidizing materials.

Lower and upper explosive (flammable) limits : Lower: 1.8%
Upper: 8.4%

Vapor pressure : 109 (psig)

Vapor density : 1.6 (Air = 1)

Specific Volume (ft ^{3}/lb) : 8.6206

Gas Density (lb/ft ^{3}) : 0.116 (25°C / 77 to °F)

Relative density : Not applicable.

Solubility : Not available.

Solubility in water : 0.02 g/l

Partition coefficient: n-octanol/water : 1.09

Auto-ignition temperature : 287°C (548.6°F)

Decomposition temperature : Not available.

Viscosity : Not applicable.

Flow time (ISO 2431) : Not available.

Molecular weight : 44.11 g/mole

Aerosol product

Heat of combustion : -46012932 J/kg

Section 10. Stability and reactivity

Reactivity : No specific test data related to reactivity available for this product or its ingredients.

Chemical stability : The product is stable.

Possibility of hazardous reactions : Under normal conditions of storage and use, hazardous reactions will not occur.

Conditions to avoid : Avoid all possible sources of ignition (spark or flame). Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition. Do not allow gas to accumulate in low or confined areas.

Incompatible materials : Oxidizers

Hazardous decomposition products : Under normal conditions of storage and use, hazardous decomposition products should not be produced.

Hazardous polymerization : Under normal conditions of storage and use, hazardous polymerization will not occur.

Section 11. Toxicological information

Information on toxicological effects

Acute toxicity

Not available.

Irritation/Corrosion

Not available.

Sensitization

Not available.

Mutagenicity

Not available.

Carcinogenicity

Not available.

Reproductive toxicity

Not available.

Teratogenicity

Not available.

Specific target organ toxicity (single exposure)

Not available.

Specific target organ toxicity (repeated exposure)

Not available.

Aspiration hazard

Not available.

Information on the likely routes of exposure : Not available.

Potential acute health effects

Eye contact : Liquid can cause burns similar to frostbite.

Inhalation : No known significant effects or critical hazards.

Skin contact : Dermal contact with rapidly evaporating liquid could result in freezing of the tissues or frostbite.

Ingestion : Ingestion of liquid can cause burns similar to frostbite.

Symptoms related to the physical, chemical and toxicological characteristics

Eye contact : Adverse symptoms may include the following:, frostbite

Inhalation : No specific data.

Skin contact : Adverse symptoms may include the following:, frostbite

Ingestion : Adverse symptoms may include the following:, frostbite

Delayed and immediate effects and also chronic effects from short and long term exposure

Short term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Long term exposure

Potential immediate effects : Not available.

Potential delayed effects : Not available.

Section 11. Toxicological information

Potential chronic health effects

Not available.

General : No known significant effects or critical hazards.
Carcinogenicity : No known significant effects or critical hazards.
Mutagenicity : No known significant effects or critical hazards.
Teratogenicity : No known significant effects or critical hazards.
Developmental effects : No known significant effects or critical hazards.
Fertility effects : No known significant effects or critical hazards.

Numerical measures of toxicity

Acute toxicity estimates

Not available.

Section 12. Ecological information

Toxicity

Not available.

Persistence and degradability

Not available.

Bioaccumulative potential

Product/ingredient name	LogP_{ow}	BCF	Potential
Propane	1.09	-	low

Mobility in soil

Soil/water partition coefficient (K_{OC}) : Not available.

Other adverse effects : No known significant effects or critical hazards.

Section 13. Disposal considerations

Disposal methods : The generation of waste should be avoided or minimized wherever possible. Disposal of this product, solutions and any by-products should at all times comply with the requirements of environmental protection and waste disposal legislation and any regional local authority requirements. Dispose of surplus and non-recyclable products via a licensed waste disposal contractor. Waste should not be disposed of untreated to the sewer unless fully compliant with the requirements of all authorities with jurisdiction. Empty Airgas-owned pressure vessels should be returned to Airgas. Waste packaging should be recycled. Incineration or landfill should only be considered when recycling is not feasible. This material and its container must be disposed of in a safe way. Empty containers or liners may retain some product residues. Do not puncture or incinerate container.

Section 14. Transport information

	DOT	**TDG**	**Mexico**	**IMDG**	**IATA**
UN number	UN1978	UN1978	UN1978	UN1978	UN1978
UN proper shipping name	PROPANE	PROPANE	PROPANE	PROPANE	PROPANE
Transport hazard class(es)	2.1 	2.1 	2.1 	2.1 	2.1 
Packing group	-	-	-	-	-
Environmental hazards	No.	No.	No.	No.	No.

“Refer to CFR 49 (or authority having jurisdiction) to determine the information required for shipment of the product.”

Additional information

DOT Classification : **Limited quantity**

Yes.

Packaging instruction

Passenger aircraft

Quantity limitation: Forbidden.

Cargo aircraft

Quantity limitation: 150 kg

Special provisions

19, T50

For domestic transportation only, UN1075 may be substituted for the UN number shown as long as the substitution is consistent on package markings, shipping papers, and emergency response information. See 49 CFR 172.102 Special Provision 19.

Containers of NON-ODORIZED liquefied petroleum gas must be marked either NON-ODORIZED or NOT ODORIZED as of September 30, 2006. [49 CFR 172.301(f), 326(d), 330(c) and 338(e)]

TDG Classification : Product classified as per the following sections of the Transportation of Dangerous Goods Regulations: 2.13-2.17 (Class 2).

Explosive Limit and Limited Quantity Index 0.125

ERAP Index 3000

Passenger Carrying Ship Index 65

Passenger Carrying Road or Rail Index Forbidden

Special provisions 29, 42

IATA : **Quantity limitation** Passenger and Cargo Aircraft: Forbidden. Cargo Aircraft Only: 150 kg.

Special precautions for user : **Transport within user’s premises:** always transport in closed containers that are upright and secure. Ensure that persons transporting the product know what to do in the event of an accident or spillage.

Transport in bulk according to Annex II of MARPOL and the IBC Code : Not available.

Section 15. Regulatory information

U.S. Federal regulations : **TSCA 8(a) CDR Exempt/Partial exemption**: Not determined
Clean Air Act (CAA) 112 regulated flammable substances: propane

Clean Air Act Section 112 (b) Hazardous Air Pollutants (HAPs) : Not listed

Clean Air Act Section 602 Class I Substances : Not listed

Clean Air Act Section 602 Class II Substances : Not listed

DEA List I Chemicals (Precursor Chemicals) : Not listed

DEA List II Chemicals (Essential Chemicals) : Not listed

SARA 302/304

Composition/information on ingredients

No products were found.

SARA 304 RQ : Not applicable.

SARA 311/312

Classification : Refer to Section 2: Hazards Identification of this SDS for classification of substance.

State regulations

Massachusetts : This material is listed.
New York : This material is not listed.
New Jersey : This material is listed.
Pennsylvania : This material is listed.

International regulations

Chemical Weapon Convention List Schedules I, II & III Chemicals

Not listed.

Montreal Protocol (Annexes A, B, C, E)

Not listed.

Stockholm Convention on Persistent Organic Pollutants

Not listed.

Rotterdam Convention on Prior Informed Consent (PIC)

Not listed.

UNECE Aarhus Protocol on POPs and Heavy Metals

Not listed.

Inventory list

Australia : This material is listed or exempted.
Canada : This material is listed or exempted.
China : This material is listed or exempted.
Europe : This material is listed or exempted.
Japan : **Japan inventory (ENCS)**: This material is listed or exempted.
Japan inventory (ISHL): This material is listed or exempted.
Malaysia : This material is listed or exempted.
New Zealand : This material is listed or exempted.
Philippines : This material is listed or exempted.
Republic of Korea : This material is listed or exempted.

Section 15. Regulatory information

Taiwan : This material is listed or exempted.
Thailand : Not determined.
Turkey : This material is listed or exempted.
United States : This material is listed or exempted.
Viet Nam : Not determined.

Section 16. Other information

Hazardous Material Information System (U.S.A.)

Health	/	2
Flammability		4
Physical hazards		3

Caution: HMIS® ratings are based on a 0-4 rating scale, with 0 representing minimal hazards or risks, and 4 representing significant hazards or risks. Although HMIS® ratings and the associated label are not required on SDSs or products leaving a facility under 29 CFR 1910.1200, the preparer may choose to provide them. HMIS® ratings are to be used with a fully implemented HMIS® program. HMIS® is a registered trademark and service mark of the American Coatings Association, Inc.

The customer is responsible for determining the PPE code for this material. For more information on HMIS® Personal Protective Equipment (PPE) codes, consult the HMIS® Implementation Manual.

National Fire Protection Association (U.S.A.)

Reprinted with permission from NFPA 704-2001, Identification of the Hazards of Materials for Emergency Response Copyright ©1997, National Fire Protection Association, Quincy, MA 02269. This reprinted material is not the complete and official position of the National Fire Protection Association, on the referenced subject which is represented only by the standard in its entirety.

Copyright ©2001, National Fire Protection Association, Quincy, MA 02269. This warning system is intended to be interpreted and applied only by properly trained individuals to identify fire, health and reactivity hazards of chemicals. The user is referred to certain limited number of chemicals with recommended classifications in NFPA 49 and NFPA 325, which would be used as a guideline only. Whether the chemicals are classified by NFPA or not, anyone using the 704 systems to classify chemicals does so at their own risk.

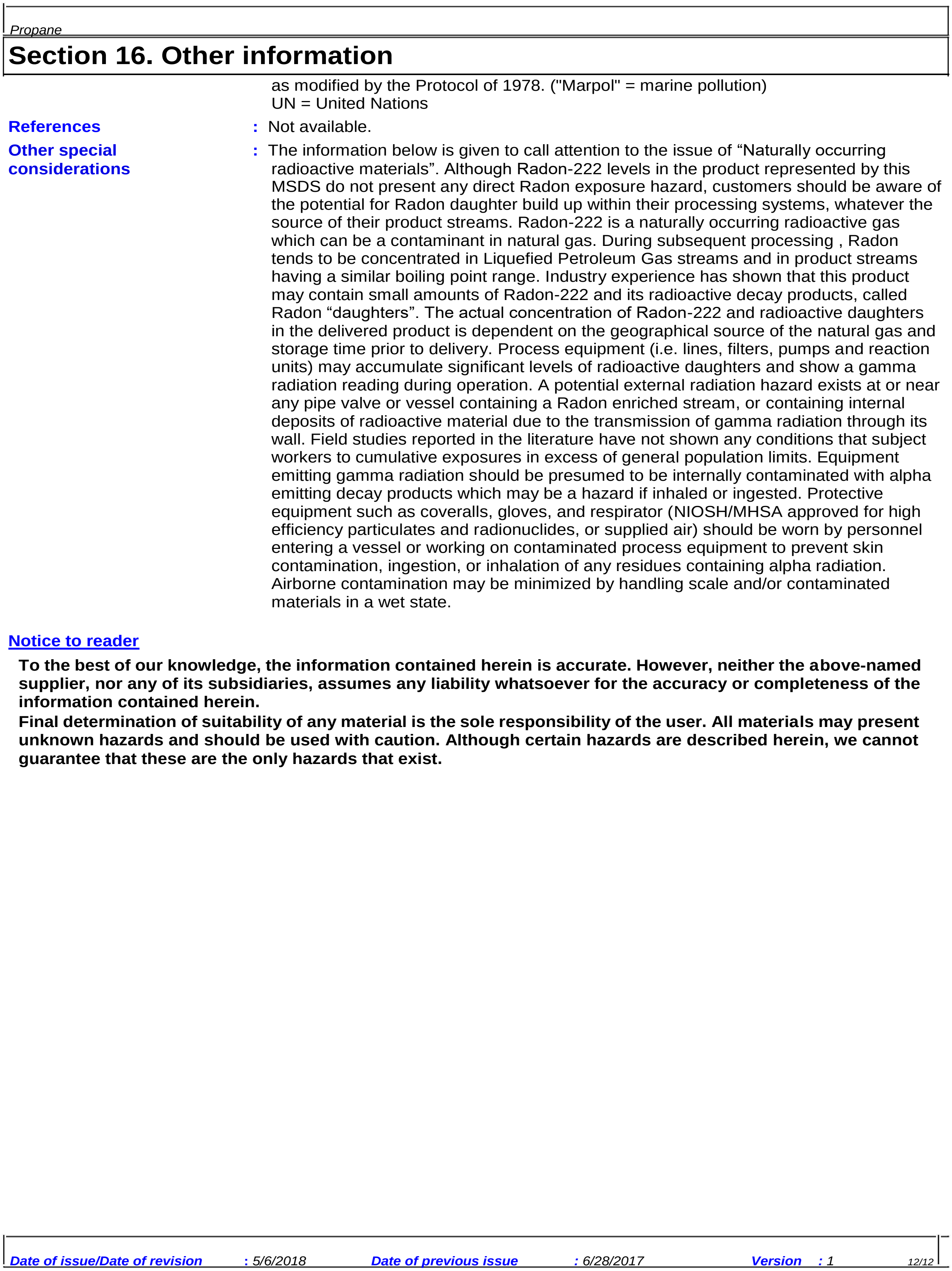
Procedure used to derive the classification

Classification	Justification
FLAMMABLE GASES - Category 1 GASES UNDER PRESSURE - Liquefied gas	Expert judgment Expert judgment

History

Date of printing : 5/6/2018
Date of issue/Date of revision : 5/6/2018
Date of previous issue : 6/28/2017
Version : 1

Key to abbreviations : ATE = Acute Toxicity Estimate
BCF = Bioconcentration Factor
GHS = Globally Harmonized System of Classification and Labelling of Chemicals
IATA = International Air Transport Association
IBC = Intermediate Bulk Container
IMDG = International Maritime Dangerous Goods
LogPow = logarithm of the octanol/water partition coefficient
MARPOL = International Convention for the Prevention of Pollution From Ships, 1973



Propane

Section 16. Other information

as modified by the Protocol of 1978. ("Marpol" = marine pollution)
UN = United Nations

References : Not available.

Other special considerations : The information below is given to call attention to the issue of “Naturally occurring radioactive materials”. Although Radon-222 levels in the product represented by this MSDS do not present any direct Radon exposure hazard, customers should be aware of the potential for Radon daughter build up within their processing systems, whatever the source of their product streams. Radon-222 is a naturally occurring radioactive gas which can be a contaminant in natural gas. During subsequent processing , Radon tends to be concentrated in Liquefied Petroleum Gas streams and in product streams having a similar boiling point range. Industry experience has shown that this product may contain small amounts of Radon-222 and its radioactive decay products, called Radon “daughters”. The actual concentration of Radon-222 and radioactive daughters in the delivered product is dependent on the geographical source of the natural gas and storage time prior to delivery. Process equipment (i.e. lines, filters, pumps and reaction units) may accumulate significant levels of radioactive daughters and show a gamma radiation reading during operation. A potential external radiation hazard exists at or near any pipe valve or vessel containing a Radon enriched stream, or containing internal deposits of radioactive material due to the transmission of gamma radiation through its wall. Field studies reported in the literature have not shown any conditions that subject workers to cumulative exposures in excess of general population limits. Equipment emitting gamma radiation should be presumed to be internally contaminated with alpha emitting decay products which may be a hazard if inhaled or ingested. Protective equipment such as coveralls, gloves, and respirator (NIOSH/MHSA approved for high efficiency particulates and radionuclides, or supplied air) should be worn by personnel entering a vessel or working on contaminated process equipment to prevent skin contamination, ingestion, or inhalation of any residues containing alpha radiation. Airborne contamination may be minimized by handling scale and/or contaminated materials in a wet state.

Notice to reader

To the best of our knowledge, the information contained herein is accurate. However, neither the above-named supplier, nor any of its subsidiaries, assumes any liability whatsoever for the accuracy or completeness of the information contained herein.
Final determination of suitability of any material is the sole responsibility of the user. All materials may present unknown hazards and should be used with caution. Although certain hazards are described herein, we cannot guarantee that these are the only hazards that exist.

Date of issue/Date of revision : 5/6/2018 Date of previous issue : 6/28/2017 Version : 1 12/12

Figure E-1 – Safety data sheet for propane gas

SIGMA-ALDRICH sigma-aldrich.com

SAFETY DATA SHEET

Version 4.8
Revision Date 01/05/2018
Print Date 05/19/2018

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1. PRODUCT AND COMPANY IDENTIFICATION

1.1 Product identifiers

Product name : Pentane

Product Number : 236705
Brand : Sigma-Aldrich
Index-No. : 601-006-00-1

CAS-No. : 109-66-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

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2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 1), H224
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 2), H401
Chronic aquatic toxicity (Category 2), H411

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H224	Extremely flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H336	May cause drowsiness or dizziness.
H411	Toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting equipment.

P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER/doctor.
P303 + P361 + P353	IF ON SKIN (or hair): Remove/ Take off immediately all contaminated clothing. Rinse skin with water/ shower.
P304 + P340 + P312	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing. Call a POISON CENTER or doctor/ physician if you feel unwell.
P331	Do NOT induce vomiting.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam for extinction.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3Hazards not otherwise classified (HNOC) or not covered by GHS

Repeated exposure may cause skin dryness or cracking.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1Substances

Formula : C_5H_{12}
Molecular weight : 72.15 g/mol
CAS-No. : 109-66-0
EC-No. : 203-692-4
Index-No. : 601-006-00-1
Registration number : 01-2119459286-30-XXXX

Hazardous components

Component	Classification	Concentration
n-Pentane		
	Flam. Liq. 1; STOT SE 3; Asp. Tox. 1; Aquatic Acute 2; Aquatic Chronic 2; H224, H304, H336, H411	90 - 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Flush eyes with water as a precaution.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

No data available

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up

Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

6.4 Reference to other sections

For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

Refrigerate before opening.
Storage class (TRGS 510): 3: Flammable liquids

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

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Storage class (TRGS 510): 3: Flammable liquids

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

---

8. EXPOSURE CONTROLS/PERSONAL PROTECTION

8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
n-Pentane	109-66-0	TWA	120.000000 ppm 350.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		C	610.000000 ppm 1,800.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
	Remarks	15 minute ceiling value		
		TWA	1,000.000000 ppm 2,950.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	600.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Peripheral neuropathy Adopted values or notations enclosed are those for which changes are proposed in the NIC See Notice of Intended Changes (NIC)		
		TWA	1,000 ppm	USA. ACGIH Threshold Limit Values (TLV)
		narcosis respiratory tract irritation 2017 Adoption		
		PEL	600 ppm 1,800 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection

Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection

Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.4 mm
Break through time: 480 min
Material tested:Camatril® (KCL 730 / Aldrich Z677442, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an

industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type AXBEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid, clear Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: -130 °C (-202 °F) - lit.
f)	Initial boiling point and boiling range	35 - 36 °C (95 - 97 °F) - lit.
g)	Flash point	-49.0 °C (-56.2 °F) - closed cup
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 8.3 %(V) Lower explosion limit: 1.4 %(V)
k)	Vapour pressure	579.0 hPa (434.3 mmHg) at 20.0 °C (68.0 °F) 1,859.7 hPa (1,394.9 mmHg) at 55.0 °C (131.0 °F)
l)	Vapour density	No data available
m)	Relative density	0.626 g/cm3 at 25 °C (77 °F)
n)	Water solubility	No data available
o)	Partition coefficient: n-octanol/water	log Pow: 3.39
p)	Auto-ignition temperature	260.0 °C (500.0 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	Not explosive
t)	Oxidizing properties	No data available

9.2 Other safety information
No data available

10. STABILITY AND REACTIVITY

10.1 Reactivity

No data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

Vapours may form explosive mixture with air.

10.4 Conditions to avoid

Heat, flames and sparks.

10.5 Incompatible materials

Strong oxidizing agents

10.6 Hazardous decomposition products

Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity

LD50 Oral - Mouse - 5,000 mg/kg

LC50 Inhalation - Rat - 4 h - 364,000 mg/m3

LD50 Dermal - Rabbit - 3,000 mg/kg

No data available

Skin corrosion/irritation

Skin - Rabbit
Result: No skin irritation
(OECD Test Guideline 404)

Serious eye damage/eye irritation

No data available

Respiratory or skin sensitisation

No data available

Germ cell mutagenicity

Ames test
S. typhimurium
Result: negative

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels greater than or equal to 0.1% is on OSHA's list of regulated carcinogens.

Reproductive toxicity

No data available

No data available

Specific target organ toxicity - single exposure

May cause drowsiness or dizziness.

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information
RTECS: RZ9450000

Contact with eyes can cause:, Redness, Blurred vision, Provokes tears., Prolonged or repeated contact with skin may cause:, defatting, Dermatitis, Central nervous system depression, Damage to the lungs.
To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

Stomach - Irregularities - Based on Human Evidence
Stomach - Irregularities - Based on Human Evidence

---

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to daphnia and other aquatic invertebrates	EC50 - Daphnia magna (Water flea) - 9.74 mg/l - 48 h

12.2 Persistence and degradability

Biodegradability	Biotic/Aerobic - Exposure time 192 h Result: 70 % - Readily biodegradable.

12.3 Bioaccumulative potential

No data available

12.4 Mobility in soil

No data available

12.5 Results of PBT and vPvB assessment

PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects

An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Toxic to aquatic life with long lasting effects.

Avoid release to the environment. Do not empty into drains.

---

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

---

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1265 Class: 3 Packing group: II
Proper shipping name: Pentanes
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
UN number: 1265 Class: 3 Packing group: II EMS-No: F-E, S-D
Proper shipping name: PENTANES
Marine pollutant:yes

15. REGULATORY INFORMATION

SARA 302 Components

No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302. **SARA 313 Components**

This material does not contain any chemical components with known CAS numbers that exceed the threshold (De Minimis) reporting levels established by SARA Title III, Section 313.

SARA 311/312 Hazards

Fire Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
n-Pentane	109-66-0	1993-04-24

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
n-Pentane	109-66-0	1993-04-24

New Jersey Right To Know Components

	CAS-No.	Revision Date
n-Pentane	109-66-0	1993-04-24

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

---

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H224	Extremely flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H336	May cause drowsiness or dizziness.
H401	Toxic to aquatic life.
H411	Toxic to aquatic life with long lasting effects.
STOT SE	Specific target organ toxicity - single exposure

HMIS Rating

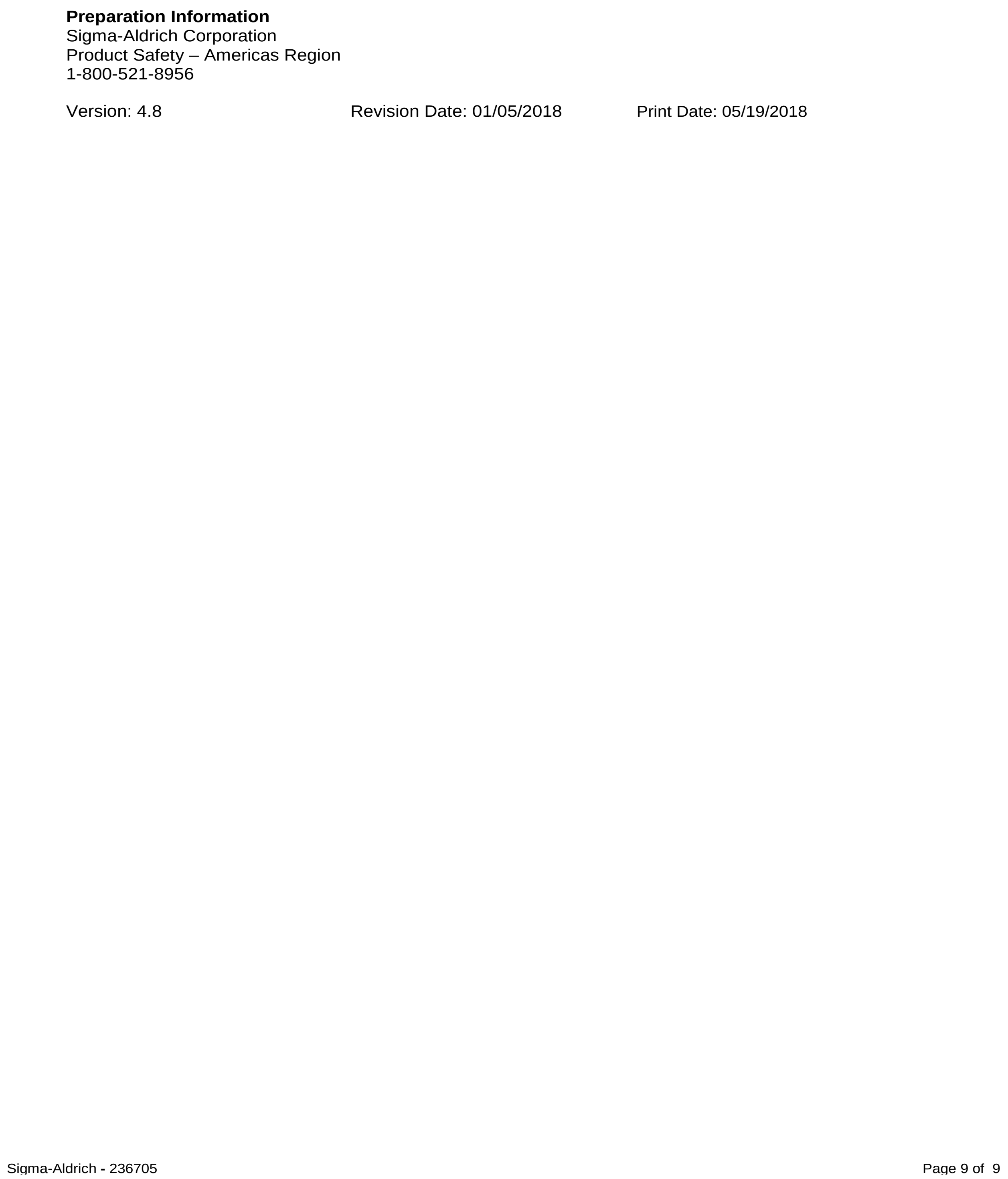
Health hazard:	0
Chronic Health Hazard:	*
Flammability:	4
Physical Hazard	0

NFPA Rating

Health hazard:	0
Fire Hazard:	4
Reactivity Hazard:	0

Further information

The above information is believed to be correct but does not purport to be all inclusive and shall be used only as a guide. The information in this document is based on the present state of our knowledge and is applicable to the product with regard to appropriate safety precautions. It does not represent any guarantee of the properties of the product. Sigma-Aldrich Corporation and its Affiliates shall not be held liable for any damage resulting from handling or from contact with the above product. See www.sigma-aldrich.com and/or the reverse side of invoice or packing slip for additional terms and conditions of sale.



Preparation Information
Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.8 Revision Date: 01/05/2018 Print Date: 05/19/2018

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Figure E-2 – Safety data sheet for pentane

SIGMA-ALDRICH

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SAFETY DATA SHEET

Version 5.2
Revision Date 02/17/2016
Print Date 05/19/2018

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1. PRODUCT AND COMPANY IDENTIFICATION

1.1Product identifiers

Product name : Hexane

Product Number : V001086
Brand : Vetec
Index-No. : 601-037-00-0

CAS-No. : 110-54-3

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

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2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Flammable liquids (Category 2), H225
Skin irritation (Category 2), H315
Reproductive toxicity (Category 2), H361
Specific target organ toxicity - single exposure (Category 3), Central nervous system, H336
Specific target organ toxicity - repeated exposure, Oral (Category 2), Nervous system, H373
Aspiration hazard (Category 1), H304
Acute aquatic toxicity (Category 2), H401
Chronic aquatic toxicity (Category 2), H411

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word Danger

Hazard statement(s)

H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H361	Suspected of damaging fertility or the unborn child.
H373	May cause damage to organs (Nervous system) through prolonged or

	repeated exposure if swallowed.
H411	Toxic to aquatic life with long lasting effects.

Precautionary statement(s)	
P201	Obtain special instructions before use.
P202	Do not handle until all safety precautions have been read and understood.
P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P233	Keep container tightly closed.
P240	Ground/bond container and receiving equipment.
P241	Use explosion-proof electrical/ ventilating/ lighting/ equipment.
P242	Use only non-sparking tools.
P243	Take precautionary measures against static discharge.
P260	Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P271	Use only outdoors or in a well-ventilated area.
P273	Avoid release to the environment.
P280	Wear protective gloves/ protective clothing/ eye protection/ face protection.
P301 + P310	IF SWALLOWED: Immediately call a POISON CENTER or doctor/ physician.
P303 + P361 + P353	IF ON SKIN (or hair): Remove/ Take off immediately all contaminated clothing. Rinse skin with water/ shower.
P304 + P340	IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
P308 + P313	IF exposed or concerned: Get medical advice/ attention.
P321	Specific treatment (see supplemental first aid instructions on this label).
P331	Do NOT induce vomiting.
P332 + P313	If skin irritation occurs: Get medical advice/ attention.
P362	Take off contaminated clothing and wash before reuse.
P370 + P378	In case of fire: Use dry sand, dry chemical or alcohol-resistant foam for extinction.
P391	Collect spillage.
P403 + P233	Store in a well-ventilated place. Keep container tightly closed.
P403 + P235	Store in a well-ventilated place. Keep cool.
P405	Store locked up.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3Hazards not otherwise classified (HNOC) or not covered by GHS - none

---

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.1Substances

Formula : C_6H_{14}
Molecular weight : 86.18 g/mol
CAS-No. : 110-54-3
EC-No. : 203-777-6
Index-No. : 601-037-00-0

Hazardous components

Component	Classification	Concentration
n-Hexane		
	Flam. Liq. 2; Skin Irrit. 2; Repr. 2; STOT SE 3; STOT RE 2; Asp. Tox. 1; Aquatic Acute 2; Aquatic Chronic 2; H225, H304, H315, H336, H361, H373, H411	<= 100 %

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.Move out of dangerous area.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Do NOT induce vomiting. Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING MEASURES

5.1 Extinguishing media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

Carbon oxides

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Remove all sources of ignition. Evacuate personnel to safe areas. Beware of vapours accumulating to form explosive concentrations. Vapours can accumulate in low areas.
For personal protection see section 8.

6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up

Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13).

6.4 Reference to other sections

For disposal see section 13.

7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid inhalation of vapour or mist.
Use explosion-proof equipment.Keep away from sources of ignition - No smoking.Take measures to prevent the build up of electrostatic charge.

For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Keep container tightly closed in a dry and well-ventilated place. Containers which are opened must be carefully resealed and kept upright to prevent leakage.

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

---

8. EXPOSURE CONTROLS/PERSONAL

PROTECTION 8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
n-Hexane	110-54-3	TWA	50.000000 ppm	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Central Nervous System impairment Eye irritation Peripheral neuropathy Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Danger of cutaneous absorption		
		TWA	50.000000 ppm 180.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	500.000000 ppm 1,800.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	50 ppm	USA. ACGIH Threshold Limit Values (TLV)
		Central Nervous System impairment Eye irritation Peripheral neuropathy Substances for which there is a Biological Exposure Index or Indices (see BEI® section) Danger of cutaneous absorption		
		TWA	50 ppm 180 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	500 ppm 1,800 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		The value in mg/m3 is approximate.		
		TWA	50 ppm 180 mg/m3	USA. OSHA - TABLE Z-1 Limits for Air Contaminants - 1910.1000

Biological occupational exposure limits

Component	CAS-No.	Parameters	Value	Biological specimen	Basis
n-Hexane	110-54-3	2,5-Hexanedione	0.4 mg/l	Urine	ACGIH - Biological Exposure Indices (BEI)
	Remarks	End of shift at end of workweek			

8.2 Exposure controls

Appropriate engineering controls

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection

Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection

Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Body Protection

Complete suit protecting against chemicals, Flame retardant antistatic protective clothing., The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection

Where risk assessment shows air-purifying respirators are appropriate use a full-face respirator with multi-purpose combination (US) or type ABEK (EN 14387) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure

Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: liquid Colour: colourless
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	7.0
e)	Melting point/freezing point	-95.0 °C (-139.0 °F)
f)	Initial boiling point and boiling range	68.0 - 70.0 °C (154.4 - 158.0 °F)
g)	Flash point	-26.0 °C (-14.8 °F) - closed cup
h)	Evaporation rate	15.8
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	Upper explosion limit: 7.7 %(V) Lower explosion limit: 1.2 %(V)
k)	Vapour pressure	341.3 hPa (256.0 mmHg) at 37.7 °C (99.9 °F) 176.0 hPa (132.0 mmHg) at 20.0 °C (68.0 °F)
l)	Vapour density	No data available
m)	Relative density	0.66 g/cm3
n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	log Pow: 3.90 - 4.11
p)	Auto-ignition temperature	234.0 °C (453.2 °F)
q)	Decomposition temperature	No data available

r) Viscosity No data available

s) Explosive properties No data available

t) Oxidizing properties No data available

9.2 Other safety information
No data available

---

10. STABILITY AND REACTIVITY

10.1 Reactivity
No data available

10.2 Chemical stability
Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions
Vapours may form explosive mixture with air.

10.4 Conditions to avoid
Heat, flames and sparks. Extremes of temperature and direct sunlight.

10.5 Incompatible materials
Oxidizing agents

10.6 Hazardous decomposition products
In the event of fire: see section 5

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11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity
LD50 Oral - Rat - 25,000 mg/kg

LC50 Inhalation - Rat - 4 h - 48000 ppm

Dermal: No data available

No data available

Skin corrosion/irritation
Irritating to skin.

Serious eye damage/eye irritation
Eyes - Rabbit
Result: Mild eye irritation

Respiratory or skin sensitisation
No data available

Germ cell mutagenicity
No data available

Carcinogenicity

IARC:	No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.
ACGIH:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by ACGIH.
NTP:	No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.
OSHA:	No component of this product present at levels greater than or equal to 0.1% is identified as a carcinogen or potential carcinogen by OSHA.

Overexposure may cause reproductive disorder(s) based on tests with laboratory animals. Suspected human reproductive toxicant Suspected of damaging fertility.

Specific target organ toxicity - single exposure
May cause drowsiness or dizziness.

Specific target organ toxicity - repeated exposure Ingestion - May cause damage to organs through prolonged or repeated exposure. - Nervous system

Aspiration hazard
May be fatal if swallowed and enters airways.

Additional Information
RTECS: MN9275000

Prolonged or repeated contact with skin may cause:, defatting, Dermatitis, Contact with eyes can cause:, Redness, Blurred vision, Provokes tears., Effects due to ingestion may include:, Gastrointestinal discomfort, Central nervous system depression, Lung irritation, chest pain, pulmonary edema, giddiness, slowed reaction time, slurred speech, Headache, Dizziness, Drowsiness, Unconsciousness

Testes. - Irregularities - Based on Human Evidence

12. ECOLOGICAL INFORMATION

12.1 Toxicity

Toxicity to fish	LC50 - Pimephales promelas (fathead minnow) - 2.5 mg/l - 96.0 h
Toxicity to daphnia and other aquatic invertebrates	EC50 - Daphnia magna (Water flea) - 3,878.00 mg/l - 48 h
Toxicity to algae	EC50 - Chlorella vulgaris (Fresh water algae) - 12,840.00 mg/l - 3 h
	EC50 - SKELETOMA - 0.30 mg/l - 8 h

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Toxic to aquatic life with long lasting effects.

13. DISPOSAL CONSIDERATIONS

13.1 Waste treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company. Contact a licensed professional waste disposal service to dispose of this material.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 1208 Class: 3 Packing group: II
Proper shipping name: Hexanes
Reportable Quantity (RQ): 5000 lbs

Poison Inhalation Hazard: No

IMDG

UN number: 1208	Class: 3	Packing group: II	EMS-No: F-E, S-D

Proper shipping name: HEXANES
Marine pollutant:yes

IATA

UN number: 1208	Class: 3	Packing group: II

15. REGULATORY INFORMATION

SARA 302 Components
No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components
The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

SARA 311/312 Hazards
Fire Hazard, Acute Health Hazard, Chronic Health Hazard

Massachusetts Right To Know Components

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

New Jersey Right To Know Components

	CAS-No.	Revision Date
n-Hexane	110-54-3	2007-07-01

California Prop. 65 Components
This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

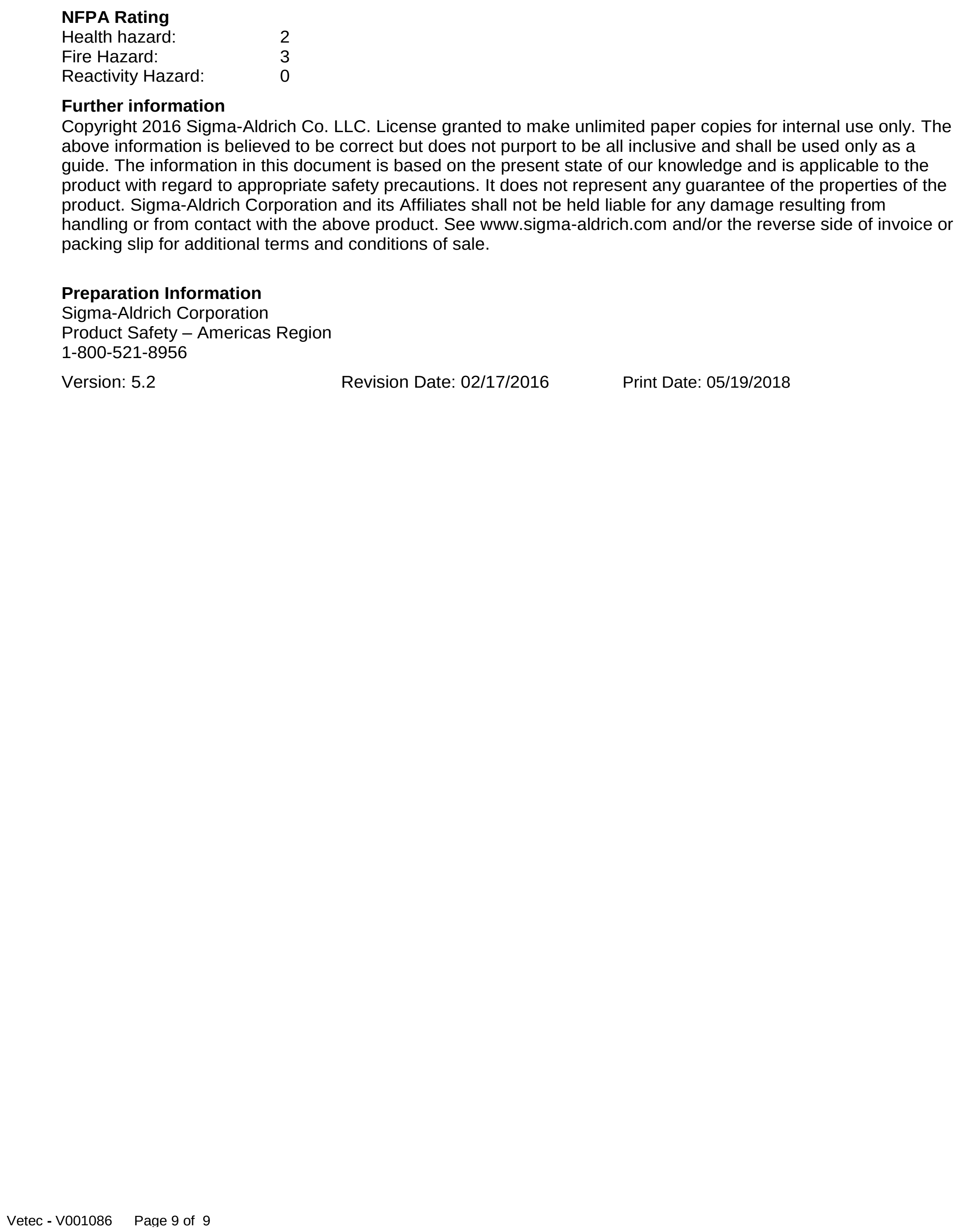
16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Asp. Tox.	Aspiration hazard
Flam. Liq.	Flammable liquids
H225	Highly flammable liquid and vapour.
H304	May be fatal if swallowed and enters airways.
H315	Causes skin irritation.
H336	May cause drowsiness or dizziness.
H361	Suspected of damaging fertility or the unborn child.
H373	May cause damage to organs through prolonged or repeated exposure if swallowed.
H401	Toxic to aquatic life.
H411	Toxic to aquatic life with long lasting effects.
Repr.	Reproductive toxicity

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	*
Flammability:	3
Physical Hazard	0



NFPA Rating

Health hazard:	2
Fire Hazard:	3
Reactivity Hazard:	0

Further information

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Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 5.2 Revision Date: 02/17/2016 Print Date: 05/19/2018

Figure E-3 – Safety data sheet for hexane

SECTION 1. PRODUCT AND COMPANY IDENTIFICATION

Product name : Toluene

Number : 000000020210

Product Use Description : Laboratory chemicals

Manufacturer or supplier's details : Honeywell International Inc.
1953 South Harvey Street
Muskegon, MI 49442

For more information call : 1-800-368-0050
+1-231-726-3171
(Monday-Friday, 9:00am-5:00pm)

In case of emergency call : **Medical: 1-800-498-5701 or +1-303-389-1414**
: **Transportation (CHEMTREC): 1-800-424-9300 or +1-703-527-3887**
:
: (24 hours/day, 7 days/week)

SECTION 2. HAZARDS IDENTIFICATION

Emergency Overview

Form : liquid

Color : colourless

Odor : sweet pungent

Classification of the substance or mixture

Classification of the substance or mixture : Flammable liquids, Category 2
Skin irritation, Category 2
Reproductive toxicity, Category 2
Specific target organ toxicity - single exposure, Category 3, Central nervous system
Specific target organ toxicity - repeated exposure, Category 2, Central nervous system, Kidney, Liver
Aspiration hazard, Category 1

GHS Label elements, including precautionary statements

Symbol(s) :

Signal word : Danger

Hazard statements : Highly flammable liquid and vapour.
May be fatal if swallowed and enters airways.
Causes skin irritation.
May cause drowsiness and dizziness.
Suspected of damaging fertility or the unborn child.
May cause damage to organs through prolonged or repeated exposure.

Precautionary statements : **Prevention:**
Obtain special instructions before use.
Do not handle until all safety precautions have been read and understood.
Keep away from heat/sparks/open flames/hot surfaces. No smoking.
Keep container tightly closed.
Ground/bond container and receiving equipment.
Use explosion-proof electrical/ ventilating/ lighting/ equipment.
Use only non-sparking tools.
Take precautionary measures against static discharge.
Do not breathe dust/ fume/ gas/ mist/ vapours/ spray.
Wash skin thoroughly after handling.
Use only outdoors or in a well-ventilated area.
Wear protective gloves/protective clothing/eye protection/face protection.

Response:
IF SWALLOWED: Immediately call a POISON CENTER/doctor.
IF ON SKIN (or hair): Remove/ Take off immediately all contaminated clothing. Rinse skin with water/ shower.
IF INHALED: Remove victim to fresh air and keep at rest in a position comfortable for breathing.
IF exposed or concerned: Get medical advice/ attention.
Do NOT induce vomiting.
If skin irritation occurs: Get medical advice/ attention.
Take off contaminated clothing and wash before reuse.
In case of fire: Use dry sand, dry chemical or alcohol-resistant foam for extinction.

Storage:
Store in a well-ventilated place. Keep container tightly closed.
Keep cool.

Store locked up.

Disposal:
Dispose of contents/ container to an approved waste disposal plant.

Carcinogenicity

No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP, IARC, or OSHA.

SECTION 3. COMPOSITION/INFORMATION ON INGREDIENTS

Formula : C7H8

Chemical nature : Substance

Chemical name	CAS-No.	Concentration
Toluene	108-88-3	100.00 %

SECTION 4. FIRST AID MEASURES

Inhalation	: Call a physician immediately. Remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Use oxygen as required, provided a qualified operator is present.
Skin contact	: Wash off immediately with plenty of water for at least 15 minutes. Take off contaminated clothing and shoes immediately. Wash contaminated clothing before re-use. Call a physician.
Eye contact	: Rinse immediately with plenty of water, also under the eyelids, for at least 15 minutes. Call a physician if irritation develops or persists.
Ingestion	: Do not induce vomiting without medical advice. If a person vomits when lying on his back, place him in the recovery position. Call a physician immediately. Never give anything by mouth to an unconscious person.

Notes to physician

Treatment : Treat symptomatically.

SECTION 5. FIREFIGHTING MEASURES

Suitable extinguishing media	: Foam Carbon dioxide (CO2) Dry chemical Cool closed containers exposed to fire with water spray.
Unsuitable extinguishing media	: Do not use a solid water stream as it may scatter and spread fire.
Specific hazards during firefighting	: Flammable. Vapours may form explosive mixtures with air. Vapours are heavier than air and may spread along floors. Vapors may travel to areas away from work site before igniting/flashing back to vapor source. In case of fire hazardous decomposition products may be produced such as: Carbon monoxide Carbon dioxide (CO2)
Special protective equipment for firefighters	: Wear an approved positive pressure self-contained breathing apparatus in addition to standard fire fighting gear.
Further information	: Use extinguishing measures that are appropriate to local circumstances and the surrounding environment.

SECTION 6. ACCIDENTAL RELEASE MEASURES

Personal precautions	: Wear personal protective equipment. Immediately evacuate personnel to safe areas. Keep people away from and upwind of spill/leak. Ensure adequate ventilation. Remove all sources of ignition. Do not swallow. Do not breathe vapours or spray mist. Avoid contact with skin, eyes and clothing.
Environmental precautions	: Prevent further leakage or spillage if safe to do so. Prevent product from entering drains. Discharge into the environment must be avoided.

Do not flush into surface water or sanitary sewer system.
Do not allow run-off from fire fighting to enter drains or water courses.

Methods for cleaning up : Ventilate the area.
No sparking tools should be used.
Use explosion-proof equipment.
Contain spillage, soak up with non-combustible absorbent material, (e.g. sand, earth, diatomaceous earth, vermiculite) and transfer to a container for disposal according to local / national regulations (see section 13).

SECTION 7. HANDLING AND STORAGE

Handling

Handling : Wear personal protective equipment.
Use only in well-ventilated areas.
Keep container tightly closed.
Do not smoke.
Do not swallow.
Do not breathe vapours or spray mist.
Avoid contact with skin, eyes and clothing.

Advice on protection against fire and explosion : Keep away from fire, sparks and heated surfaces.
Take precautionary measures against static discharges.
Ensure all equipment is electrically grounded before beginning transfer operations.
Use explosion-proof equipment.
Keep product and empty container away from heat and sources of ignition.
No sparking tools should be used.
No smoking.

Storage

Requirements for storage areas and containers : Store in area designed for storage of flammable liquids.
Protect from physical damage.
Keep containers tightly closed in a dry, cool and well-ventilated place.
Containers which are opened must be carefully resealed and kept upright to prevent leakage.
Keep away from heat and sources of ignition.
Keep away from direct sunlight.
Store away from incompatible substances.
Container hazardous when empty.
Do not pressurize, cut, weld, braze, solder, drill, grind or expose containers to heat or sources of ignition.

SECTION 8. EXPOSURE CONTROLS/PERSONAL PROTECTION

Protective measures : Ensure that eyewash stations and safety showers are close to the workstation location.
Legal requirements are to be considered in regard of the selection, use and care of personal protective equipment.
Do not breathe vapours or spray mist.

Engineering measures : Use with local exhaust ventilation.
Prevent vapour buildup by providing adequate ventilation during and after use.

Eye protection : Do not wear contact lenses.
Wear as appropriate:
Safety glasses with side-shields
If splashes are likely to occur, wear:
Goggles or face shield, giving complete protection to eyes

Hand protection : Solvent-resistant gloves
Gloves must be inspected prior to use.
Replace when worn.

Skin and body protection : Wear as appropriate:
Solvent-resistant apron
Flame retardant antistatic protective clothing.
If splashes are likely to occur, wear:
Protective suit

Respiratory protection : In case of insufficient ventilation, wear suitable respiratory equipment.

Hygiene measures : When using do not eat, drink or smoke.
Wash hands before breaks and immediately after handling the product.
Keep working clothes separately.
Remove and wash contaminated clothing before re-use.
Do not swallow.
Do not breathe vapours or spray mist.
Avoid contact with skin, eyes and clothing.
This material has an established AIHA ERPG exposure limit.
The current list of ERPG exposure limits can be found at http://www.aiha.org/insideaiha/GuidelineDevelopment/ERPG/Documents/2011erpgweelhandbook_table -only.pdf.

Exposure Guidelines

Components	CAS-No.	Value	Control parameters	Update	Basis

Toluene	108-88-3	TWA : Time weighted average	(20 ppm)	2008	ACGIH:US. ACGIH Threshold Limit Values
Toluene	108-88-3	REL : Recommended exposure limit (REL):	375 mg/m3 (100 ppm)	2005	NIOSH/GUIDE:US. NIOSH: Pocket Guide to Chemical Hazards
Toluene	108-88-3	STEL : Short term exposure limit	560 mg/m3 (150 ppm)	2005	NIOSH/GUIDE:US. NIOSH: Pocket Guide to Chemical Hazards
Toluene	108-88-3	STEL : Short term exposure limit	560 mg/m3 (150 ppm)	1989	Z1A:US. OSHA Table Z-1-A (29 CFR 1910.1000)
Toluene	108-88-3	TWA : Time weighted average	375 mg/m3 (100 ppm)	1989	Z1A:US. OSHA Table Z-1-A (29 CFR 1910.1000)
Toluene	108-88-3	TWA : Time weighted average	(200 ppm)	02 2006	OSHA/Z2:US. OSHA Table Z-2 (29 CFR 1910.1000)
Toluene	108-88-3	MAX. CONC : Maximum concentration:	(500 ppm)	02 2006	OSHA/Z2:US. OSHA Table Z-2 (29 CFR 1910.1000)
Toluene	108-88-3	Ceiling : Ceiling Limit Value:	(300 ppm)	02 2006	OSHA/Z2:US. OSHA Table Z-2 (29 CFR 1910.1000)

SECTION 9. PHYSICAL AND CHEMICAL PROPERTIES

Physical state	: liquid
Color	: colourless
Odor	: sweet pungent
pH	: Note: no data available
Melting point/range	: -95 °C
Boiling point/boiling range	: 110.6 °C
Flash point	: 39 °F (4 °C) Method: closed cup
Lower explosion limit	: 1.1 %(V)
Upper explosion limit	: 7.1 %(V)
Vapor pressure	: 38 hPa at 25 °C(77 °F)
Vapor density	: 3.1 Note: (Air = 1.0)
Density	: 0.867 g/cm3 at 20 °C
Water solubility	: 0.74 g/l at 20 °C
Solubility in other solvents	: Note: Soluble in most organic solvents
Ignition temperature	: 480 °C
Molecular weight	: 92.14 g/mol

SECTION 10. STABILITY AND REACTIVITY

Chemical stability	: Stable under recommended storage conditions.
Possibility of hazardous reactions	: Hazardous polymerisation does not occur.
Conditions to avoid	: Heat, flames and sparks. Keep away from direct sunlight.
Incompatible materials to avoid	: Strong oxidizing agents Strong acids and strong bases May attack many plastics, rubbers and coatings.
Hazardous decomposition products	: In case of fire hazardous decomposition products may be produced such as: Carbon monoxide Carbon dioxide (CO2)

SECTION 11. TOXICOLOGICAL INFORMATION

Acute oral toxicity	: LD50: > 5,000 mg/kg Species: Rat Method: EC Directive 92/69/EEC B.1 Acute Toxicity (Oral)
Acute inhalation toxicity	: LC50: > 20 mg/l Exposure time: 4 h Species: Rat Method: OECD Test Guideline 403
Acute dermal toxicity	: LD50: > 5,000 mg/kg Species: Rabbit
Skin irritation	: Species: Rabbit Result: Irritating to skin.
Eye irritation	: Species: Rabbit Result: slight irritation

		Method: OECD Test Guideline 405
Sensitisation	:	Species: Guinea pig Result: non-sensitizing Method: EEC 92/69, B.6
Repeated dose toxicity	:	Species: Rat Application Route: Inhalation Exposure time: 15 Weeks Note: Chronic toxicity 2500 ppm Based on experimental results, may cause adverse health effects on the following: Heart Liver Kidney Urinary tract Bladder
Genotoxicity in vitro	:	Test Method: Ames test Result: negative
	:	Test Method: Chromosome aberration test in vitro Cell type: Chinese Hamster Ovary Cells Result: negative
Aspiration toxicity	:	May be fatal if swallowed and enters airways.

SECTION 12. ECOLOGICAL INFORMATION

Ecotoxicity effects

Toxicity to fish	:	flow-through test LC50: 5.5 mg/l Exposure time: 96 h Species: Oncorhynchus kisutch (coho salmon)
Toxicity to daphnia and other aquatic invertebrates	:	LC50: 3.78 mg/l Exposure time: 48 h Species: Ceriodaphnia dubia (water flea)
Toxicity to algae	:	static test EC50: 207 mg/l Exposure time: 3 h Species: Chlorella vulgaris (Fresh water algae)

Toxicity to bacteria	: EC50: 19.7 mg/l Exposure time: 0.5 h Species: Photobacterium phosphoreum

Elimination information (persistence and degradability)

Biodegradability	: Result: Readily biodegradable Value: 81 %

Further information on ecology

Additional ecological information	: Bioaccumulation is unlikely. Harmful to aquatic organisms.

SECTION 13. DISPOSAL CONSIDERATIONS

Disposal methods	: Observe all Federal, State, and Local Environmental regulations.

SECTION 14. TRANSPORT INFORMATION

DOT	UN/ID No.	: UN 1294
	Proper shipping name	: TOLUENE
	Class	3
	Packing group	II
	Hazard Labels	3
IATA	UN/ID No.	: UN 1294
	Description of the goods	: TOLUENE
	Class	: 3
	Packaging group	: II
	Hazard Labels	: 3
	Packing instruction (cargo aircraft)	: 364
	Packing instruction (passenger aircraft)	: 353
	Packing instruction (passenger aircraft)	: Y341
IMDG	UN/ID No.	: UN 1294
	Description of the goods	: TOLUENE
	Class	: 3
	Packaging group	: II

Hazard Labels	: 3
EmS Number	: F-E, S-D
Marine pollutant	: no

SECTION 15. REGULATORY INFORMATION

Inventories

US. Toxic Substances Control Act	: On TSCA Inventory
Australia. Industrial Chemical (Notification and Assessment) Act	: On the inventory, or in compliance with the inventory
Canada. Canadian Environmental Protection Act (CEPA). Domestic Substances List (DSL)	: All components of this product are on the Canadian DSL
Japan. Kashin-Hou Law List	: On the inventory, or in compliance with the inventory
Korea. Toxic Chemical Control Law (TCCL) List	: On the inventory, or in compliance with the inventory
Philippines. The Toxic Substances and Hazardous and Nuclear Waste Control Act	: On the inventory, or in compliance with the inventory
China. Inventory of Existing Chemical Substances	: On the inventory, or in compliance with the inventory
New Zealand. Inventory of Chemicals (NZIoC), as published by ERMA New Zealand	: On the inventory, or in compliance with the inventory

National regulatory information

SARA 302 Components	: No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.
SARA 313 Components	: The following components are subject to reporting levels established by SARA Title III, Section 313: : Toluene 108-88-3

SARA 311/312 Hazards : Fire Hazard
Acute Health Hazard
Chronic Health Hazard

CERCLA Reportable Quantity : 1000 lbs

California Prop. 65 : WARNING! This product contains a chemical known to the State of California to cause cancer.

Benzene	71-43-2

: WARNING: This product contains a chemical known to the State of California to cause birth defects or other reproductive harm.

Toluene	108-88-3
Benzene	71-43-2

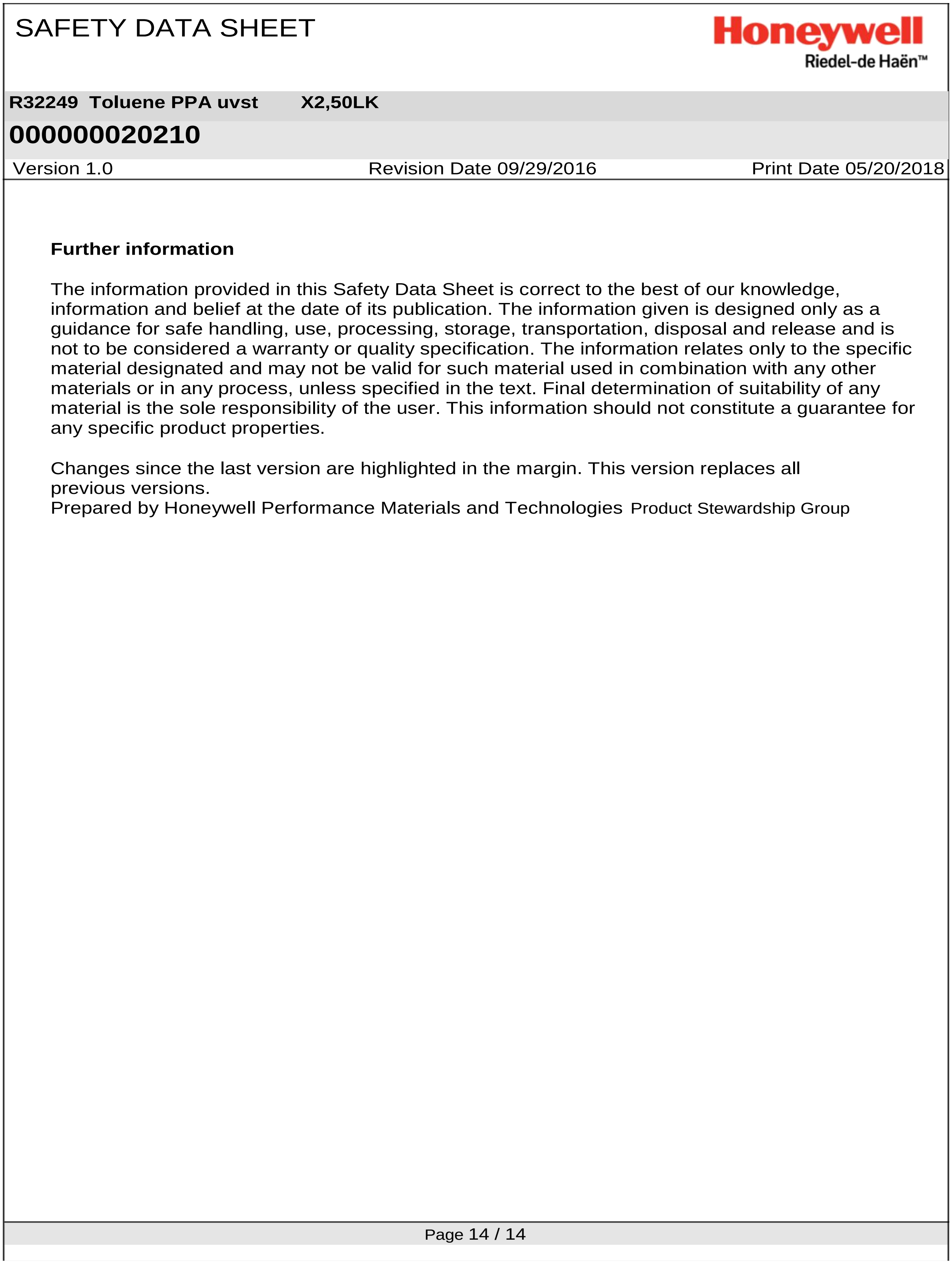
Massachusetts RTK	: Toluene	108-88-3
	: Benzene	71-43-2
New Jersey RTK	: Toluene	108-88-3
Pennsylvania RTK	: Toluene	108-88-3
	: Benzene	71-43-2

SECTION 16. OTHER INFORMATION

	HMIS III	**NFPA**
Health hazard	: 2*	2
Flammability	: 3	3
Physical Hazard	: 0	
Instability	:	0

* - Chronic health hazard

Hazard rating and rating systems (e.g. HMIS® III, NFPA): This information is intended solely for the use of individuals trained in the particular system.



SAFETY DATA SHEET

Honeywell
Riedel-de Haën™

R32249 Toluene PPA uvst X2,50LK

000000020210

Version 1.0 Revision Date 09/29/2016 Print Date 05/20/2018

Further information

The information provided in this Safety Data Sheet is correct to the best of our knowledge, information and belief at the date of its publication. The information given is designed only as a guidance for safe handling, use, processing, storage, transportation, disposal and release and is not to be considered a warranty or quality specification. The information relates only to the specific material designated and may not be valid for such material used in combination with any other materials or in any process, unless specified in the text. Final determination of suitability of any material is the sole responsibility of the user. This information should not constitute a guarantee for any specific product properties.

Changes since the last version are highlighted in the margin. This version replaces all previous versions.
Prepared by Honeywell Performance Materials and Technologies Product Stewardship Group

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Figure E-4 – Safety data sheet for toluene

SIGMA-ALDRICH

sigma-aldrich.com

SAFETY DATA SHEET

Version 4.12
Revision Date 02/02/2018
Print Date 05/19/2018

1. PRODUCT AND COMPANY IDENTIFICATION

1.1Product identifiers

Product name : Luperox® A75, Benzoyl peroxide

Product Number : 517909
Brand : Aldrich

CAS-No. : 94-36-0

1.2 Relevant identified uses of the substance or mixture and uses advised against

Identified uses : Laboratory chemicals, Synthesis of substances

1.3 Details of the supplier of the safety data sheet

Company : Sigma-Aldrich
3050 Spruce Street
SAINT LOUIS MO 63103
USA

Telephone : +1 800-325-5832
Fax : +1 800-325-5052

1.4 Emergency telephone number

Emergency Phone # : +1-703-527-3887 (CHEMTREC)

2. HAZARDS IDENTIFICATION

2.1 Classification of the substance or mixture

GHS Classification in accordance with 29 CFR 1910 (OSHA HCS)
Organic peroxides (Type C), H242
Eye irritation (Category 2A), H319
Skin sensitisation (Category 1), H317
Acute aquatic toxicity (Category 1), H400
Chronic aquatic toxicity (Category 1), H410

For the full text of the H-Statements mentioned in this Section, see Section 16.

2.2 GHS Label elements, including precautionary statements

Pictogram

Signal word : Danger

Hazard statement(s)

H242	Heating may cause a fire.
H317	May cause an allergic skin reaction.
H319	Causes serious eye irritation.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P220	Keep/Store away from clothing/ combustible materials.
P234	Keep only in original container.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P272	Contaminated work clothing should not be allowed out of the workplace.

P280	Wear protective gloves/ protective clothing/ eye protection/ face protection.
P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P321	Specific treatment (see supplemental first aid instructions on this label).
P333 + P313	If skin irritation or rash occurs: Get medical advice/ attention.
P337 + P313	If eye irritation persists: Get medical advice/ attention.
P363	Wash contaminated clothing before reuse.
P410	Protect from sunlight.
P411 + P235	Store at temperatures not exceeding 38 °C/ 100 °F. Keep cool.
P420	Store away from other materials.
P501	Dispose of contents/ container to an approved waste disposal plant.

Pictogram

Signal word Danger

Hazard statement(s)

H242	Heating may cause a fire.
H317	May cause an allergic skin reaction.
H319	Causes serious eye irritation.
H410	Very toxic to aquatic life with long lasting effects.

Precautionary statement(s)

P210	Keep away from heat/sparks/open flames/hot surfaces. No smoking.
P220	Keep/Store away from clothing/ combustible materials.
P234	Keep only in original container.
P261	Avoid breathing dust/ fume/ gas/ mist/ vapours/ spray.
P264	Wash skin thoroughly after handling.
P272	Contaminated work clothing should not be allowed out of the workplace.
P273	Avoid release to the environment.
P280	Wear protective gloves/ eye protection/ face protection.
P302 + P352	IF ON SKIN: Wash with plenty of soap and water.
P305 + P351 + P338	IF IN EYES: Rinse cautiously with water for several minutes. Remove contact lenses, if present and easy to do. Continue rinsing.
P333 + P313	If skin irritation or rash occurs: Get medical advice/ attention.
P337 + P313	If eye irritation persists: Get medical advice/ attention.
P363	Wash contaminated clothing before reuse.
P391	Collect spillage.
P410	Protect from sunlight.
P411 + P235	Store at temperatures not exceeding .? °C/ .? °F. Keep cool.
P420	Store away from other materials.
P501	Dispose of contents/ container to an approved waste disposal plant.

2.3Hazards not otherwise classified (HNOC) or not covered by GHS

Explosive when dry.

3. COMPOSITION/INFORMATION ON INGREDIENTS

3.2Mixtures

Synonyms : Dibenzoyl peroxide
Benzoyl peroxide

Formula : $C_{14}H_{10}O_4$

Molecular weight : 242.23 g/mol

Hazardous components

Component		Classification	Concentration
Benzoyl peroxide			
CAS-No. EC-No.	94-36-0 202-327-6	Org. Perox. B; Eye Irrit. 2A; Skin Sens. 1; Aquatic Acute 1;	70 - 90 %

Index-No.	617-008-00-0	Aquatic Chronic 1; H241, H317, H319, H241, H317, H319, H410	

For the full text of the H-Statements mentioned in this Section, see Section 16.

4. FIRST AID MEASURES

4.1 Description of first aid measures

General advice
Consult a physician. Show this safety data sheet to the doctor in attendance.

If inhaled
If breathed in, move person into fresh air. If not breathing, give artificial respiration. Consult a physician.

In case of skin contact
Wash off with soap and plenty of water. Consult a physician.

In case of eye contact
Rinse thoroughly with plenty of water for at least 15 minutes and consult a physician.

If swallowed
Never give anything by mouth to an unconscious person. Rinse mouth with water. Consult a physician.

4.2 Most important symptoms and effects, both acute and delayed

The most important known symptoms and effects are described in the labelling (see section 2.2) and/or in section 11

4.3 Indication of any immediate medical attention and special treatment needed

No data available

5. FIREFIGHTING

MEASURES 5.1 Extinguishing

media

Suitable extinguishing media
Use water spray, alcohol-resistant foam, dry chemical or carbon dioxide.

5.2 Special hazards arising from the substance or mixture

No data available

5.3 Advice for firefighters

Wear self-contained breathing apparatus for firefighting if necessary.

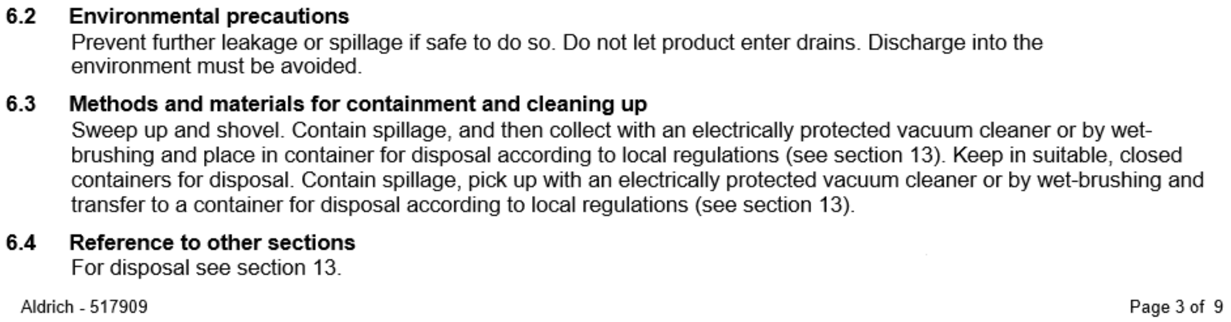
5.4 Further information

Use water spray to cool unopened containers.

6. ACCIDENTAL RELEASE MEASURES

6.1 Personal precautions, protective equipment and emergency procedures

Use personal protective equipment. Avoid dust formation. Avoid breathing vapours, mist or gas. Ensure adequate ventilation. Evacuate personnel to safe areas. Avoid breathing dust. For personal protection see section 8.



6.2 Environmental precautions

Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

6.3 Methods and materials for containment and cleaning up

Sweep up and shovel. Contain spillage, and then collect with an electrically protected vacuum cleaner or by wet-brushing and place in container for disposal according to local regulations (see section 13). Keep in suitable, closed containers for disposal. Contain spillage, pick up with an electrically protected vacuum cleaner or by wet-brushing and transfer to a container for disposal according to local regulations (see section 13).

6.4 Reference to other sections

For disposal see section 13.

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7. HANDLING AND STORAGE

7.1 Precautions for safe handling

Avoid contact with skin and eyes. Avoid formation of dust and aerosols.Further processing of solid materials may result in the formation of combustible dusts. The potential for combustible dust formation should be taken into consideration before additional processing occurs.
Provide appropriate exhaust ventilation at places where dust is formed.Keep away from sources of ignition - No smoking.Keep away from heat and sources of ignition.
For precautions see section 2.2.

7.2 Conditions for safe storage, including any incompatibilities

Store in original container. Keep container tightly closed in a dry and well-ventilated place.

Recommended storage temperature 2 - 8 °C
Storage class (TRGS 510): 5.2: Organic peroxides and self-reacting hazardous materials

7.3 Specific end use(s)

Apart from the uses mentioned in section 1.2 no other specific uses are stipulated

8. EXPOSURE CONTROLS/PERSONAL PROTECTION 8.1 Control parameters

Components with workplace control parameters

Component	CAS-No.	Value	Control parameters	Basis
Benzoyl peroxide	94-36-0	TWA	5 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
	Remarks	Upper Respiratory Tract irritation Skin irritation Not classifiable as a human carcinogen		
		TWA	5.000000 mg/m3	USA. ACGIH Threshold Limit Values (TLV)
		Upper Respiratory Tract irritation Skin irritation Not classifiable as a human carcinogen		
		TWA	5.000000 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		TWA	5.000000 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	5 mg/m3	USA. NIOSH Recommended Exposure Limits
		TWA	5 mg/m3	USA. Occupational Exposure Limits (OSHA) - Table Z-1 Limits for Air Contaminants
		PEL	5 mg/m3	California permissible exposure limits for chemical contaminants (Title 8, Article 107)

8.2 Exposure controls

Appropriate engineering controls

Handle in accordance with good industrial hygiene and safety practice. Wash hands before breaks and at the end of workday.

Personal protective equipment

Eye/face protection

Face shield and safety glasses Use equipment for eye protection tested and approved under appropriate government standards such as NIOSH (US) or EN 166(EU).

Skin protection
Handle with gloves. Gloves must be inspected prior to use. Use proper glove removal technique (without touching glove's outer surface) to avoid skin contact with this product. Dispose of contaminated gloves after use in accordance with applicable laws and good laboratory practices. Wash and dry hands.

Full contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

Splash contact
Material: Nitrile rubber
Minimum layer thickness: 0.11 mm
Break through time: 480 min
Material tested:Dermatril® (KCL 740 / Aldrich Z677272, Size M)

data source: KCL GmbH, D-36124 Eichenzell, phone +49 (0)6659 87300, e-mail sales@kcl.de, test method: EN374
If used in solution, or mixed with other substances, and under conditions which differ from EN 374, contact the supplier of the CE approved gloves. This recommendation is advisory only and must be evaluated by an industrial hygienist and safety officer familiar with the specific situation of anticipated use by our customers. It should not be construed as offering an approval for any specific use scenario.

Body Protection
Complete suit protecting against chemicals, The type of protective equipment must be selected according to the concentration and amount of the dangerous substance at the specific workplace.

Respiratory protection
Where risk assessment shows air-purifying respirators are appropriate use a full-face particle respirator type N100 (US) or type P3 (EN 143) respirator cartridges as a backup to engineering controls. If the respirator is the sole means of protection, use a full-face supplied air respirator. Use respirators and components tested and approved under appropriate government standards such as NIOSH (US) or CEN (EU).

Control of environmental exposure
Prevent further leakage or spillage if safe to do so. Do not let product enter drains. Discharge into the environment must be avoided.

---

9. PHYSICAL AND CHEMICAL PROPERTIES

9.1 Information on basic physical and chemical properties

a)	Appearance	Form: solid
b)	Odour	No data available
c)	Odour Threshold	No data available
d)	pH	No data available
e)	Melting point/freezing point	Melting point/range: 105 °C (221 °F) - lit.
f)	Initial boiling point and boiling range	No data available
g)	Flash point	No data available
h)	Evaporation rate	No data available
i)	Flammability (solid, gas)	No data available
j)	Upper/lower flammability or explosive limits	No data available
k)	Vapour pressure	No data available
l)	Vapour density	No data available
m)	Relative density	No data available

n)	Water solubility	insoluble
o)	Partition coefficient: n-octanol/water	No data available
p)	Auto-ignition temperature	80 °C (176 °F)
q)	Decomposition temperature	No data available
r)	Viscosity	No data available
s)	Explosive properties	Explosive when dry.
t)	Oxidizing properties	No data available

9.2 Other safety information

No data available

---

10. STABILITY AND REACTIVITY

10.1 Reactivity

No data available

10.2 Chemical stability

Stable under recommended storage conditions.

10.3 Possibility of hazardous reactions

No data available

10.4 Conditions to avoid

Heat, flames and sparks.

10.5 Incompatible materials

Metals, Alcohols

10.6 Hazardous decomposition products

Hazardous decomposition products formed under fire conditions. - Carbon oxides
Other decomposition products - No data available
In the event of fire: see section 5

---

11. TOXICOLOGICAL INFORMATION

11.1 Information on toxicological effects

Acute toxicity

No data available

Inhalation: No data available

Dermal: No data available

No data available

Skin corrosion/irritation

No data available

Serious eye damage/eye irritation

No data available

Respiratory or skin sensitisation

No data available

Germ cell mutagenicity

No data available

Carcinogenicity

IARC: No component of this product present at levels greater than or equal to 0.1% is identified as probable, possible or confirmed human carcinogen by IARC.

NTP: No component of this product present at levels greater than or equal to 0.1% is identified as a known or anticipated carcinogen by NTP.

OSHA: No component of this product present at levels than or equal to 0.1% is on OSHA's greater list of regulated carcinogens.

Reproductive toxicity
No data available
No data available

Specific target organ toxicity - single exposure
No data available

Specific target organ toxicity - repeated exposure
No data available

Aspiration hazard
No data available

Additional Information
RTECS: Not available

To the best of our knowledge, the chemical, physical, and toxicological properties have not been thoroughly investigated.

12. ECOLOGICAL INFORMATION

12.1 Toxicity
No data available

12.2 Persistence and degradability
No data available

12.3 Bioaccumulative potential
No data available

12.4 Mobility in soil
No data available

12.5 Results of PBT and vPvB assessment
PBT/vPvB assessment not available as chemical safety assessment not required/not conducted

12.6 Other adverse effects
An environmental hazard cannot be excluded in the event of unprofessional handling or disposal.
Very toxic to aquatic life with long lasting effects.

13. DISPOSAL

CONSIDERATIONS 13.1 Waste

treatment methods

Product
Burn in a chemical incinerator equipped with an afterburner and scrubber but exert extra care in igniting as this material is highly flammable. Offer surplus and non-recyclable solutions to a licensed disposal company.

Contaminated packaging
Dispose of as unused product.

14. TRANSPORT INFORMATION

DOT (US)
UN number: 3104 Class: 5.2
Proper shipping name: Organic peroxide type C, solid (Dibenzoyl peroxide, ≤77%)
Reportable Quantity (RQ):
Poison Inhalation Hazard: No

IMDG
UN number: 3104 Class: 5.2 EMS-No: F-J, S-R
Proper shipping name: ORGANIC PEROXIDE TYPE C, SOLID (DIBENZOYL PEROXIDE)

IATA

UN number: 3104 Class: 5.2 (HEAT)

Proper shipping name: Organic peroxide type C, solid (Dibenzoyl peroxide)Special Provisions: “Keep away from heat” label required.

---

15. REGULATORY INFORMATION

SARA 302 Components

No chemicals in this material are subject to the reporting requirements of SARA Title III, Section 302.

SARA 313 Components

The following components are subject to reporting levels established by SARA Title III, Section 313:

	CAS-No.	Revision Date
Benzoyl peroxide	94-36-0	2007-07-01

Massachusetts Right To Know Components

	CAS-No.	Revision Date
Benzoyl peroxide	94-36-0	2007-07-01

Pennsylvania Right To Know Components

	CAS-No.	Revision Date
Benzoyl peroxide	94-36-0	2007-07-01
Water	7732-18-5	

New Jersey Right To Know Components

	CAS-No.	Revision Date
Benzoyl peroxide	94-36-0	2007-07-01
Water	7732-18-5	

California Prop. 65 Components

This product does not contain any chemicals known to State of California to cause cancer, birth defects, or any other reproductive harm.

---

16. OTHER INFORMATION

Full text of H-Statements referred to under sections 2 and 3.

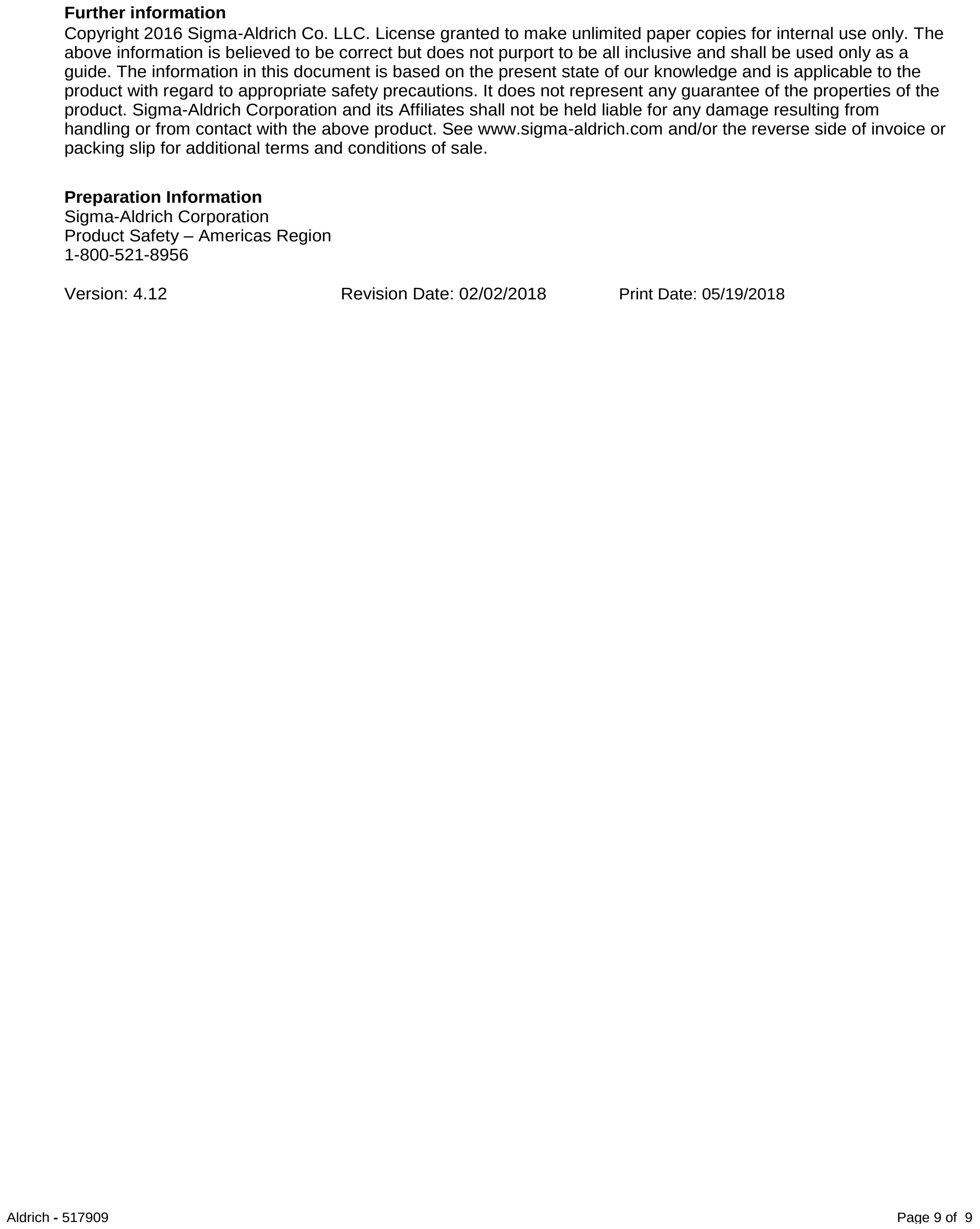
Aquatic Acute	Acute aquatic toxicity
Aquatic Chronic	Chronic aquatic toxicity
Eye Irrit.	Eye irritation
H241	Heating may cause a fire or explosion.
H242	Heating may cause a fire.
H317	May cause an allergic skin reaction.
H319	Causes serious eye irritation.
H400	Very toxic to aquatic life.
H410	Very toxic to aquatic life with long lasting effects.
Org. Perox.	Organic peroxides
Skin Sens.	Skin sensitisation

HMIS Rating

Health hazard:	2
Chronic Health Hazard:	
Flammability:	0
Physical Hazard	1

NFPA Rating

Health hazard:	2
Fire Hazard:	0
Reactivity Hazard:	1
Special hazard.I:	OX



Further information

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Preparation Information

Sigma-Aldrich Corporation
Product Safety – Americas Region
1-800-521-8956

Version: 4.12 Revision Date: 02/02/2018 Print Date: 05/19/2018

Figure E-5 – Safety data sheet for benzoyl peroxide

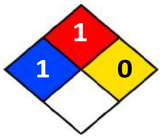
SAFETY DATA SHEET
GREEN SOLVENT MS

Date Issued: September 7, 2017
Revision No: 1

Section 1: PRODUCT AND COMPANY IDENTIFICATION

Manufacturer: Ethical Solutions, LLC
Address: 177 Governor's Hwy, South Windsor, CT 06074
Phone Number: (860) 640-0074

Product Name: Green Solvent MS
Issue Date: September 7, 2017



Section 2: HAZARDS IDENTIFICATION

Emergency Overview

Appearance/Odor: Yellow/amber liquid.

Stability: Stable under normal conditions.

Potential Health Effects: See Section 11 for more information.

Likely Routes of Exposure: Eye contact, skin contact, inhalation.
Eye: Causes irritation and redness.
Skin: May cause dermatitis on contact.
Inhalation: May cause nose, throat, and respiratory tract irritation, coughing, headache.
Ingestion: Not likely to be toxic, but ingestion may cause irritation of the gastrointestinal tract.

Medical Conditions Aggravated By Exposure: May irritate the skin. May cause skin dermatitis on contact.

This product does not contain any carcinogens or potential carcinogens as listed by OSHA, IARC, ACGIH or NTP.

Section 3: COMPOSITION/INFORMATION ON INGREDIENTS

	Percent	**CAS**
Plant-based oil	100%	Proprietary

Section 4: FIRST AID MEASURES

Eye Contact:
Remove contacts at once. Flush with water for at least 15 minutes. If irritation persists, seek medical attention.

Skin Contact:
Wash affected area with copious amounts of soap and water for at least 15 minutes. Remove contaminated clothing. If irritation develops, seek medical attention.

Inhalation:
Move to fresh air immediately. If breathing is difficult or discomfort persists, seek medical attention.

Ingestion:
Rinse mouth with water. Do not induce vomiting. Seek medical attention immediately. Do not administer anything by mouth to an unconscious person. Do not leave victim unattended.

General:

As with any chemical, employees should thoroughly wash hands with soap and water.

Section 5: FIRE FIGHTING MEASURES

Suitable Extinguishing Media: Carbon dioxide, alcohol resistant foam and water spray.

Unsuitable Extinguishing Media: None known.

Products of Combustion: Carbon monoxide, carbon dioxide.

Protection of Firefighters:
Vapors may be irritating to eyes, skin and respiratory tract. Firefighters should wear self-contained breathing apparatus (SCBA) and full fire-fighting turnout gear.

Section 6: ACCIDENTAL RELEASE MEASURES

Methods for Accidental Release:
Use personal protection recommended in Section 8. Product is slippery when spilled. Dike spill area and cap leaking containers as necessary to prevent further spreading of spilled material. Contain spill.

Larger spills should be contained by blocking access to nearby sewers, drains, or bodies of water. Rinse any cloth or paper materials with water prior to disposal if they come in contact with material.

Waste Disposal:
Manage in accordance with applicable local, state, and federal waste regulations.

Other Information: Keep out of streams, rivers and lakes. Mixture is regulated as oil under the Clean Water Act. Abide by all laws per this regulation.

Section 7: HANDLING AND STORAGE

Handling
Normal precautions should be observed as for handling all chemicals. Keep away from heat, sparks and flame. Open container slowly to release pressure caused by temperature variation. Wear chemical splash goggles or face shield if potential for splashing. Wear chemical resistant gloves and avoid direct and prolonged contact with skin.

Avoid prolonged contact with skin. Use in well ventilated areas. Do not breathe vapors. Thoroughly wash hands with soap and water after handling this material.

Storage

Storage area:	Store in dry area. Store at room temperature. Store in dyke area to contain any spills. Protect from heat.
Packaging materials:	Polyethylene, stainless steel (grade 304) and rubber lined or epoxy lined tanks or drums. Graphite or rubber gaskets. : Kraft or polyethylene bags for flake, bead or powder form.
Incompatibilities:	Strong oxidizers.

Section 8: EXPOSURE CONTROLS/PERSONAL PROTECTION

Engineering Controls: Provide ventilation to minimize the release of vapors and mist into the work environment. Spills should be minimized or confined to prevent release from work area. Remove contaminated clothing immediately and wash before reuse.

Eye/Face Protection: Wear chemical splash-type safety glasses or goggles. Use full face mask if severe splashing is expected during use.

Skin Protection: Nitrile gloves are recommended. Wear boots, apron, or chemical resistant clothing as necessary.

Respiratory Protection: Not normally required. If adequate ventilation is unavailable, use NIOSH/DHHS approved air-purifying respirator (APR) with organic vapor cartridge or canister.

General Hygiene Considerations: As with any chemical, wash hands thoroughly after handling. Have eyewash facilities immediately available. Launder contaminated clothing before reuse.

Section 9: PHYSICAL AND CHEMICAL PROPERTIES

Color:	Yellow	**Odor:**	Mild
Physical State:	Liquid	**Boiling Point:**	200°C
Specific Gravity:	0.88 @ 25°C	**Vapor Pressure**:	N/A
Flash Point:	>200°F	**Solubility:**	Soluble in ethanol and acetone

Note: These specifications represent a typical sample of this product, but actual values may vary. Certificates of Analysis and Specification Sheets are available upon request.

Section 10: STABILITY AND REACTIVITY

Stability: Stable.

Conditions to Avoid: None

Incompatible Materials: Strong oxidizing agents

Hazardous Decomposition Products: Carbon dioxide and carbon monoxide

Section 11: ECOLOGICAL INFORMATION

Ecotoxicity: No information available.

Persistence/Degradability: No information available.

Bioaccumulation/Accumulation: No information available.

Mobility in Environment: Volatilize rapidly.

Carcinogenicity:

National Toxicology Program:	Not listed.
International Agency for Research on Cancer:	Not listed.
OSHA:	Not listed.
NIOSH:	Not listed.

Section 12: DISPOSAL CONSIDERATIONS

Disposal:
Manage in accordance with applicable local, state, and federal waste regulations. Upon dilution with water as recommended for typical use, product is not regulated or an EPA listed or characteristic material or substance.

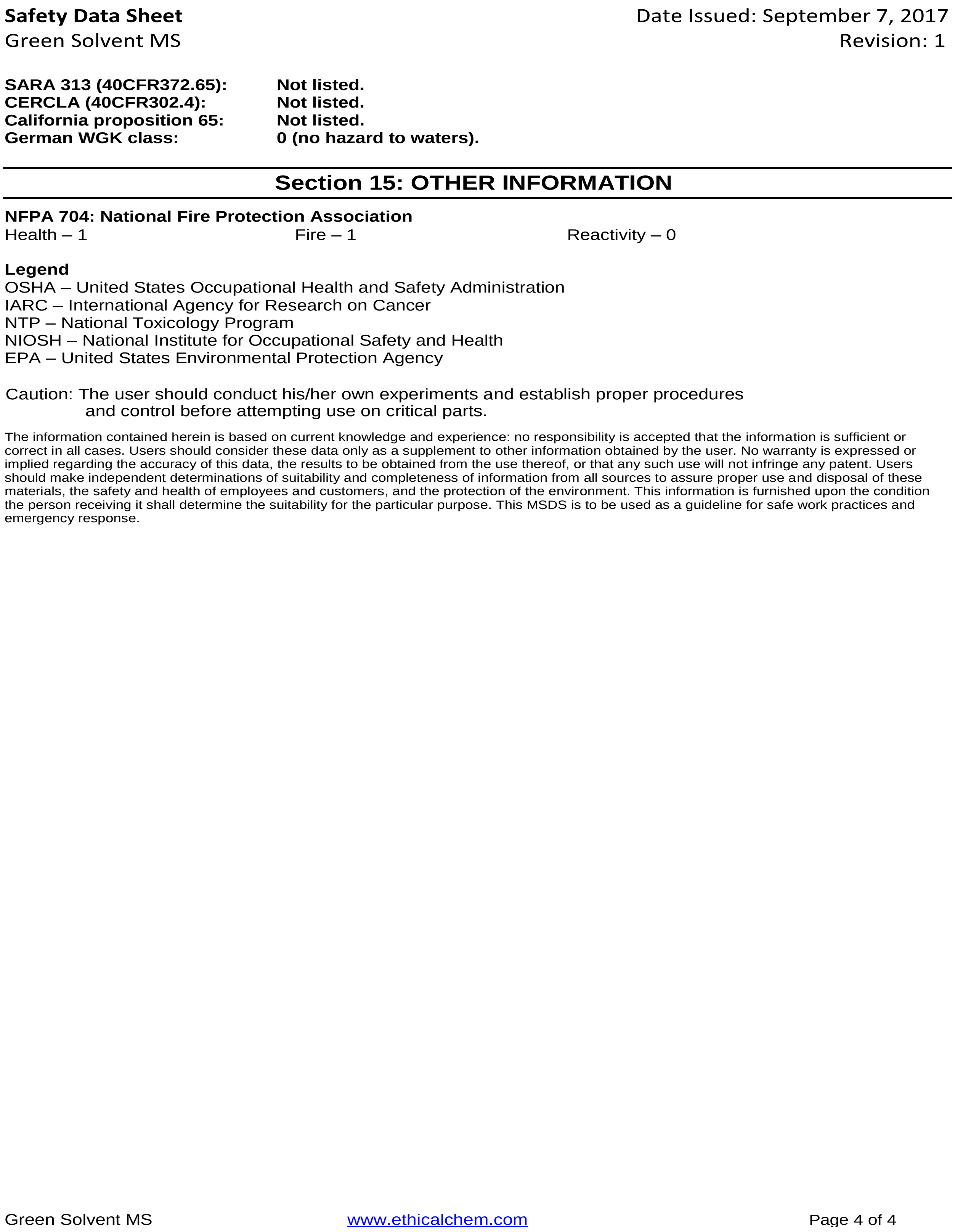
Section 13: TRANSPORT INFORMATION

US DOT:	Not Regulated
TDG Status:	Not Regulated
IMO Status:	Not Regulated
IATA Status:	Not Regulated

The listed transportation classification does not address regulatory variations due to changes in package size, mode of shipment, or other regulatory descriptions.

Section 14: REGULATORY INFORMATION

SARA 302 (40CFR355):	**Not listed.**
SARA 311/312 (40CFR370.66):	**Not listed.**



Safety Data Sheet
Green Solvent MS

Date Issued: September 7, 2017
Revision: 1

SARA 313 (40CFR372.65):	**Not listed.**
CERCLA (40CFR302.4):	**Not listed.**
California proposition 65:	**Not listed.**
German WGK class:	**0 (no hazard to waters).**

Section 15: OTHER INFORMATION

NFPA 704: National Fire Protection Association
Health – 1
Fire – 1
Reactivity – 0

Legend
OSHA – United States Occupational Health and Safety Administration
IARC – International Agency for Research on Cancer
NTP – National Toxicology Program
NIOSH – National Institute for Occupational Safety and Health
EPA – United States Environmental Protection Agency

Caution: The user should conduct his/her own experiments and establish proper procedures and control before attempting use on critical parts.

The information contained herein is based on current knowledge and experience: no responsibility is accepted that the information is sufficient or correct in all cases. Users should consider these data only as a supplement to other information obtained by the user. No warranty is expressed or implied regarding the accuracy of this data, the results to be obtained from the use thereof, or that any such use will not infringe any patent. Users should make independent determinations of suitability and completeness of information from all sources to assure proper use and disposal of these materials, the safety and health of employees and customers, and the protection of the environment. This information is furnished upon the condition the person receiving it shall determine the suitability for the particular purpose. This MSDS is to be used as a guideline for safe work practices and emergency response.

Green Solvent MS
www.ethicalchem.com
Page 4 of 4

Figure E-6 – Safety data sheet for MS environmentally friendly solvent

Material Safety Data Sheet
Dichloromethane, Reagent ACS, Spectro Grade, 99.5% (GC)

ACC# 96274

Section 1 - Chemical Product and Company Identification

MSDS Name: Dichloromethane, Reagent ACS, Spectro Grade, 99.5% (GC)
Catalog Numbers: AC406935000
Synonyms: Methylene chloride; Methane dichloride; Methylene bichloride; Methylene dichloride; Dichloromethane; DCM.
Company Identification:

Acros Organics N.V.
One Reagent Lane
Fair Lawn, NJ 07410

For information in North America, call: 800-ACROS-01
For emergencies in the US, call CHEMTREC: 800-424-9300

Section 2 - Composition, Information on Ingredients

CAS#	Chemical Name	Percent	EINECS/ELINCS
75-09-2	Methylene Chloride	99.5	200-838-9

Hazard Symbols: XN
Risk Phrases: 40

Section 3 - Hazards Identification

EMERGENCY OVERVIEW

Appearance: colorless liquid. This substance has caused adverse reproductive and fetal effects in animals. Potential cancer hazard. **Warning!** Causes eye and skin irritation. Causes respiratory tract irritation. Harmful if swallowed. May be harmful if inhaled. May cause central nervous system effects. Methylene chloride is metabolically converted to carbon monoxide after systemic absorption, which yields increased concentrations of carboxyhemoglobin in the blood. May cause kidney damage. **Target Organs:** Blood, kidneys, heart, central nervous system, liver, lungs, pancreas.

Potential Health Effects

Eye: Contact with eyes may cause severe irritation, and possible eye burns.
Skin: May be absorbed through the skin. Causes irritation with burning pain, itching, and redness. Prolonged exposure may result in skin burns.
Ingestion: Causes gastrointestinal irritation with nausea, vomiting and diarrhea. May cause kidney damage. May cause central nervous system depression, characterized by excitement, followed by headache, dizziness, drowsiness, and nausea. Advanced stages may cause collapse, unconsciousness, coma and possible death due to respiratory failure. May cause carboxyhemoglobinemia.
Inhalation: Inhalation of high concentrations may cause central nervous system effects characterized by nausea, headache, dizziness, unconsciousness and coma. Causes respiratory tract irritation. May cause narcotic effects in high concentration. Vapors may cause dizziness or suffocation. May cause blood changes. Overexposure may cause an increase in carboxyhemoglobin levels in the blood. Can produce delayed pulmonary edema. Because of its high volatility, airborne concentrations of methylene c hloride can accumulate in poorly ventilated areas. Odor is a poor indi cator of possibly dangerous air concentrations of methylene chloride.
Chronic: Possible cancer hazard based on tests with laboratory animals. Prolonged or repeated skin contact may cause dermatitis. May cause reproductive and fetal effects. Laboratory experiments have resulted in mutagenic effects. Chronic exposure may cause lung, liver, and pancreatic tumors. May cause conjunctivitis and/or corneal burns.

Section 4 - First Aid Measures

Eyes: In case of contact, immediately flush eyes with plenty of water for at least 15 minutes. Get medical aid.
Skin: In case of contact, flush skin with plenty of water. Remove contaminated clothing and shoes. Get medical aid if irritation develops and persists. Wash clothing before reuse.
Ingestion: If swallowed, do not induce vomiting unless directed to do so by medical personnel. Never give anything by mouth to an unconscious person. Get medical aid.
Inhalation: If inhaled, remove to fresh air. If not breathing, give artificial respiration. If breathing is difficult, give oxygen. Get medical aid.
Notes to Physician: Treat symptomatically and supportively.

Section 5 - Fire Fighting Measures

General Information: As in any fire, wear a self-contained breathing apparatus in pressure-demand, MSHA/NIOSH (approved or equivalent), and full protective gear. Use water spray to keep fire-exposed containers cool. No flash point in conventional closed tester, but forms flammable vapor-air mixtures in larger volumes and may be an explosion hazard in a confined space. **Extinguishing Media:** Use water spray, dry chemical, carbon dioxide, or appropriate foam.
Flash Point: Not applicable.

Section 6 - Accidental Release Measures

General Information: Use proper personal protective equipment as indicated in Section 8.
Spills/Leaks: Absorb spill with inert material (e.g. vermiculite, sand or earth), then place in suitable container. Avoid runoff into storm sewers and ditches which lead to waterways. Clean up spills immediately, observing precautions in the Protective Equipment section. Remove all sources of ignition. Provide ventilation.

Section 7 - Handling and Storage

Handling: Wash thoroughly after handling. Remove contaminated clothing and wash before reuse. Avoid contact with eyes, skin, and clothing. Keep container tightly closed. Keep away from heat, sparks and flame. Use only with adequate ventilation. Avoid breathing vapor or mist.
Storage: Store in a tightly closed container. Keep from contact with oxidizing materials. Store in a cool, dry, well-ventilated area away from incompatible substances. Store below 40°C. Keep away from active metals.

Section 8 - Exposure Controls, Personal Protection

Engineering Controls: Facilities storing or utilizing this material should be equipped with an eyewash facility and a safety shower. Use adequate general or local exhaust ventilation to keep airborne concentrations below the permissible exposure limits.

Exposure Limits

Chemical Name	ACGIH	NIOSH	OSHA - Final PELs
Methylene Chloride	50 ppm TWA	2300 ppm IDLH	25 ppm TWA (8 hr); 125 ppm STEL (15 min); 12.5 ppm Action Level (See 29 CFR 1910 .1052)

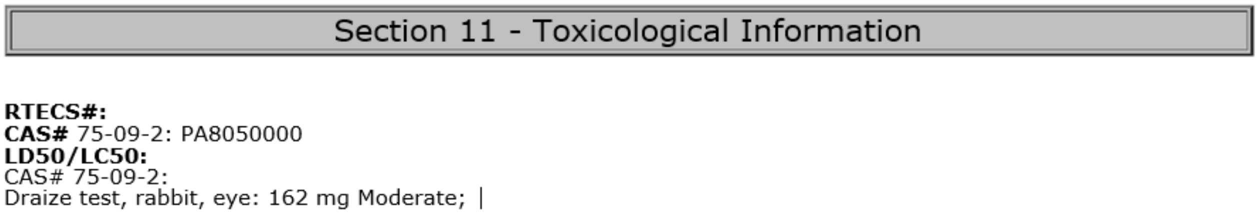
OSHA Vacated PELs: Methylene Chloride: 500 ppm TWA
Personal Protective Equipment
Eyes: Wear chemical goggles.
Skin: Wear appropriate protective gloves to prevent skin exposure.
Clothing: Wear appropriate protective clothing to prevent skin exposure.
Respirators: A respiratory protection program that meets OSHA's 29 CFR 1910.134 and ANSI Z88.2 requirements or European Standard EN 149 must be followed whenever workplace conditions warrant a respirator's use.

Section 9 - Physical and Chemical Properties

Physical State: Liquid
Appearance: colorless
Odor: ethereal odor - chloroform-like
pH: Not available.
Vapor Pressure: 350 mm Hg @ 20 deg C
Vapor Density: 2.93 (Air=1)
Evaporation Rate: Not available.
Viscosity: Not available.
Boiling Point: 40 deg C
Freezing/Melting Point:-97 deg C
Decomposition Temperature: Not available.
Solubility: Slightly soluble.
Specific Gravity/Density:1.33 (Water=1)
Molecular Formula:CH_2Cl_2
Molecular Weight:84.92

Section 10 - Stability and Reactivity

Chemical Stability: Stable at room temperature in closed containers under normal storage and handling conditions. May form explosive mixtures in atmospheres having high oxygen content.
Conditions to Avoid: Excess heat, attacks some plastics, rubber, and coatings, confined spaces, When no water is present, dichloromethane is not corrosive to metals. At high temperatures and in the presence of water (causing slow decomposition forming HCl), corrosion of iron, some stainless steels, copper and aluminum can occur..
Incompatibilities with Other Materials: Strong oxidizing agents, strong bases, chemically active metals.
Hazardous Decomposition Products: Hydrogen chloride, phosgene, carbon monoxide, carbon dioxide.
Hazardous Polymerization: Will not occur.



Section 11 - Toxicological Information

RTECS#:
CAS# 75-09-2: PA8050000
LD50/LC50:
CAS# 75-09-2:
Draize test, rabbit, eye: 162 mg Moderate; |

Draize test, rabbit, eye: 10 mg Mild;
Draize test, rabbit, eye: 500 mg/24H Mild;
Draize test, rabbit, skin: 810 mg/24H Severe;
Draize test, rabbit, skin: 100 mg/24H Moderate;
Inhalation, mouse: LC50 = 14400 ppm/7H;
Inhalation, mouse: LC50 = 49100 mg/m3/6H;
Inhalation, mouse: LC50 = 54000 mg/m3/2H;
Inhalation, mouse: LC50 = 56220 mg/m3/7H;
Inhalation, rat: LC50 = 52 gm/m3;
Inhalation, rat: LC50 = 76000 mg/m3/4H;
Inhalation, rat: LC50 = 52000 mg/m3/6H;
Oral, mouse: LD50 = 873 mg/kg;
Oral, rabbit: LD50 = 2000 mg/kg;
Oral, rat: LD50 = 1600 mg/kg;
Oral, rat: LD50 = 985 mg/kg;

Carcinogenicity:
CAS# 75-09-2:
ACGIH: A3 - Confirmed animal carcinogen with unknown relevance to humans
California: carcinogen, initial date 4/1/88
NTP: Suspect carcinogen
IARC: Group 2B carcinogen
Epidemiology: There are few reports of injury despite widespread use of dichloromethane (ACGIH, 1991). Solvent abuse has led to death (Harbison, 1998).
Teratogenicity: Inhalation, rat: TCLo = 4500 ppm/24H (female 1-17 day(s) after conception) Effects on Newborn - behavioral.; Inhalation, rat: TCLo = 1250 ppm/7H (female 6-15 day(s) after conception) Specific Developmental Abnormalities - musculoskeletal system and urogenital system.
Reproductive Effects: Reproductive effects have occurred in experimental animals.
Neurotoxicity: No information available.
Mutagenicity: DNA inhibition: Human, Fibroblast = 5000 ppm/1H (Continuous).; Morphological transformation: Rat, Embryo = 160 umol/L.; DNA damage: Oral, rat = 1275 mg/kg.; Inhalation, mouse: TCLo = 2000 ppm/5H/2Y-C (Tumorigenic - Carcinogenic by RTECS criteria-- Lungs, Thorax, or Respiration - Tumors).
Other Studies: See actual entry in RTECS for complete information.

Section 12 - Ecological Information

Ecotoxicity: Fish: Bluegill/Sunfish: 230mg/L; 24H; StaticFish: Fathead Minnow: 196mg/L; 96H; This chemical has a moderate potential to affect some aquatic organisms. It is resistant to biodegradation, and has a low potential to persist in the aquatic environment. 96-hr. EC50 (loss of equilibrium); Fathead minnow: 99mg/L; 96-hr. EC10: 66.3 mg/L. Bluegill sunfish: 96-hr. LC50=220 mg/L; Water flea: 24-hr. LC50=2270 mg/L; No observed effect level:1550 mg/L.
Environmental: Terrestrial: Expected to evaporate from near surface soil into the atmosphere; expected to leach. Aquatic: Primarily lost by evaporation to the atmosphere which should take several hours depending on wind and mixing conditions. Atmospheric: Will degrade by reaction with hydroxyl radicals with a half life of several months. . Dichloromethane is reported to completely biodegrade under aerobic conditions with sewage seed or activated sludge between 6 hours to 7 days. Not expected to bioconcentrate due to its low octanol/water coefficient.
Physical: No information available.
Other: No information available.

Section 13 - Disposal Considerations

Chemical waste generators must determine whether a discarded chemical is classified as a hazardous waste. US EPA guidelines for the classification determination are listed in 40 CFR Parts 261.3. Additionally, waste generators must consult state and local hazardous waste regulations to ensure complete and accurate classification.
RCRA P-Series: None listed.
RCRA U-Series: CAS# 75-09-2: waste number U080.

Section 14 - Transport Information

	US DOT	IATA	RID/ADR	IMO	Canada TDG
Shipping Name:	DICHLOROMETHANE				No information available.
Hazard Class:	6.1				
UN Number:	UN1593				
Packing Group:	III				

Section 15 - Regulatory Information

US FEDERAL

TSCA
CAS# 75-09-2 is listed on the TSCA inventory.

None of the chemicals are listed under TSCA Section 12b.

TSCA Significant New Use Rule

None of the chemicals in this material have a SNUR under TSCA.

SARA

CERCLA Hazardous Substances and corresponding RQs

CAS# 75-09-2: 1000 lb final RQ; 454 kg final RQ

SARA Section 302 Extremely Hazardous Substances

None of the chemicals in this product have a TPQ.

SARA Codes

CAS # 75-09-2: acute, chronic.

Section 313

This material contains Methylene Chloride (CAS# 75-09-2, 99 5%),which is subject to the reporting requirements of Section 313 of SARA Title III and 40 CFR Part 373.

Clean Air Act:

CAS# 75-09-2 is listed as a hazardous air pollutant (HAP). This material does not contain any Class 1 Ozone depletors. This material does not contain any Class 2 Ozone depletors.

Clean Water Act:

None of the chemicals in this product are listed as Hazardous Substances under the CWA. CAS# 75-09-2 is listed as a Priority Pollutant under the Clean Water Act. CAS# 75-09-2 is listed as a Toxic Pollutant under the Clean Water Act.

OSHA:

None of the chemicals in this product are considered highly hazardous by OSHA.

STATE

CAS# 75-09-2 can be found on the following state right to know lists: California, New Jersey, Pennsylvania, Minnesota, Massachusetts.

The following statement(s) is(are) made in order to comply with the California Safe Drinking Water Act: WARNING: This product contains Methylene Chloride, a chemical known to the state of California to cause cancer. California No Significant Risk Level: CAS# 75-09-2: 200 æg/day NSRL (inhalation); 50 æg/day NSRL (except inhalation)

European/International Regulations

European Labeling in Accordance with EC Directives

Hazard Symbols:

XN

Risk Phrases:

R 40 Limited evidence of a carcinogenic effect.

Safety Phrases:

S 23 Do not inhale gas/fumes/vapour/spray.
S 24/25 Avoid contact with skin and eyes.
S 36/37 Wear suitable protective clothing and gloves.

WGK (Water Danger/Protection)

CAS# 75-09-2: 2

Canada - DSL/NDSL

CAS# 75-09-2 is listed on Canada's DSL List.

Canada - WHMIS

This product does not have a WHMIS classification.

Canadian Ingredient Disclosure List

CAS# 75-09-2 is listed on the Canadian Ingredient Disclosure List.

Exposure Limits

CAS# 75-09-2: OEL-AUSTRALIA:TWA 100 ppm (350 mg/m3);Carcinogen OEL-AUSTRIA:TWA 100 ppm (360 mg/m3) OEL-BELGIUM:TWA 50 ppm (174 mg/m3);Carcinogen OEL-CZECHOSLOVAKIA:TWA 500 mg/m3;STEL 2500 mg/m3 OEL-DENMARK:TWA 50 ppm (175 mg/m3);Skin;Carcinoge OEL-FINLAND:TWA 100 ppm (350 mg/m3);STEL 250 ppm (870 mg/m3) OEL-FRANCE:TWA 100 ppm (360 mg/m3);ST EL 500 ppm (1800 mg/m3) OEL-GERMANY:TWA 100 ppm (360 mg/m3);Carcinogen OEL-HUNGARY:STEL 10 mg/m3;Carcinogen OEL-JAPAN:TWA 100 ppm (350 mg /m3) OEL-THE NETHERLANDS:TWA 100 ppm (350 mg/m3);STEL 500 ppm OEL-TH E PHILIPINES:TWA 500 ppm (1740 mg/m3) OEL-POLAND:TWA 50 mg/m3 OEL-RUSSIA:TWA 100 ppm;STEL 50 mg/m3 OEL-SWEDEN:TWA 35 ppm (120 mg/m3);STEL 70 ppm (25 mg/m3);Skin OEL-SWITZERLAND:TWA 100 ppm (360 mg/m3);STEL 500 ppm OEL-THAILAND:TWA 500 mg/m3;STEL 1000 mg/m3 OEL-TURKEY:TWA 50 0 ppm (1740 mg/m3) OEL-UNITED KINGDOM:TWA 100 ppm (350 mg/m3);STEL 25 0 ppm OEL IN BULGARIA, COLOMBIA, JORDAN, KOREA check ACGIH TLV OEL IN NEW ZEALAND, SINGAPORE, VIETNAM check ACGI TLV

Section 16 - Additional Information

MSDS Creation Date: 4/20/1999
Revision #5 Date: 2/20/2003

Figure E-7 – Safety data sheet for dichloromethane