Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 1: GENERAL INFORMATION

Property/Information	**Hydrogen** H_2 (gas)	**CNG** CH_4 83-99%; C_2H_6 1-13% (gas)	**Propane** C3 (liquid)	**Methanol** CH_3OH (liquid)	**Ethanol** C_2H_5OH (liquid)	**Gasoline** C_4-C_{12} (liquid)	**No. 2 Diesel** C_8-C_{25} (liquid)	**B100 Biodiesel** C_{12}-C_{22} (liquid)
DOT Number	UN 1049 UN 1966	UN 1971	UN 1075 UN 1978	UN 1230	UN 1170	UN 1203	UN 1202 NA 1993	-
DOT Hazard Class or Division	2.1 flammable gas	2.1 flammable gas	2.1 flammable gas	3.6.1 flammable liquid	3 flammable liquid	3 flammable liquid	3 flammable liquid	3 flammable liquid
DOT Guide Number	22	17	22	28	26	27	128	-
CAS Number	1333-74-0	74-82-8	74-98-6	65-56-1	64-17-5	8006-61-9	68476-34-6	67784-80-9
STCC Number	4905746	4905755	4905781	4909230	-	4908178	-	-
ICC, OSHA, NFPA Liquid Flammability Class	-	-	-	IB flammable liquid	IB flammable liquid	IB flammable liquid	2 combustible liquid	2 combustible liquid
DOT Packing Group	-	-	-	PG II	PG II	PG II	PG III	PG III
DOT Packaging (non-bulk/bulk)	302/302	302/302	304/314	202/242	202/242	202/242	203/242	203/242
Types of Shipping Containers	Pressurized cylinders & tank cars	Pressurized cylinders	pressurized cylinders, tank trucks, tank cars,	**NON-BULK:** 1-119 gal DOT PG-II performance-oriented containers **BULK:** tank cars, tank trucks	**NON-BULK:** 1-119 gal DOT PG-II performance-oriented containers **BULK:** tank cars, tank trucks	**BULK:** pipelines, tank cars, tank trucks	**BULK:** pipelines, tank cars, tank trucks	**BULK:** pipelines, tank cars, tank trucks

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 1: GENERAL INFORMATION (CONT.)

Property/Information	**Hydrogen** H_2 (gas)	**CNG** CH_4 83-99%; C_2H_6 1-13% (gas)	**Propane** C3 (liquid)	**Methanol** CH_3OH (liquid)	**Ethanol** C_2H_5OH (liquid)	**Gasoline** C_4-C_{12} (liquid)	**No. 2 Diesel** C_8-C_{25} (liquid)	**B100 Biodiesel** C_{12}-C_{22} (liquid)
Shipping Container Hazards	rupture, BLEVE: containers may fragment & rocket in fire	rupture, BLEVE: containers may fragment & rocket in fire	rupture, BLEVE: containers may fragment & rocket in fire	rupture, BLEVE: containers may fragment & rocket in fire	rupture, BLEVE: containers may fragment & rocket in fire	rupture, BLEVE: containers may fragment & rocket in fire	rupture, BLEVE: containers may fragment & rocket in fire	rupture, BLEVE: containers may fragment & rocket in fire
Special Fire Hazards	blue flame invisible in daylight; flame flashes back from ignition source to leak point; accumulated vapor may explode if ignited in confined or in unconfined area	yellow luminous flame visible in daylight; flame flashes back from ignition source to leak point; accumulated vapor may explode if ignited in confined area or deflagrate as a buoyant radiant fireball in unconfined area	yellow luminous flame visible in daylight; flame flashes back from ignition source to leak point; accumulated vapor may explode if ignited in confined area or deflagrate as a non-buoyant radiant fire ball in unconfined area	blue flame invisible in daylight; flame flashes back from ignition source to leak point; accumulated vapor may explode if ignited in confined area or deflagrate as a near- neutral-buoyancy radiant fire ball in unconfined poorly ventilated area	blue flame invisible in daylight; flame flashes back from ignition source to leak point; accumulated vapor may explode if ignited in confined area, or deflagrate as a near-neutral-buoyancy fire ball in unconfined poorly ventilated area	yellow luminous flame visible in daylight; flame flashes back from ignition source to leak point; accumulated vapor may explode if ignited in confined area or deflagrate as a non-buoyant radiant fire ball in unconfined area	yellow luminous flame visible in daylight; dense black smoke	yellow luminous flame visible in daylight; dense black smoke

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 1: GENERAL INFORMATION (CONT.)

Property/Information	**Hydrogen** H_2 (gas)	**CNG** CH_4 83-99%; C_2H_6 1-13% (gas)	**Propane** C3 (liquid)	**Methanol** CH_3OH (liquid)	**Ethanol** C_2H_5OH (liquid)	**Gasoline** C_4-C_{12} (liquid)	**No. 2 Diesel** C_8-C_{25} (liquid)	**B100 Biodiesel** C_{12}-C_{22} (liquid)
Other Information	H_2 gas release is very buoyant and invisible	CNG gas release is buoyant and invisible, natural gas has characteristic odor	liquid floats & boils on water; heavier-than-air visible vapor cloud	liquid floats & mixes with water; near neutral vapor buoyancy	liquid floats & mixes with water; near neutral vapor buoyancy	liquid floats on water; high vapor pressure, expected to form negative buoyancy vapor cloud	liquid floats on water; low vapor pressure, formation of vapor cloud not expected	liquid floats on water; low vapor pressure, formation of vapor cloud not expected
Molecular Weight	2.02 [2]	16.04 [2]	44.1 [2]	32.04 [1,2]	46.07 [1,2]	100-105 [1,2]	~200 [1,2]	~292 [2]
Chemical Composition								
Carbon (w/w%)	0 [2]	75 [2]	82 [2]	37.5 [2]	52.2 [2]	85-88 [2]	87 [2]	77 [2]
Hydrogen (w/w%)	100 [2]	25 [2]	18 [2]	12.6 [2]	13.1 [2]	12-15 [2]	13 [2]	12 [2]
Oxygen (w/w%)	0 [2]	-	-	49.9 [2]	34.7 [2]	0	0 [2]	11 [2]

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 2: LIQUID PROPERTIES

Property/Information	Hydrogen H_2 (gas)	CNG CH_4 83-99%; C_2H_6 1-13% (gas)	Propane C3 (liquid)	Methanol CH_3OH (liquid)	Ethanol C_2H_5OH (liquid)	Gasoline C_4-C_{12} (liquid)	No. 2 Diesel C_8-C_{25} (liquid)	B100 Biodiesel C_{12}-C_{22} (liquid)
Freezing Point Temp. (°F)	-435 [2]	-296 [2]	-305.8 [2]	-143.5 [1,2]	-173.2 [1,2]	-40 [1,2]	-40 to -30 [1,2]	26-66 [2]
Specific Gravity (@ 60 °F/60 °F)	0.07 [2]	0.424 [2]	0.508 [2]	0.796 [1]	0.794 [1]	0.72-0.78 [2]	0.85 [2]	0.88 [2]
Density (lb/gal @ 60 °F)	-	1.07 [2]	4.22 [2]	6.63 [1,2]	6.61 [1,2]	6.0 – 6.5 [1,2]	6.7 – 7.4 [1] 7.079 [2]	7.328 [2]
Viscosity								
@ -4 °F (centipoises / mm2/s)	-	-	-	1.15 [1] 1.345 [2]	2.84 [1] 3.435 [2]	0.6-.77 [1] 0.8 - 1.0 [2]	9.7-17.6 [1] 9.0 - 24.0 [2]	-
@ 68 °F (centipoises / mm2/s)	-	-	-	0.59 [1] 0.74 [2]	1.19 [1] 1.50 [2]	0.37–0.44 [1] 0.5 – 0.6 [2]	2.6-4.1 [1] 2.8 – 5.0 [2]	-
@ 104 °F (centipoises / mm2/s)	- -	- -	- -	- -	- -	- -	- 1.3 – 4.1 [2]	 4.0 – 6.0 [2]
Specific Heat (C_p, Btu/lb-°F)	-	-	-	0.60 [1,2]	0.57 [1,2]	0.48 [1,2]	0.43 [1,2]	-
Thermal Conductivity (Btu/hr-ft-°F)	0.097 [4]	0.17 [4]	0.075 [6]	0.12 [3]	0.099 [3]	0.087 [4]	0.081-0.087 [5,6]	0.09-0.12 [7]
Coefficient of Thermal Volume Expansion (@ 60 °F & 1 atm)	-	-	-	0.00067 [1]	0.00062 [1]	0.00067 [1]	0.00046 [1]	-
Electrical Conductivity								
Neat or without additives	-	-	-	4.4×10^7 pS/m [1,26,32]	1.35×10^5 pS/m [1,26,32]	25 pS/m [7]	5 pS/m [7]	-

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 2: LIQUID PROPERTIES (CONT.)

Property/Information	Hydrogen H_2 (gas)	CNG CH_4 83-99%; C_2H_6 1-13% (gas)	Propane C3 (liquid)	Methanol CH_3OH (liquid)	Ethanol C_2H_5OH (liquid)	Gasoline C_4-C_{12} (liquid)	No. 2 Diesel C_8-C_{25} (liquid)	B100 Biodiesel C_{12}-C_{22} (liquid)
Electrical Conductivity Cont.								
Industrial use	-	-	-	30 µS/m [28]	-	-	-	-
Fuel specification	-	-	-	< 1000 µS/m [32]	< 500 µS/m [27]	-	< 250 pS/m [28]	-
Latent Heat of Vaporization								
(Btu/gal @ 60 °F)	-	-	775 [2]	3,340 [1,2]	2,378 [1,2]	≈900 [1,2]	≈710 [1,2]	-
(Btu/lb @ 60 °F)	192.1 [2]	219 [2]	193.1 [2]	506 [1,2]	396 [1,2]	≈150 [1,2]	≈100 [1,2]	-
Heating Value [a]								
Lower [liquid fuel combusted to water as vapor] (Btu/gal @ 60 °F)[1]	-	-	- 84250 [2]	56800 [1] 57250 [2]	76000 [1] 76330 [2]	109000-119000 [1] 116090 [2]	126000-130800 [1] 128450 [2]	- 119,550 [2]
Lower [liquid fuel combusted to water as vapor] (Btu/lb)	- 52217 [2]	- 20263 [2]	- 19900 [2]	8570 [1] 8637 [2]	11500 [1] 11585 [2]	18000-19000 [1] 18676 [2]	18000-19000 [1] 18394 [2]	16,131 [2]
Higher [liquid fuel combusted to liquid water] (Btu/gal)	-	-	91420 [2]	65200 [2]	84530 [2]	124340 [2]	137380 [2]	127960 [2]
Higher [liquid fuel combusted to liquid water] (Btu/lb)	- 59806 [2]	- 22449 [2]	21594 [2]	9750 [1] 9837 [2]	12800 [1] 12830 [2]	18800-20400 [1] 20004 [2]	19200-20000 [1] 19673 [2]	17266 [2]

[a] The higher heating value (HHV) and heat of combustion are cited for completeness only. No vehicles currently in use or under development for future use have engines capable of recovering heat of condensation from water of combustion. Use the lower heating value (LHV) for practical comparison between fuels which combust accidentally as a result of a spill or containment failure.

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 2: LIQUID PROPERTIES (CONT.)

Property/Information	Hydrogen H_2 (gas)	CNG CH_4 83-99%; C_2H_6 1-13% (gas)	Propane C3 (liquid)	Methanol CH_3OH (liquid)	Ethanol C_2H_5OH (liquid)	Gasoline C_4-C_{12} (liquid)	No. 2 Diesel C_8-C_{25} (liquid)	B100 Biodiesel C_{12}-C_{22} (liquid)
Heat of Combustion [ΔH_c^0] [liquid fuel combusted to liquid water] (Btu/lb)	60000 [30,31] 61000 [34]	23000 [30,31]	21500 [30,31] 21000 [34]	9900 [30,31] 9378 [35]	12900 [30,31] 12000 [34] 12764 [36]	20000 [30,31,34]	20700 [30,31] 19300 [34]	≈18,145 [30,31]
Equilibrium Vapor Pressure								
Reid [RVP] (psi @ 100 °F)	-	2400 [2]	208 [2]	4.6 [1,2]	2.3 [1,2]	8 – 15 [1,2]	<0.2 [1,2]	<0.04 [2]
True Vapor Pressure [TVP] (mm Hg @ 68 °F)	-	-	6257.7 [13]	92 [10] 104 [11]	43 [9]	258-775 [15] (@ 100 °F)	0.4 [14]	-
Boiling Pt. Temperature (°F)	-423 [2]	-263.2 – 126.4 [2]	-44 [2]	149 [1,2]	172 [1,2]	80 – 437 [2]	356–644 [2]	599 – 662 [2]
Water Solubility @ 70 °F								
Fuel in Water (v/v %)	-	Negligible [2]	Negligible [2]	100 [1,2]	100 [1,2]	Negligible [1,2]	Negligible [1,2]	-
Water in Fuel (v/v %)	-	-	-	100 [1,2]	100 [1,2]	Negligible [1,2]	Negligible [1,2]	-
Vapor Specific Heat (Btu/lb/°F)	3.42 [16]	0.59 [16]	0.39 [16]	0.38 [18]	0.45 [19]	0.38 [33](b)	-	-

[b] This value of C_p for an ideal gas at STP (60 °F and 1 atm of pressure) uses the heat capacity of heptane (C_7H_{16}) as a surrogate for gasoline vapor.

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 2: LIQUID PROPERTIES (CONT.)

Property/Information	**Hydrogen** H_2 (gas)	**CNG** CH_4 83-99%; C_2H_6 1-13% (gas)	**Propane** C3 (liquid)	**Methanol** CH_3OH (liquid)	**Ethanol** C_2H_5OH (liquid)	**Gasoline** C_4-C_{12} (liquid)	**No. 2 Diesel** C_8-C_{25} (liquid)	**B100 Biodiesel** C_{12}-C_{22} (liquid)
Equilibrium Vapor Pressure [c]								
Reid (psi @ 100 °F)	-	2400 [2]	208 [2]	4.6 [1,2]	2.3 [1,2]	8 – 15 [1,2]	<0.2 [1,2]	<0.04 [2]
True Vapor Pressure (mm Hg @ 68 °F)	-	-	6257.7 [13]	92 [10] 104 [11]	43 [9]	258-775 [15] (@ 100 °F)	0.4 [14]	-
Vapor Density (air=1)	0.07 [24,calc'd]	0.55-0.69 [25,calc'd]	1.5 [12]	1.1 [23]	1.6 [11]	3 – 4 [15]	>3 [14]	-
Vapor Heat of Combustion								
Lower [gaseous fuel combusted to water as vapor] (Btu/lb @ 60 °F)	-	-	-	9080 [1]	11900 [1]	19000-19300 [1]	-	-

[c] True Vapor Pressure is the partial pressure of fuel vapor in air, compared to Reid Vapor Pressure which is the total pressure of fuel vapor, and air contained in the small volume of laboratory test apparatus. Reid Vapor Pressure (RVP) is determined experimentally, and is typically used in reference to hydrocarbon mixtures such as natural gas, Liquid Petroleum Gas (LPG), propane, butane, gasoline, kerosene, diesel, and fuel oil. RVP is expressed as differential pressure in pounds per square inch (psi); true vapor pressure is expressed as absolute pressure in millimeters of mercury (mmHg) or pounds per square inch absolute (psia). One atmosphere of pressure is equivalent to 0.0 psi of differential pressure, and 14.7 psia or 760 mmHg of absolute pressure.

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

SECTION 4: FLAMMABILITY PROPERTIES

Property/Information	**Hydrogen** H_2 (gas)	**CNG** CH_4 83-99%; C_2H_6 1-13% (gas)	**Propane** C3 (liquid)	**Methanol** CH_3OH (liquid)	**Ethanol** C_2H_5OH (liquid)	**Gasoline** C_4-C_{12} (liquid)	**No. 2 Diesel** C_8-C_{25} (liquid)	**B100 Biodiesel** C_{12}-C_{22} (liquid)
Flash Point Temperature								
Closed Cup (°F)	-	-300 [2]	-156 [1]	52 [1]	55 [1]	-45 [2]	140 - 176 [2]	212 - 338 [2]
Open Cup (°F)	-	-	-	-	-	-	-	-
Autoignition Temperature (°F)	932 [2]	900 – 1170 [2]	842 [2]	867 [1,2]	793 [1,2]	495 [1,2]	≈600 [1,2]	-
Flammability Limits								
Lower (v/v %)	4.1 [2]	5.3 [2]	2.2 [2]	7.3 [1,2]	4.3 [1,2]	1.4 [1,2]	1.0 [1,2]	-
Upper (v/v%)	74 [2]	15.0 [2]	9.5 [2]	36.0 [1,2]	19.0 [1,2]	7.6 [1,2]	6.0 [1,2]	-
Flammability Range (v/v %)	69.9 (calc bydiff)	9.7 (calc bydiff)	7.3 (calc bydiff)	28.7 (calc bydiff)	14.7 (calc bydiff)	6.2 (calc bydiff)	5 (calc bydiff)	-
Stoichiometric air/fuel ratio (w/w)	34.3 [2]	17.2 [2]	15.7 [2]	6.45 [1,2]	9.00 [1,2]	14.7 [1,2]	14.7 [1,2]	13.8 [2]
Fuel in Vaporized Stoichiometric Mixture (v/v%)	-	-	-	12.3 [2]	6.5 [2]	2.0 [2]	-	-
Stoichiometric Flame Speed (ft/s)	10.63 –14.44 [20]	1.48 [20]	1.48 [20]	1.41 [20]	-	1.12 [20]	-	-
Minimum Ignition Energy (mJ)	0.017 [20]	0.30 [20]	0.26 [20]	0.14 [20]	-	0.29 [20]	0.23 [21]	-
Adiabatic Flame Temperature (°F)	3807 [21]	3542 [21]	3610 [21]	3470 [21]	3281 [21]	3525 [21]	-	-
Flame Temperature (°F)	3722 [20]	3542 [20]	3497 [20]	3,398 [20]	3,488 [20]	3,686 [20]	-	-
Mass Burning Rate (lb/ft^2)	-	-	-	0.083[29]	-	0.27[29]	0.22[29]	-

Using Physical and Chemical Properties to Manage Flammable Liquid Hazards

Part 1-B: Physical & Chemical Properties of Selected Fuels

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