

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

GENERAL INFORMATION

SECTION 1 GENERAL INFORMATION								
Property/Information	Hydrogen H ₂ (gas)	CNG CH ₄ 83-99%; C ₂ H ₆ 1-13% (gas)	Propane C ₃ (liquefied gas)	Methanol CH ₃ OH (liquid)	Ethanol C ₂ H ₅ OH (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: <u>1-119 gal</u> DOT PG-II performance- oriented containers; bulk: tank cars, tank trucks	non-bulk: <u>1-119 gal</u> 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

1. This three-part Methanol Institute Technical Bulletin was researched and written by Mr. Robert R. Roberts of Roberts & Roberts Risk & Reliability Engineering for Alliance Consulting International, San Diego, California.

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Physical & Chemical Properties of Selected Fuels -

SECTION 1: GENERAL INFORMATION CONTINUED

Physical & Chemical Properties of Selected Fuels (Section 1: General Information continued)								
Property	Hydrogen ⁽²⁾ H ₂ (gas)	CNG ⁽²⁾ CH ₄ 83-99%; C ₂ H ₆ 1-13% (gas)	Propane ⁽²⁾ C ₃ (liquid)	Methanol ⁽¹⁾ CH ₃ OH (liquid)	Ethanol (1) C ₂ H ₅ OH (liquid)	Gasoline ⁽²⁾ C ₄ -C ₁₂ (liquid)	No. 2 Diesel ⁽²⁾ C ₈ -C ₂₅ (liquid)	Biodiesel ⁽²⁾ 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



Physical & Chemical Properties of Selected Fuels -

SECTION 1: GENERAL INFORMATION CONTINUED

Physical & Chemical Properties of Selected Fuels (Section 1: General Information continued)								
Property	Hydrogen ⁽²⁾ H ₂ (gas)	CNG ⁽²⁾ CH ₄ 83-99% C ₂ H ₆ 1-13% (gas)	Propane ⁽²⁾ C ₃ (compressed gas liquid)	Methanol ⁽¹⁾ CH ₃ OH (liquid)	Ethanol ⁽¹⁾ C ₂ H ₅ OH (liquid)	Gasoline ^(1,2) C ₄ -C ₁₂ (liquid)	No. 2 Diesel ^(1,2) C ₈ -C ₂₅ (liquid)	Biodiesel ⁽²⁾ 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⁾



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

SECTION 2: LIQUID PROPERTIES

Part 1-B: Physical & Chemical Properties of Selected Fuels								
SECTION 2 LIQUID PROPERTIES								
Property	Hydrogen ⁽²⁾ H ₂ (gas)	CNG ⁽²⁾ CH ₄ 83-99% C ₂ H ₆ 1-13% (gas)	Propane ⁽²⁾ C ₃ (liquid)	Methanol ⁽¹⁾ CH ₃ OH (liquid)	Ethanol ⁽¹⁾ C ₂ H ₅ OH (liquid)	Gasoline ⁽²⁾ C ₄ -C ₁₂ (liquid)	No. 2 Diesel ⁽²⁾ C ₈ -C ₂₅ (liquid)	Biodiesel ⁽²⁾ 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 / mm ² /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 / mm ² /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 / mm ² /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	-	-	-	4.4 x 10 ⁷ pS/m ^(1,26, 32)	1.35 x 10 ⁵ pS/m ^(1,26, 32)	25 pS/m ⁽⁷⁾	5 pS/m ⁽⁷⁾	-
• Neat or without additives	-	-	-	30 μS/m ⁽²⁸⁾	-	-	-	-
• Industrial use	-	-	-	< 1000 μS/m ⁽³²⁾	< 500 μS/m ⁽²⁷⁾	-	< 250 pS/m ⁽²⁸⁾	-
• Fuel specification	-	-	-	-	-	-	-	-
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)	-



Physical & Chemical Properties of Selected Fuels -

SECTION 2: LIQUID PROPERTIES CONTINUED

Physical & Chemical Properties of Selected Fuels								
LIQUID PROPERTIES (Section 2: Liquid Properties continued)								
Property	Hydrogen ⁽²⁾ H ₂ (gas)	CNG ⁽²⁾ CH ₄ 83-99% C ₂ H ₆ 1-13% (gas)	Propane ⁽²⁾ C ₃ (liquid)	Methanol ⁽¹⁾ CH ₃ OH (liquid)	Ethanol ⁽¹⁾ C ₂ H ₅ OH (liquid)	Gasoline ⁽²⁾ C ₄ -C ₁₂ (liquid)	No. 2 Diesel ⁽²⁾ C ₈ -C ₂₅ (liquid)	Biodiesel ⁽²⁾ C ₁₂ -C ₂₂ (liquid)
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⁾
Heat of Combustion [ΔH_c°] [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)	-

(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.



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

SECTION 3: VAPOR PROPERTIES

Part 1-B: Physical & Chemical Properties of Selected Fuels								
SECTION 3 VAPOR PROPERTIES								
Property	Hydrogen H ₂ (gas)	CNG CH ₄ 83-99%; C ₂ H ₆ 1-13% (gas)	Propane C ₃ (liquid)	Methanol CH ₃ OH (liquid)	Ethanol C ₂ H ₅ OH (liquid)	Gasoline C ₄ -C ₁₂ (liquid)	No. 2 Diesel C ₈ -C ₂₅ (liquid)	Biodiesel C ₁₂ -C ₂₂ (liquid)
Vapor Specific Heat (Btu/lb/°F)	3.42 ⁽¹⁶⁾	0.59 ⁽¹⁶⁾	0.39 ⁽¹⁶⁾	0.38 ⁽¹⁸⁾	0.45 ⁽¹⁹⁾	0.38 ^{(33) (c)}	-	-
Equilibrium Vapor Pressure (b)								
• 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 Specific Gravity (@ 68 °F & 14.7 psia)	0.0696 ⁽¹⁷⁾	0.5537 ⁽¹⁷⁾	1.5219 ⁽¹⁷⁾	-	-	-	-	-
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⁾	-	-

(a) 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.

(b) This value of Cp for an ideal gas at STP (60 °F and 1 atm of pressure) uses the heat capacity of heptane (C₇H₁₆) as a surrogate for gasoline vapor.



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

SECTION 4: FLAMMABILITY PROPERTIES

Part 1-B: Physical & Chemical Properties of Selected Fuels								
SECTION 4 FLAMMABILITY PROPERTIES								
Property	Hydrogen ⁽²⁾ H ₂ (gas)	CNG ⁽²⁾ CH ₄ 83-99%; C ₂ H ₆ 1-13% (gas)	Propane ⁽²⁾ C ₃ (liquid)	Methanol ⁽¹⁾ CH ₃ OH (liquid)	Ethanol ⁽¹⁾ C ₂ H ₅ OH (liquid)	Gasoline ⁽²⁾ C ₄ -C ₁₂ (liquid)	No. 2 Diesel ⁽²⁾ C ₈ -C ₂₅ (liquid)	Biodiesel ⁽²⁾ 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 by diff)	9.7 (calc by diff)	7.3 (calc by diff)	28.7 (calc by diff)	14.7 (calc by diff)	6.2 (calc by diff)	5 (calc by diff)	-
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⁾	-



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