IC Engine Fuels

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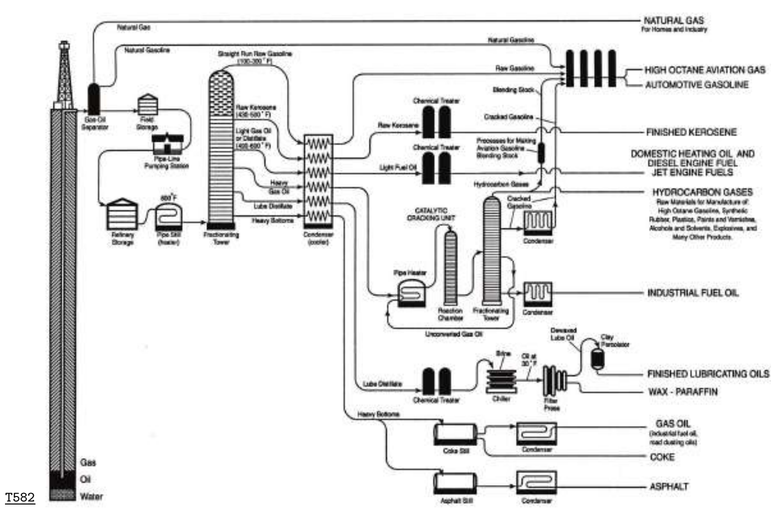
ME 401: Internal Combustion Engines

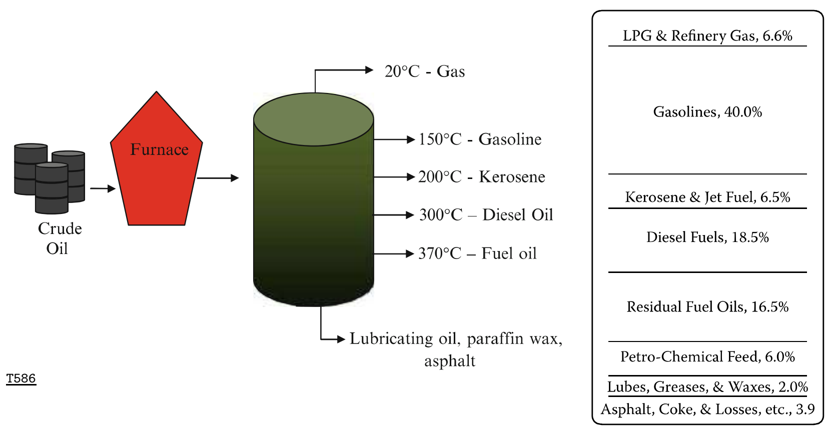
Ideal Characteristics of Fuels

- High energy density (content)
- High heat of combustion (release)
- Good thermal stability (storage)
- Low vapour pressure (volatility)
- Non-toxicity (environmental impact)

Simplified Petroleum Distillation Refinery



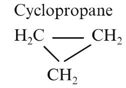
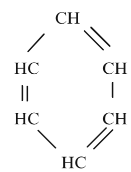
T582



T586 T604

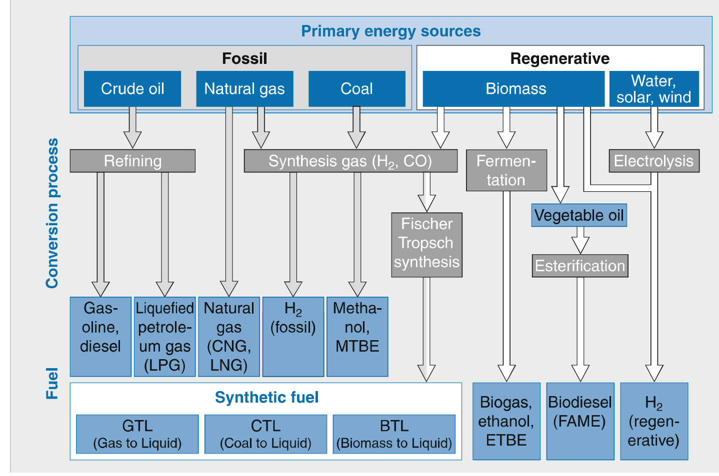
For proper engine performance, fuels must have boiling points within approximate ranges: from 30°C to 230°C for gasoline, and for 230°C to 370°C for diesel.

Naming Conventions for HC Fuels

Family Name	Formula	C-C	Structure	Example
Alkanes (saturated, Paraffins)	$C_\alpha H_{2\alpha+2}$	Single	Straight or branched	Ethane CH_3-CH_3
Alkenes (olefins)	$C_\alpha H_{2\alpha}$	One double bond remaining single	Straight or branched	Ethene CH_2=CH_2
Alkynes (Acetylenes)	$C_\alpha H_{2\alpha-2}$	One triple bond remaining single	Straight or branched	Ethyne HC≡CH
Cyclanes (cycloalkanes)	$C_\alpha H_{2\alpha}$	Single bond	Closed rings	Cyclopropane 
Aromatics (benzene family)	$C_\alpha H_{2\alpha-6}$	Aromatic bond	Closed ring	Benzene 

T587

2 Manufacturing paths of fossil and regenerative fuels



T579

Gasoline Property Specifications & Test Procedure

Property	ASTM method
Benzene, vol%	D3606
Distillation, K	D86
Gum, mg/mL	D381
Heating value	D240
Hydrocarbons, %	D1319
Octane, motored	D2700
Octane, research	D2699
Octane, supercharged	D909
Reid vapor pressure, kPa	D323
Specific gravity	D287
Sulfur, wt%	D1266

T588

Properties of Gasoline Fuels

	Average gasoline	Gasohol	Phase 1 RFG	Phase 2 RFG
Aromatics, vol%	28.6	23.9	23.4	25.4
Olefins, vol%	10.8	8.7	8.2	4.1
Benzene, vol%	1.60	1.6	1.3	0.93
Reid vapor pressure, kPa	60-S	67-S	50-S	46
(S: summer and W: winter)	79-W	79-W	79-W	
T_{50}, K	370	367	367	367
T_{90}, K	440	431	431	418
Sulfur, mass ppm	338	305	302	31
Ethanol, vol%	0	10	4	0

Source: Adapted from EPA 420-F-95-007.

T589

1 Essential properties of gasolines, EN 228 (March 2004)		
Requirements	**Unit**	**Parameter**
Knock resistance		
Super/Premium, min.	RON/MON	95/85
Normal/Regular, min. [1]	RON/MON	91/82.5
Super Plus [1]	RON/MON	98/88
Density	kg/m³	720...775
Sulfur, max.	mg/kg	50
Benzene, max.	% vol.	1
Lead, max.	mg/l	5
Volatility		
Summer vapor pressure, min./max.	kPa	45/60
Winter vapor pressure, min./max.	kPa	60/90 [1]
Evaporated volume at 70°C in summer, min./max.	% vol.	20/48
Evaporated volume at 70°C in winter, min./max.	% vol.	22/50
Evaporated volume at 100°C, min./max.	% vol.	46/71
Evaporated volume at 150°C, min./max.	% vol.	75/–
Final boiling point, max.	°C	210
VLI transition time [3], max. [2]		1150 [1]

[1]) National values for Germany,
[2]) VLI = Vapor-Lock Index,
[3]) Spring and fall.

T578

Diesel Fuel Specifications (ASTM D975)

	ASTM Method	No. 1-D	No. 2-D	No. 4-D
Minimum cetane number	D613	40	40	30
Minimum flash point, °C	D93	38	52	55
Cloud point, °C	D2500	Local	Local	Local
Maximum water and sediment, vol%		0.05	0.05	0.05
Maximum carbon residue	D524	0.15	0.35	
Maximum ash, wt%	D482	0.01	0.01	0.10
T_{90}, K	D86	561 max	555–611	
Kinematic viscosity at 40 °C (mm^2/s)	D445	1.3–2.4	1.9–4.1	5.5–24
Maximum copper strip corrosion		No. 3	No. 3	

T590

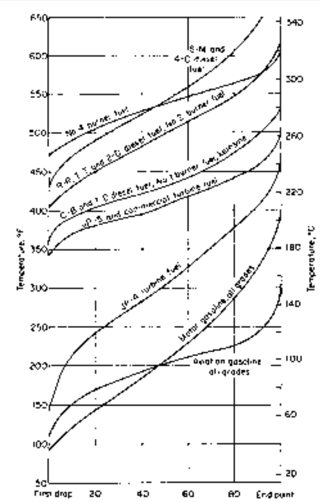
- **1-D**: is a light distillate ($\sim C_{12}H_{22}$) for cold weather.
- **2-D**: is a middle distillate ($\sim C_{15}H_{25}$) diesel fuel of lower volatility and is the most common for vehicles.
- **4-D**: is a heavy distillate fuel used for stationary applications where the engine speed is low and more or less constant.

1 European Standard EN 590: Selected requirements for diesel fuels (figures specified for moderate climate where requirements are climate-dependent)		
Criterion	**Parameter**	**Unit**
Cetane number	≥ 51	–
Cetane index	≥ 46	–
CFPP [1]) in six seasonal categories, max.	+5...–20 [2])	°C
Flash point	≥ 55	°C
Density at 15°C	820...845	kg/m³
Viscosity at 40°C	2.00...4.50	mm²/s
Lubricity	≤ 460	µm (wear scar diameter)
Sulfur content [3])	≤ 350 (until 12-31-2004); ≤ 50 (low sulfur, starting 2005 – 2008); ≤ 10 (sulfur-free, starting 2009) [4])	mg/kg
Moisture content	≤ 200	mg/kg
Total contamination	≤ 24	mg/kg
FAME content	≤ 5	% by volume

[1]) Filtration limit
[2]) Defined by national law, for Germany 0...–20°C
[3]) In Germany, sulfur-free fuel has been on sale nationwide since 2003, throughout the EU starting 2005.
[4]) EU proposal

T580

Typical ASTM Petroleum Distillation Curves



T602

- The 10% and 90% evaporation temperatures, T_{10} and T_{90}, are used in the volatility specifications.
- T_{10}: indicates the start of vaporization, is used to characterize the cold starting behaviour,
- T_{90}: indicates the finish of vaporization, is used to characterize the possibility of unburned hydrocarbons.
- The **ASTM drivability index (DI)** is a measure of fuel volatility and is defined as:

$$DI = 1.5T_{10} + 3T_{50} + T_{90}$$

Octane Number

Steps to measure the octane number of a test fuel is as follows:

1. Run the CFR engine on the test fuel at either the motor or the research operating conditions.
2. Slowly increase the compression ratio until the standard amount of knock occurs.
3. At that compression ratio, run the engine on blends of the reference fuels isooctane and n-heptane.
4. The octane number is the percentage of isooctane in the blend that produces the standardized knock at that compression ratio.

Two sets of CFR engine operating conditions for engines are employed to define two octane numbers:

1. Research Octane Number (RON) (ASTM D908)
2. Motor Octane Number (MON) (ASTM D357)

Octane Number Measurement Conditions

	Research	Motor	Aviation
ASTM method	D908	D357	D614
Air inlet temperature (K)	288	310	325
Jacket temperature (K)	373	373	463
Speed (rpm)	600	900	1200
Spark advance (degrees btdc)	13	19–26	35

T615

- The octane number label on gasoline pumps is the average of the research (RON) and the motor (MON) method octane numbers, known as **Antiknock Index (AKI)**.

$$\mathrm{AKI} = \frac{\mathrm{RON} + \mathrm{MON}}{2}$$

Diesel Cetane Number

- The Cetane number characterizes the ability of the fuel to autoignite, the opposite of octane number.
- For high Cetane numbers, ignition delay is short. Hence, combustion is initiated while the fuel is being injected, so the burning rate is controlled by the rate of fuel–air mixing.
- For low Cetane numbers, fuel will not ignite until late in the injection process. Hence, fuel is well mixed so that once combustion is initiated, the burning rate is very high, causing diesel knock to occur.
- Cetane numbers for vehicular diesel range from about 40 to 55.
- The Cetane number of n-cetane is assigned a value of 100, as it is one of the fastest-igniting hydrocarbon.
- Isocetane (heptamethylnonane) ignites slowly & its CN = 15.

Cetane Number Measurement Conditions (ASTM D613)

Inlet temperature (°C)	66
Coolant temperature (°C)	100
Speed (rpm)	900
Injection timing (btdc)	13°
Injection pressure (MPa)	10.3

T616

- A fuel is compared with mixtures of the reference fuels in standard CFR engine, and rated by the mixture which most nearly matches the ignition delay of the test fuel.

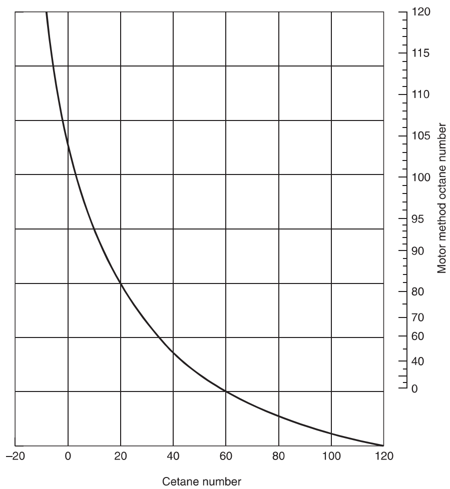
$$CN = (\%n - cetane) + 0.15(\%heptamethylnonane)$$

- **Calculated Cetane index, CCI**: an approximation using ASTM D976 empirical correlation for petroleum-based diesel fuels:

$$\mathrm{CCI} = 454.74 - 1641.416\mathrm{D} + 774.74\mathrm{D}^2 - 0.554 \log \mathrm{T}_{50} + 97.803(\log \mathrm{T}_{50})^2$$

where, $\mathrm{D} \equiv$ density at 15°C (g/ml)

Relationship between Octane & Cetane Numbers



T617

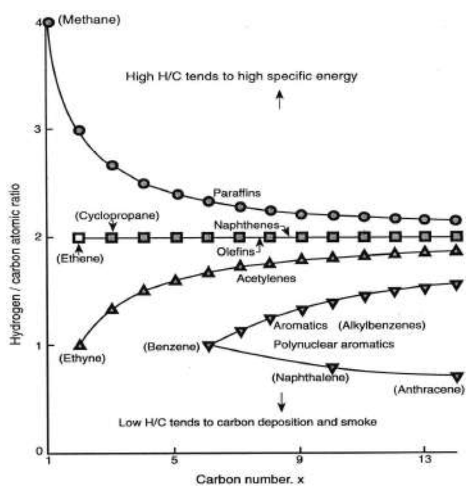
Typical Diesel Additives

Additives	Effect
Ignition accelerators (cetane improvers)	Increase cetane number
	Improve ● Engine starting characteristics ● Exhaust white-smoke emission ● Engine noise levels ● Exhaust emission levels ● Fuel consumption
Detergents	Keep nozzles cleaner
Flow improvers	Improve reliability at low temperatures
Wax anti-setting additives	Improve storage properties at low temperatures
Lubricity enhancers	Reduce fuel-injection component wear especially with hydrogenated low-sulfur fuels
Antifoaming additives	Make refuelling easier (reduce tendency to slosh over)
Anticorrosive additives (corrosion inhibitors)	Protect the fuel system

T614

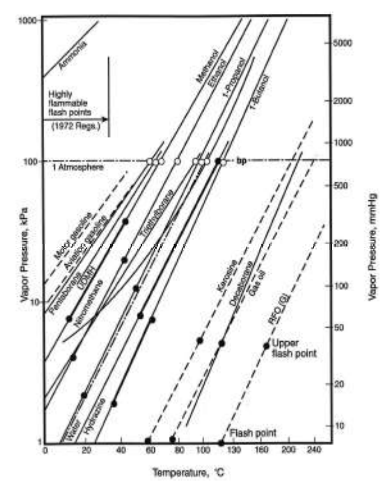
Effects of the most important diesel-fuel additives

H:C Ratio of Inorganic Hydrocarbon Compounds



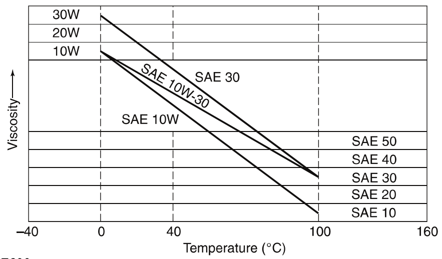
T583

Saturation P-T Curves for Liquid Fuels



T584

Lubricants: Engine Oil Viscosity



T600

$$\mu = C_1 \exp\left[\frac{C_2}{1.8T(^{o}C) + 127}\right]$$

SAE grade	C_1 (N s/m^2)	C_2 (°C)
10	1.09×10^{-4}	1157.5
20	9.38×10^{-5}	1271.6
30	9.73×10^{-5}	1360.0
40	8.35×10^{-5}	1474.4
50	1.17×10^{-4}	1509.6
60	1.29×10^{-4}	1564.0

T601

- Engine oil reduces the friction between the principal moving parts of an engine.
- It also acts as a coolant for the pistons, rings, and bearings, to enhance the rings combustion seal, to control engine wear or corrosion, and to remove impurities from lubricated regions.