Ciências ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

DISCIPLINA MIEA 2019

Technologies of combustion

Corpo docente

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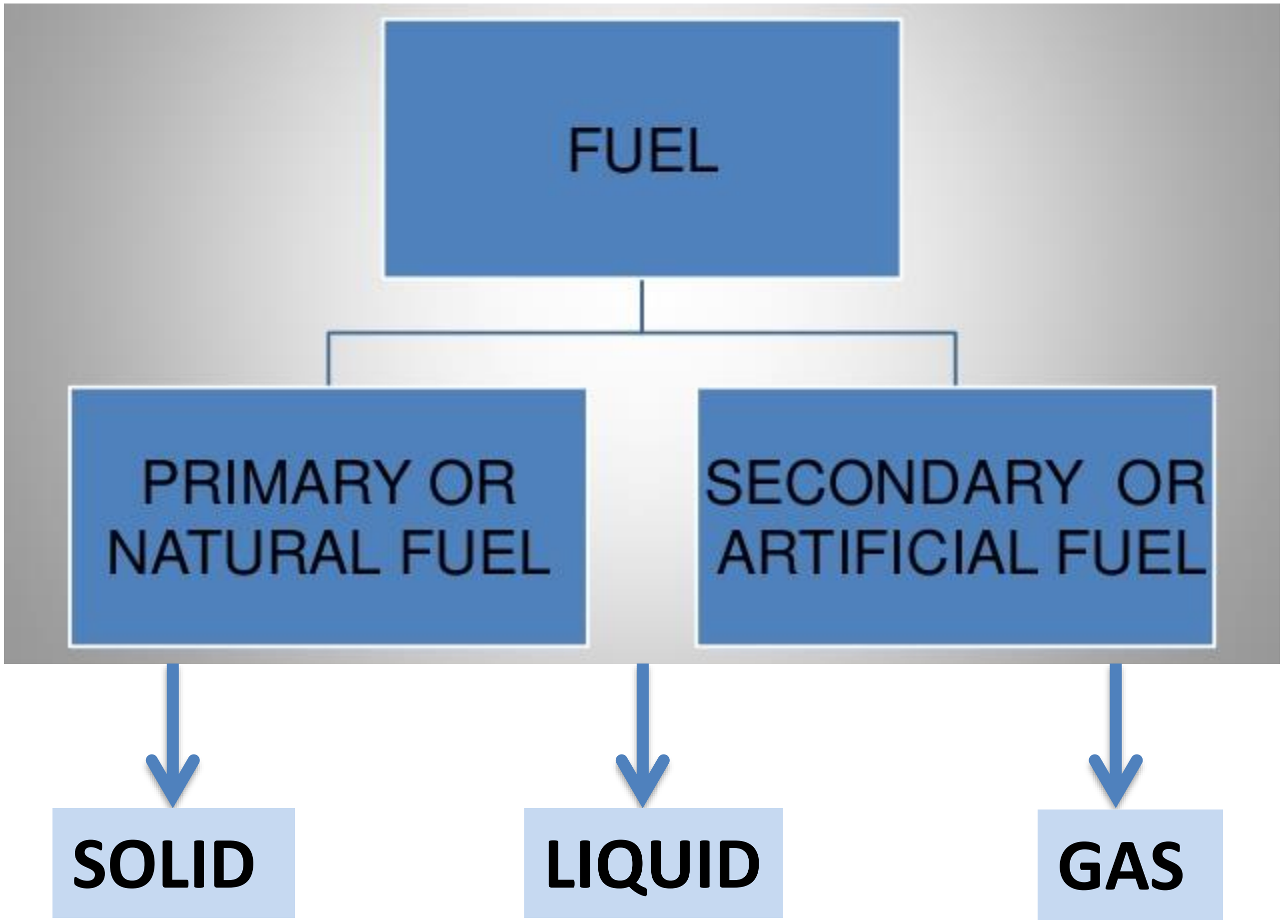
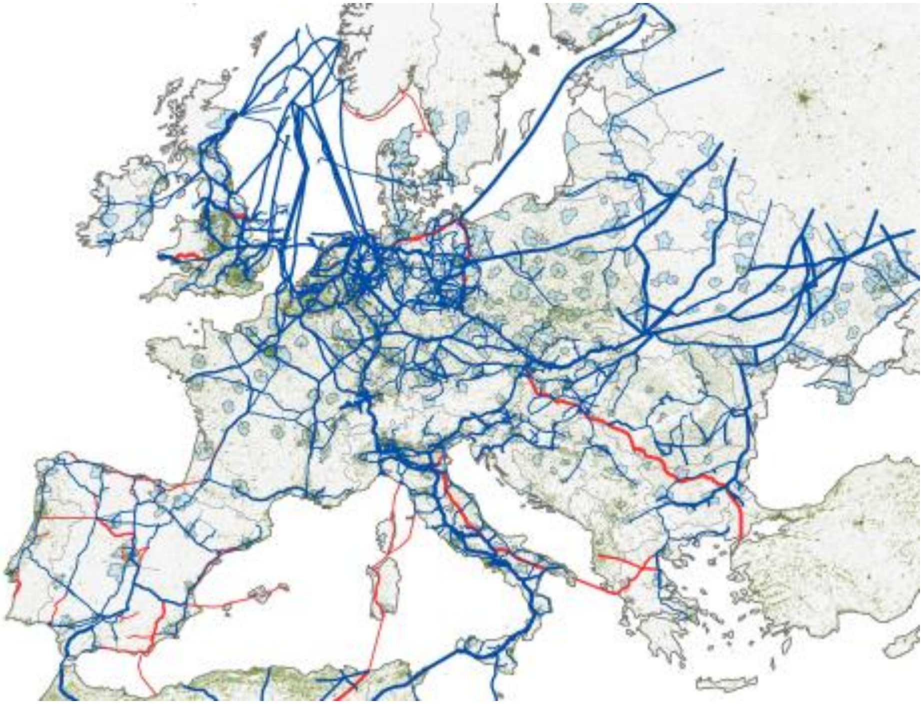
Fuel types

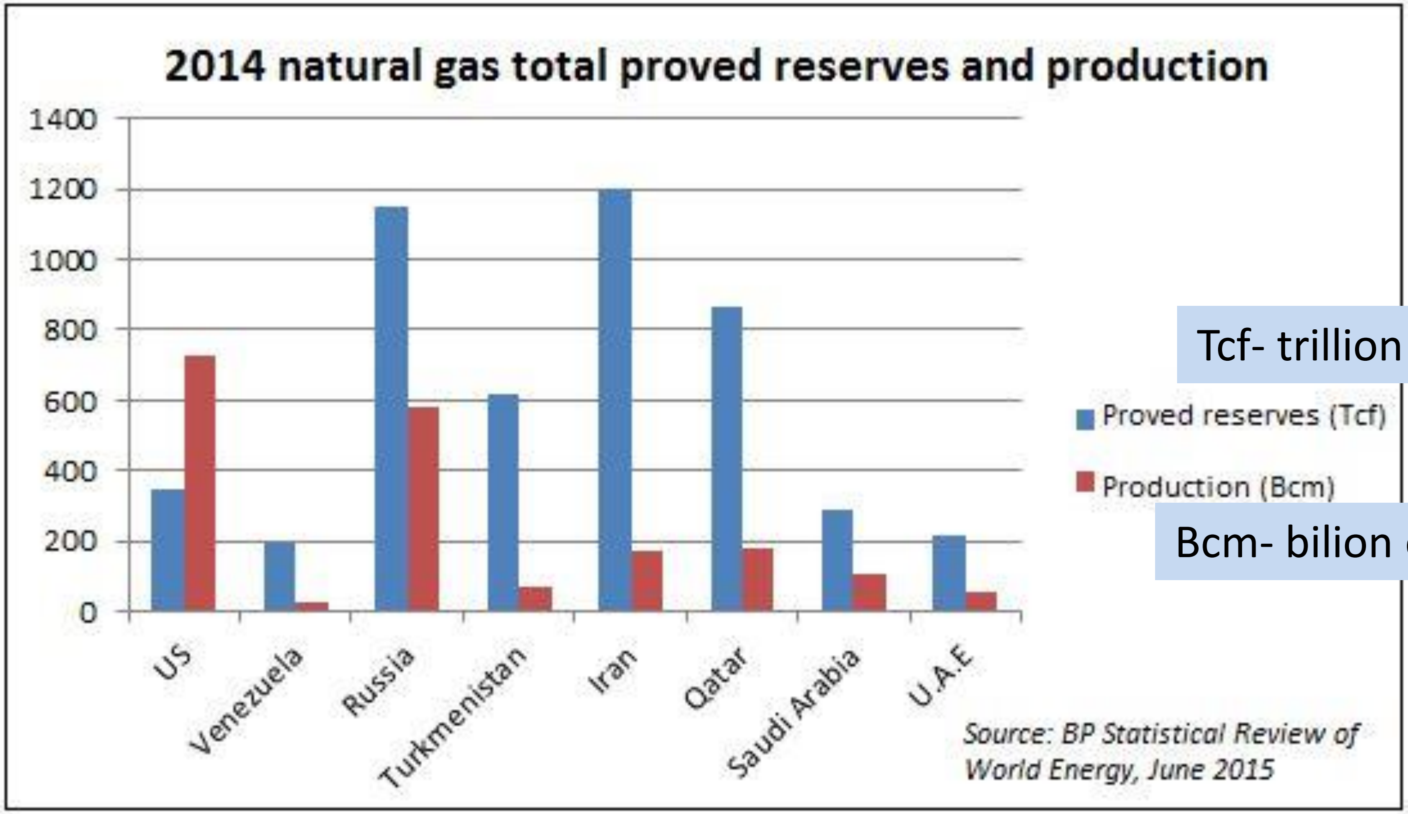

FUEL
PRIMARY OR NATURAL FUEL
SECONDARY OR ARTIFICIAL FUEL
SOLID
LIQUID
GAS

Natural gas network



The European natural gas network. The existing network is shown in blue; planned pipelines in red. Population density is represented in dark green; larger urban areas are coloured light blue. (Image: ETH Zurich)

Natural gas

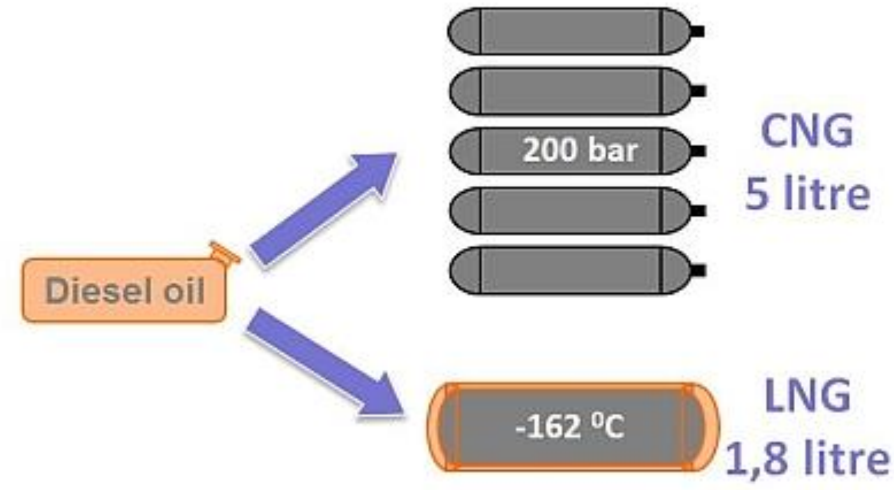


Tcf- trillion cubic feet

Bcm- bilion cubic meter

Natural gas

Visual comparison of the volumetric equivalence between diesel, CNG, and LNG for a given energy content. *(NGVA Europe).*



Addition of odorants to help identify NG in case of a leak.

Gas fuel

Quality/unit	Natural methane	LPG propane	LPG butane
Chemical formula	CH_4	C_3H_8	C_4H_{10}
Boiling point	−162°C	−42°C	−2°C
Specific gravity of liquid fuel	–	0.5	0.57
Specific gravity of gas vapour	0.58	1.78	2.0
Gross calorific value	38.5 MJ/m^3	95 MJ/m^3	121.5 MJ/m^3
Gas family	2nd	3rd	3rd
Flammability limits	5–15%	2.3–9.5%	1.9–8.5%
Air/gas ratio	9.81:1	23.8:1	30.9:1
Oxygen/gas ratio	2:1	5:1	6.5:1
Flame speed	0.36 m/s	0.46 m/s	0.38 m/s
Ignition temperature	704°C	530°C	500°C
Max. flame temperature	1000°C	1980°C	1996°C
System operating pressure	21 ± 2 mbar	37 ± 5 mbar	28 ± 5 mbar
Liquid storage vapour pressure	–	6–7 bar	1.5–2 bar

Gas fuel

OIL&GAS JOURNAL

Correlation for natural gas heat capacity developed

GAS COMPOSITIONS USED FOR GENERATING C_p VALUES

Table 1

Component	Natural gas mixtures, mole % — Gas A	B	C	D	E
CH_4	94.4	88.9	83.2	78.0	74.9
C_2H_6	2.6	5.2	8.8	10.5	10.1
C_3H_8	2.0	3.7	4.2	6.5	7.2
$i\text{-}C_4H_{10}$	0.5	0.7	1.1	1.5	2.4
$n\text{-}C_4H_{10}$	0.5	0.7	1.1	1.5	2.4
$i\text{-}C_5H_{12}$	0.0	0.4	0.8	1.0	1.5
$n\text{-}C_5H_{12}$	0.0	0.4	0.8	1.0	1.5
Mol wt	17.39	18.83	20.28	21.72	23.18
SG	0.60	0.65	0.70	0.75	0.80

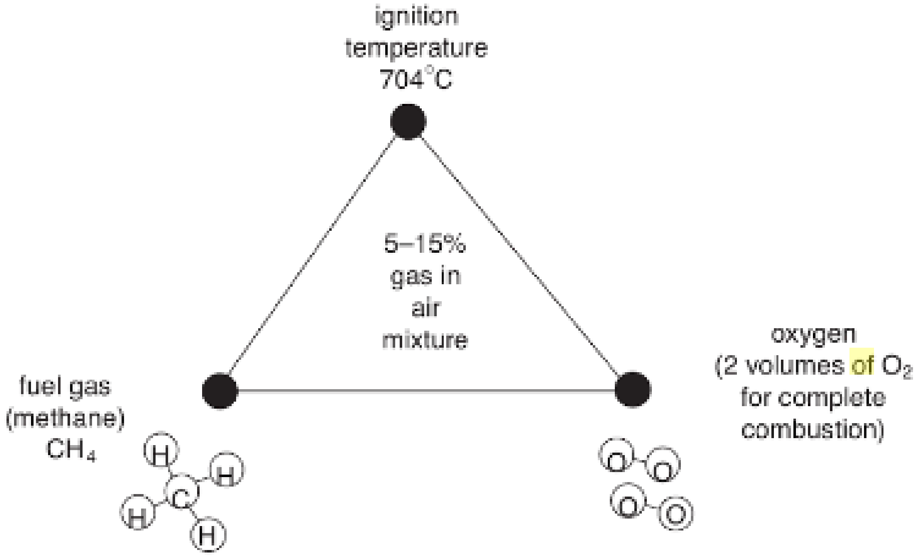
Natural gas network

Biogas		Landfill gas	Waste water treatment digester	House hold waste digester	Industrial waste/animal manure digester
Methane	vol.%	36–52[a]	65[a]	65[a]	60–80/50–70[b]
Carbon dioxide	vol.%	30–41[a]	33.5[a]	29[a]	20–40/30–50[b]
Water vapour	vol.%	0.1–3.3[a]	2[a]	0.5[a]	1–4[b]
Nitrogen	vol.%	<10[b]	<5[b]		n.d./<5[b]
Oxygen	vol.%	<3[b]	<1[b]		n.d./<1[b]
Siloxanes[c]	mg/m^3	1.4–9.8[a]	1.3[a]	1.35[a]	n.d.[a]
Sulphur	mg/m^3	29–900[a]	<25[a]	30[a]	
Hydrogen sulfide	ppm	10–1000[b]	150–3000		<30000/<5000[b]
Ammonia	ppm	<5[a]	<5[a]	<5[a]	<5[a]
Halogenated compounds[d]	mg/m^3	0–7[a]	n.d.	n.d.	<0.1[a]
Benzene	mg/m^3	<36[e]	<0.3[e]		
Toluene	mg/m^3	<287[e]	<12[e]		

[a] Arnold [4].
[b] Oasmaa and Di Felipe [9].
[c] L2–L4, D2–D4, TMS.
[d] Quantified as toluene equivalent; n.d. = not detected.
[e] Rasi et al. [10].

Gas fuel

Methane combustion essentials



CH_4 $2O_2$

Stoichiometry

Gas fuel

Natural gas interchangeability

- Appliances
- Boilers
- Burners
- Power plants
- Turbines

$$heat\ release\ burner = kd^2{}_0\sqrt{\Delta p}\left(\frac{HV\rho_{fu}}{\sqrt{\frac{\rho_{fu}}{\rho_{air}}}}\right)$$

Dimensionless constant

Hole diameter of the burner

Heat release throughout the hole

Wobbe Index (WI)

Gas fuel

Natural gas interchangeability

- Appliances
- Boilers
- Burners
- Power plants
- Turbines

e.g. biogas

MJ/Nm^3

Family	Gas type	Approx. Wobbe no.
1st	Manufactured (town gas)	24–29
2nd	Natural	48–53
3rd	LPG	72–87

Gas fuel

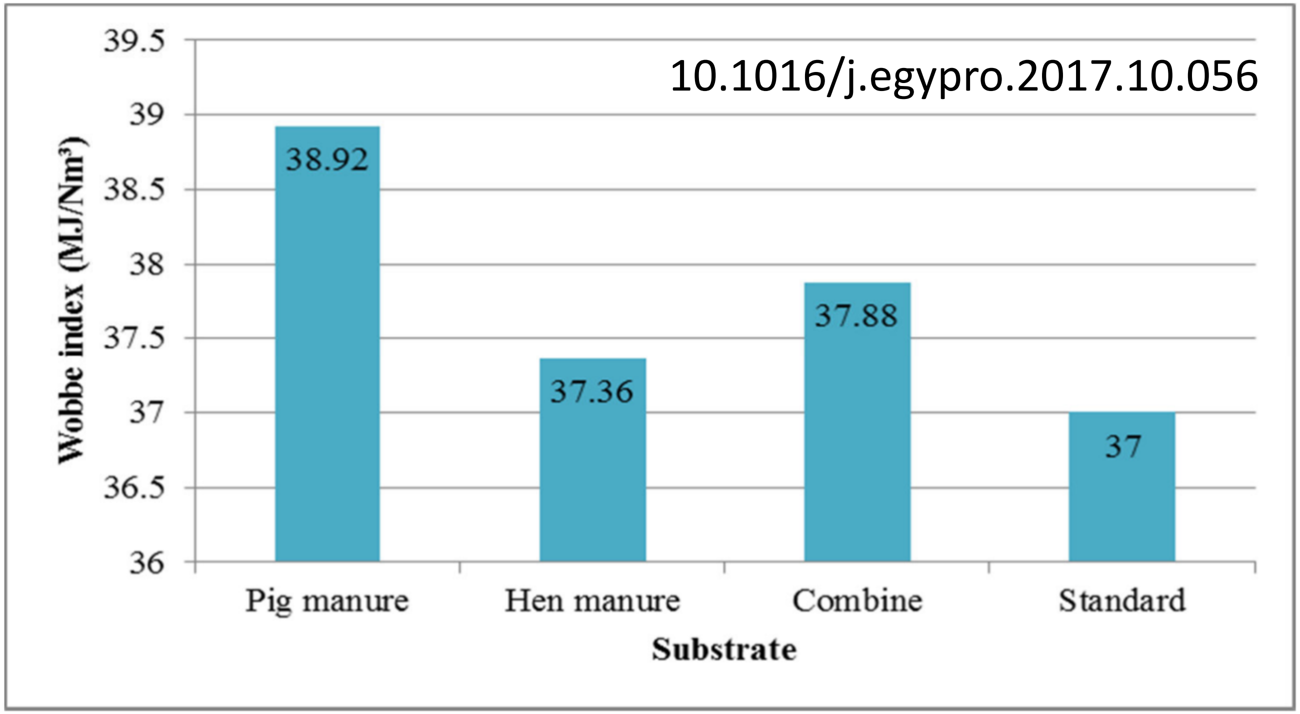


Fig. 2. Wobbe index Comparison in various substrate with standard

e.g. biogas

MJ/Nm^3

Family	Gas type	Approx. Wobbe no.
1st	Manufactured (town gas)	24–29
2nd	Natural	48–53
3rd	LPG	72–87

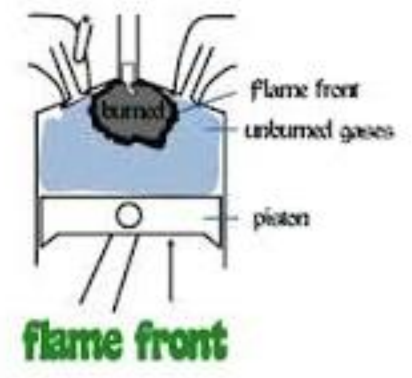
Gas fuel

Flame speed

Laminar

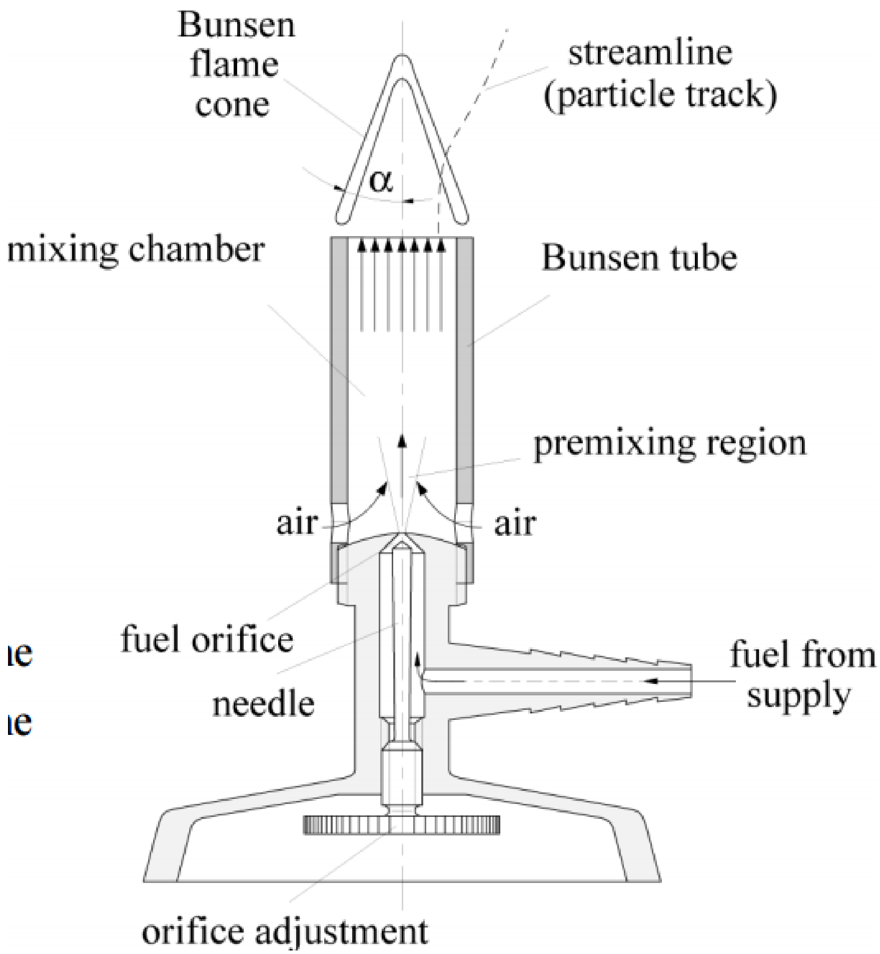
Turbulent

Pre-mixture



Difusion

Gas fuel

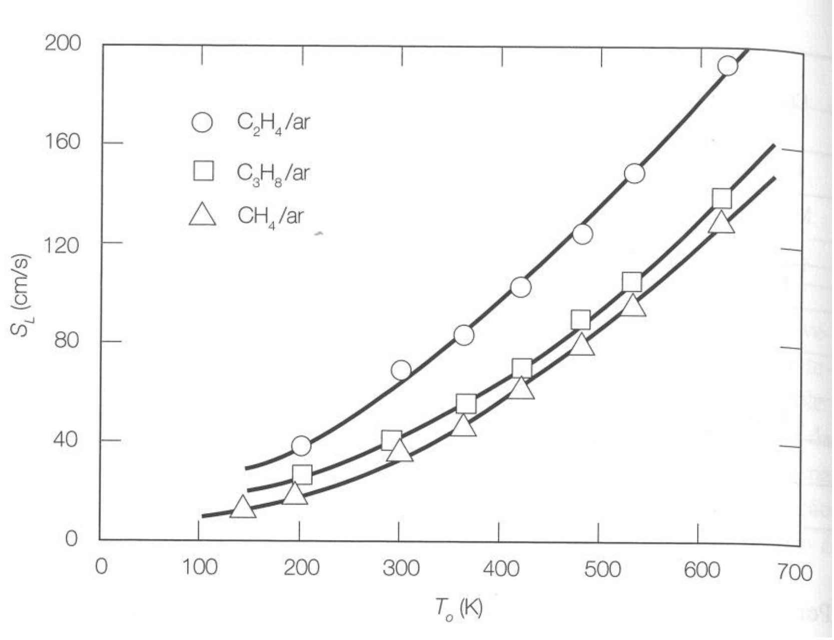

Bunsen
flame
cone
streamline
(particle track)
α
mixing chamber
Bunsen tube
premixing region
air
air
fuel orifice
needle
fuel from
supply
orifice adjustment

Gas fuel

Laminar Flame Speed

$SL \propto T^m$

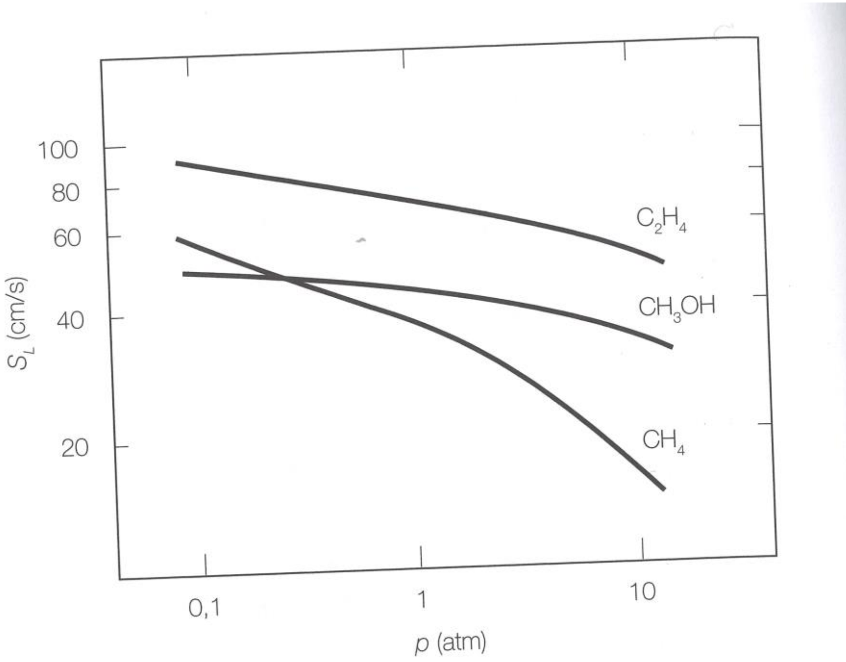
→ Reactants initial temperature



$$SL_{CH4}\left(\frac{cm}{s}\right) = 10 + 3.71x10^{-4}\mathrm{T}^2$$

Gas fuel

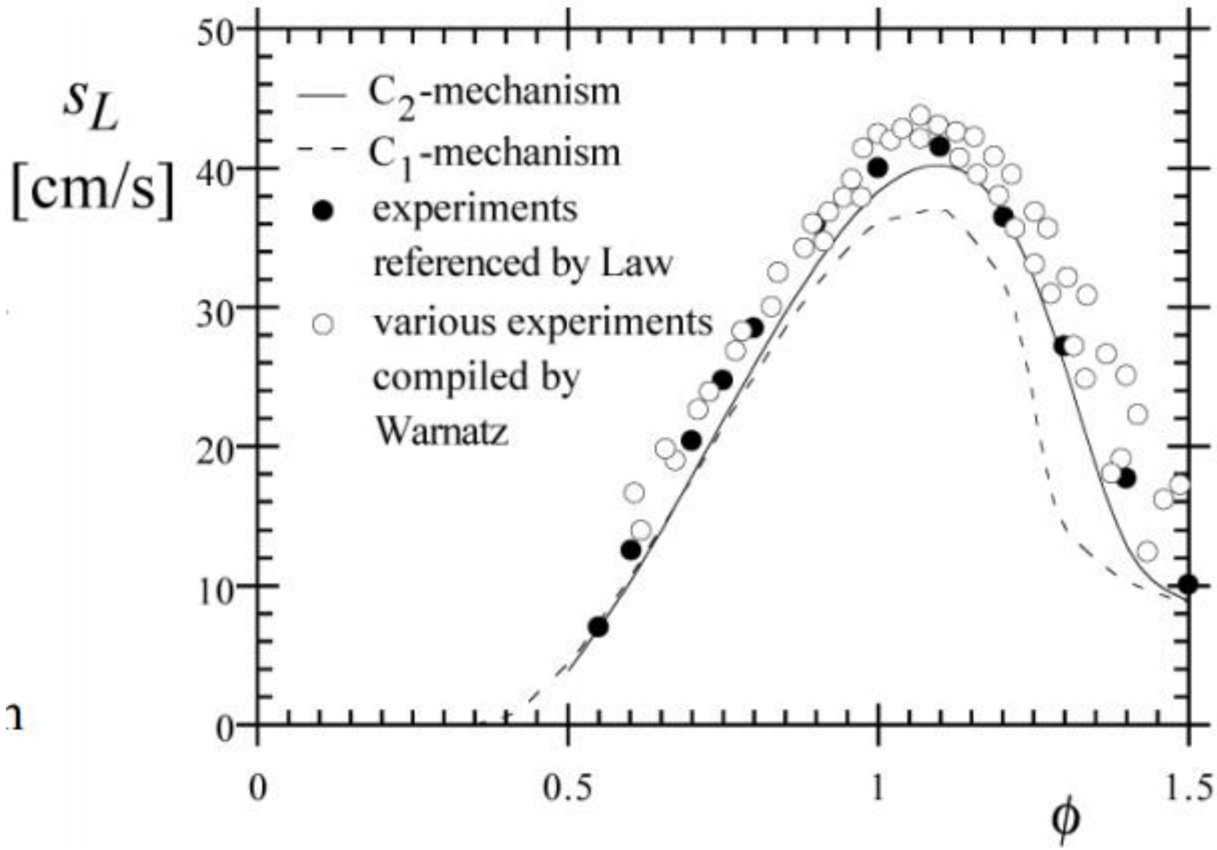
Laminar Flame Speed



$$SL_{CH4}\left(\frac{cm}{s}\right) = 43p^{-0.5}$$

p em atm

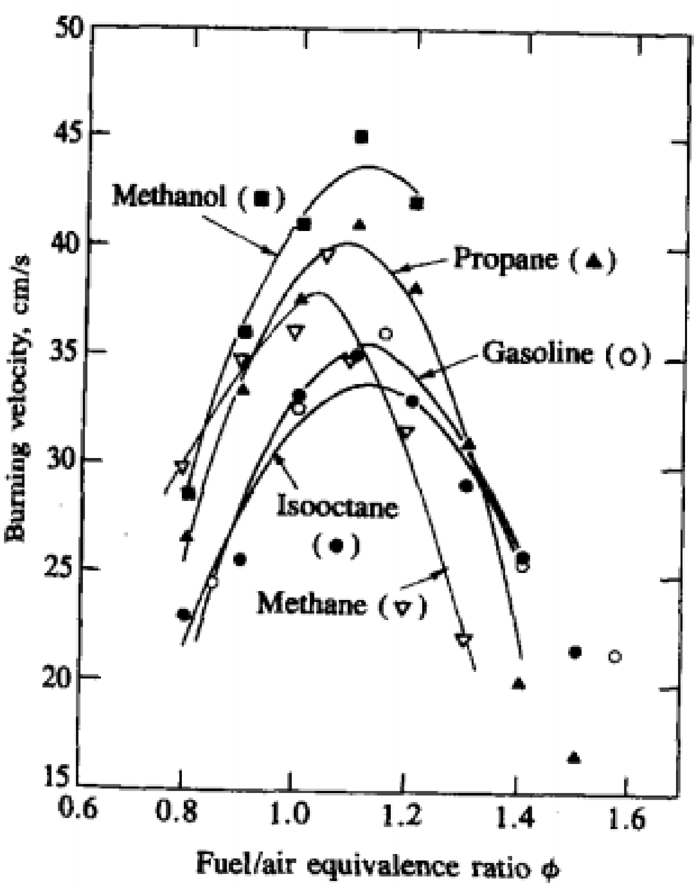
Gas fuel



s_L
[cm/s]
50
40
30
20
10
0
C_2-mechanism
C_1-mechanism
experiments
referenced by Law
various experiments
compiled by
Warnatz
0
0.5
1
1.5
ϕ

1/λ

Gas fuel



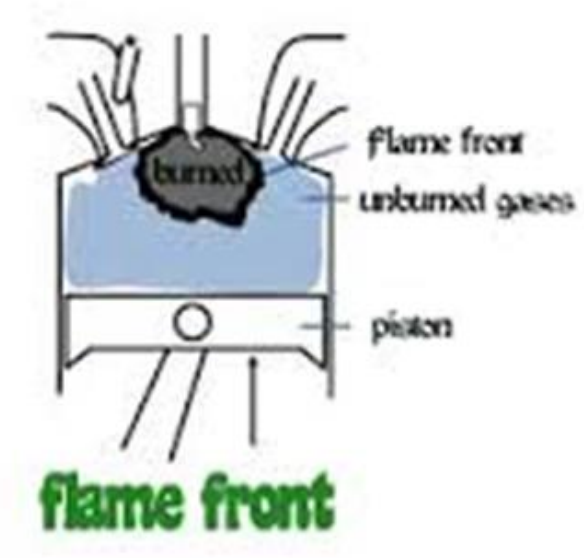


FIGURE 9-25
Laminar burning velocity for several fuels as function of equivalence ratio, at 1 atm and 300 K. Lines are least-squares polynomial fits to data.[29, 30]

Gas fuel

$$S_L = S_{L,0}\left(\frac{T_u}{T_0}\right)^{\alpha}\left(\frac{p}{p_0}\right)^{\beta} \tag{9.33}$$

where $T_0 = 298$ K and $p_0 = 1$ atm are the reference temperature and pressure, and $S_{L,0}$, α, and β are constants for a given fuel, equivalence ratio, and burned gas diluent fraction. For propane, isooctane, and methanol, these constants can be represented by

$$\alpha = 2.18 - 0.8(\phi - 1) \tag{9.34a}$$

$$\beta = -0.16 + 0.22(\phi - 1) \tag{9.34b}$$

and

$$S_{L,0} = B_m + B_\phi(\phi - \phi_m)^2 \tag{9.35}$$

where ϕ_m is the equivalence ratio at which $S_{L,0}$ is a maximum with value B_m.

Parameters ϕ_m, B_m, and B_ϕ for Eq. (9.35)

Fuel	ϕ_m	B_m, cm/s	B_ϕ, cm/s	Ref.
Methanol	1.11	36.9	−140.5	30
Propane	1.08	34.2	−138.7	30
Isooctane	1.13	26.3	−84.7	30
Gasoline	1.21	30.5	−54.9	32

Note: Values of $S_{L,0}$ given by Eq. (9.35) are obtained from least-squares fits of Eq. (9.33) to data over the range $p = 1$–8 atm, $T_u = 300$–700 K. They do not correspond exactly to the laminar flame speed data at 1 atm and 298 K in Fig. 9-25.

Metghalchi & Keck (1982)

Gas fuel

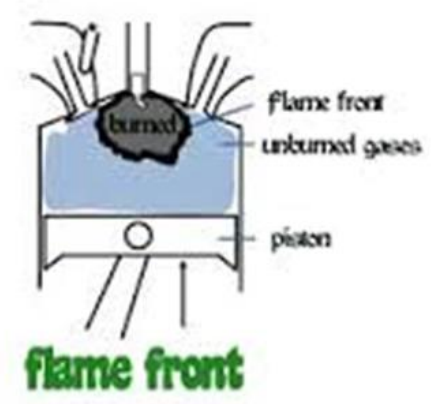
Metghalchi & Keck (1982)

$$S_L = S_{L,ref} \left(\frac{T_o}{T_{o,ref}} \right)^{\alpha_T} \left(\frac{p}{p_{ref}} \right)^{\alpha_p}$$

	$S_{L,ref}$ (m/s)	α_T	α_p
Metano ($\phi = 0{,}8$)	0,259	2,105	– 0,504
Metano ($\phi = 1{,}0$)	0,360	1,612	– 0,374
Metano ($\phi = 1{,}2$)	0,314	2,000	– 0,438
Propano ($0{,}8 \leq \phi \leq 1{,}5$)	$0{,}34 - 1{,}38\,(\phi - 1{,}08)^2$	$2{,}18 - 0{,}8\,(\phi - 1)$	$-0{,}16 + 0{,}22\,(\phi - 1)$

$1/\lambda$

Turbulence effect



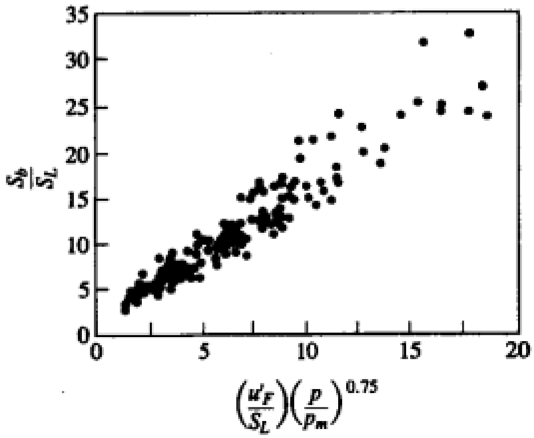
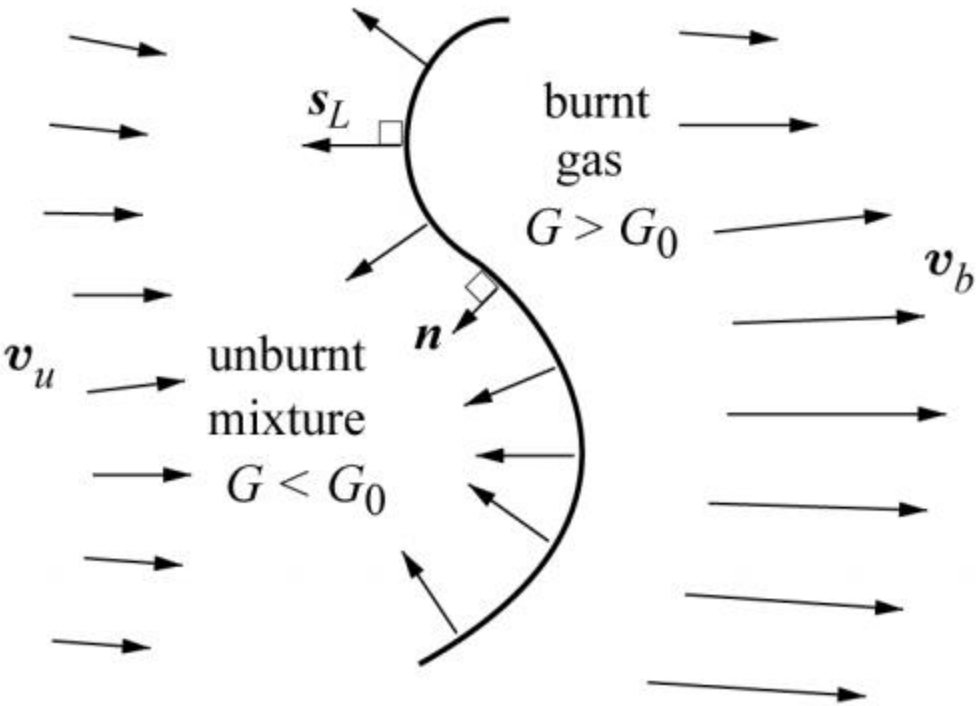
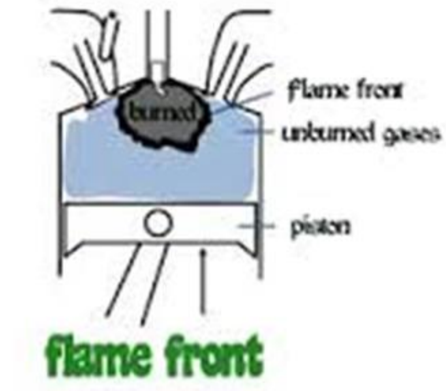


FIGURE 9-30
Variation of burning speed with turbulence intensity. The ensemble-averaged rms velocity fluctuation was measured during motoring engine operation. The ratio p/p_m (firing pressure/motoring pressure) corrects for the effect of additional compression on the turbulence intensity. Range of engine speeds and spark timings.[35]

Gas fuel

Laminar Flame Speed and reactants flow

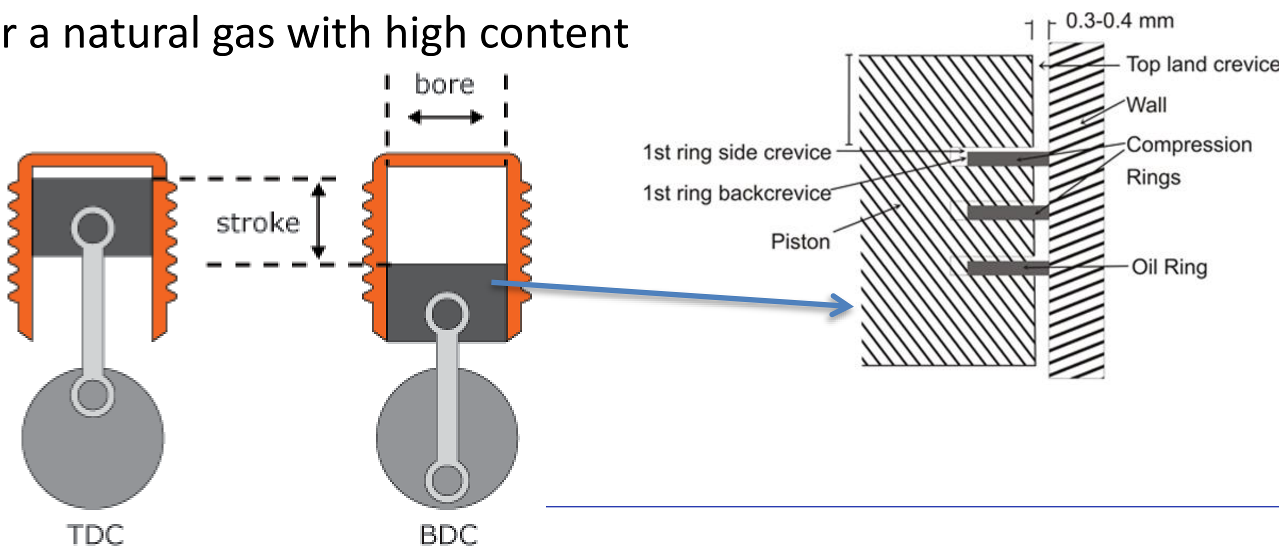




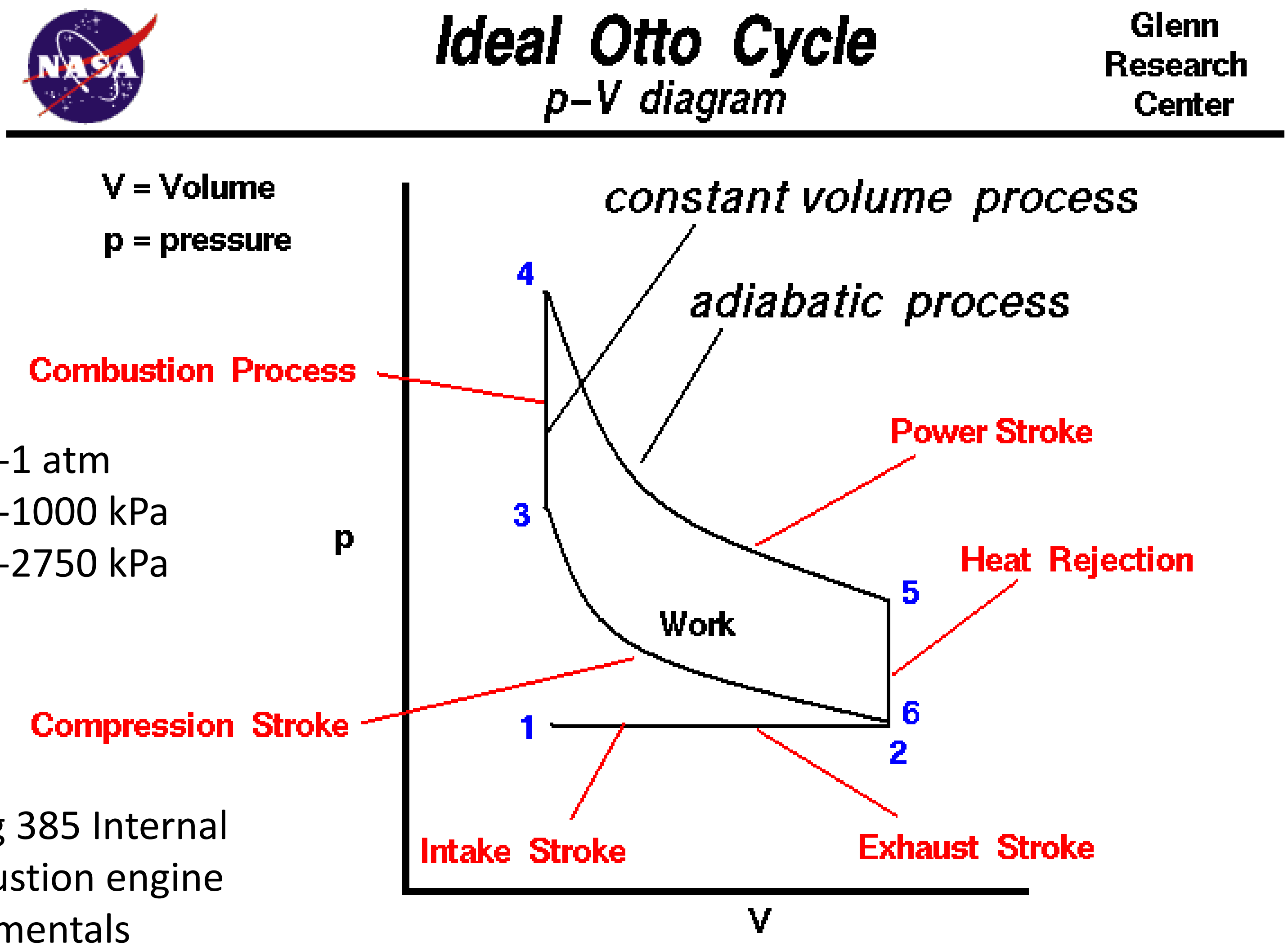
Gas fuel

P#18 Imagine you are using LPG in a 4 cylinder, 1.4 liter internal combustion engine, compression ratio 12, bore=stroke, equipped with an exhaust aftertreatment system, a three-way catalytic converter, TWC. Assume a spherical centered flame front, cold start and hot regime.

a) LPG has a high octane number. Identify the type of combustion constant volume or constant pressure?
b) Estimate the dimensions of the combustion chamber (assume bore=stroke).
c) How much time do you estimate will be the combustion duration?.
d) Discuss HC (non-methane volatile organic compounds) formation near the oil rings where the temperature is 100ºC. What would be the function of the TWC
e) Repeat for a natural gas with high content



Gas fuel



Point 1 -1 atm

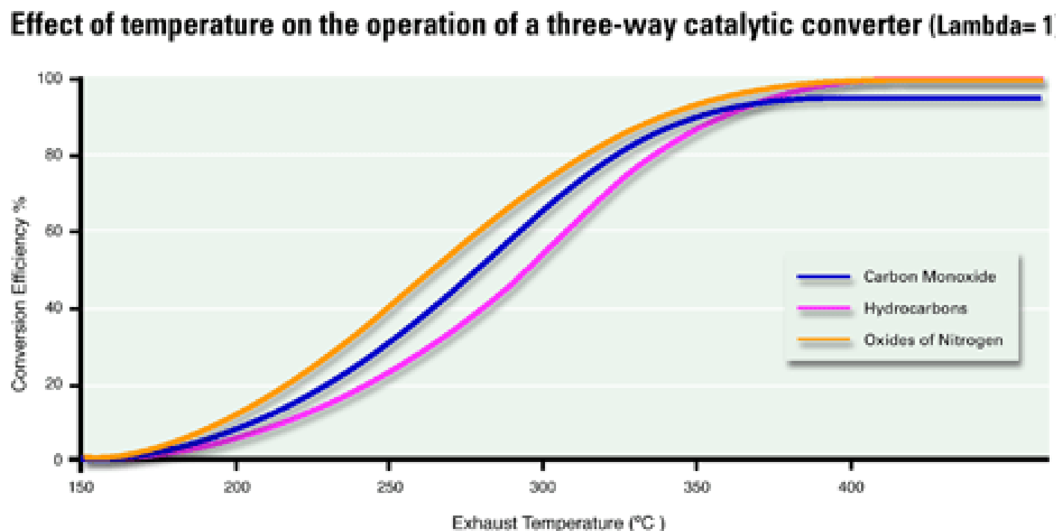
Point 3 -1000 kPa

Point 4 -2750 kPa

e.g. pg 385 Internal combustion engine fundamentals

Emissions

P#19 A mixture of methane gas and air at 25°C and 1 atm is burned in a water heater at 100% theoretical air. The mass flow rate of methane is 1.15 kg/h. The exhaust gas temperature was measured to be 500 °C and approximately 1 atm and is subjected to exhaust aftertreatment. The volumetric flow rate of cold water (at 22 °C) to the heater is 4 L/min. Flue gas is equipped with a TWC.



(a) Determine the combustion efficiency.
(b) Calculate the temperature of the hot water if the heat exchanger were to have an efficiency of 1.0, i.e., perfect heat transfer.
(c) Consider the following concentrations of emissions at the combustion products: 5000 ppm NO. Estimate the NO exhaust gas emissions in g/h.

Emissions

P#20 The following sentences are true or false?

a) The molar mass of an ideal mixture is equal to the sum of each species molar mass weighted by its molar fractions.

b) In a rich mixture $\phi>1$.

c) The adiabatic flame temperature, at constant pressure, increases with the increase in the reactants temperature.

d) At 3000 K H_2 is more likely to dissociate to its monoatomic form, than N_2.

e) In 2 adiabatic recipients, different dimensions, it was introduced the same mass of air and fuel at Tamb. After ignition, and once reached the equilibrium, the dissociation is higher in the smallest recipient.

Obrigado

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