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DISCIPLINA MIEA 2019

Technologies of combustion

Corpo docente

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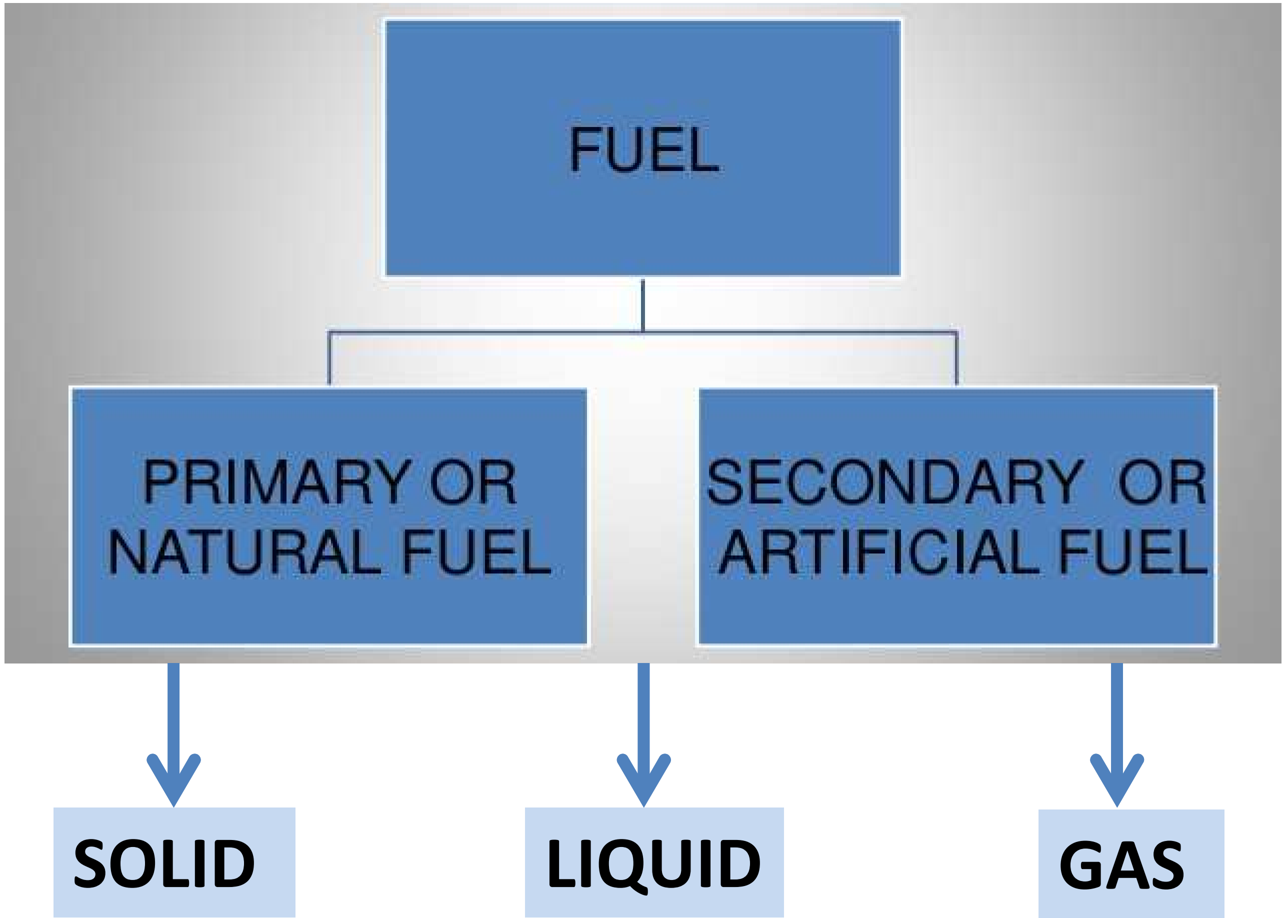
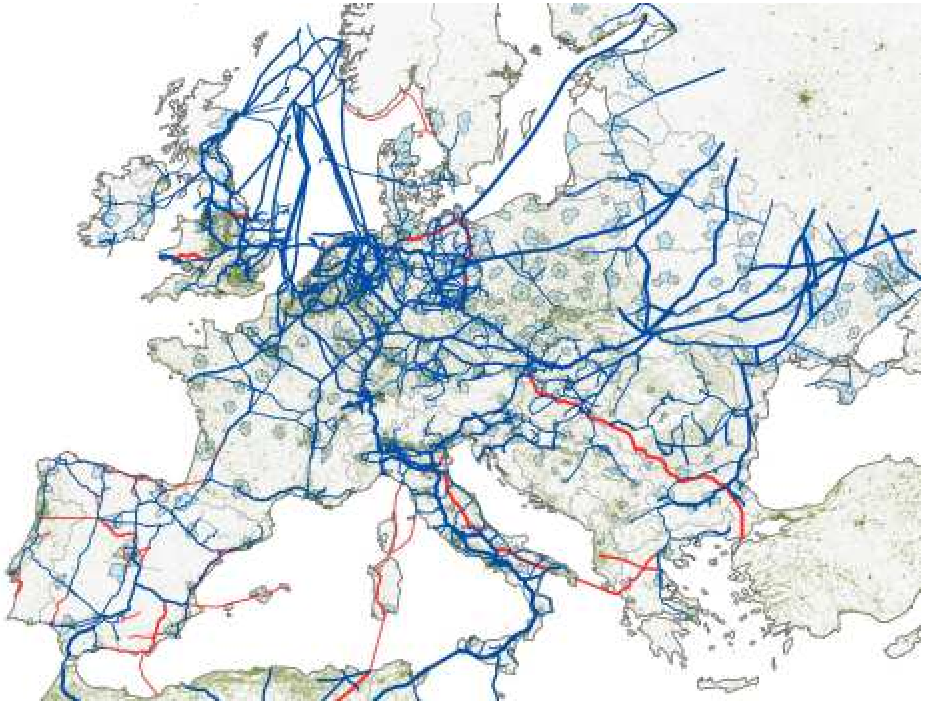
Fuel types

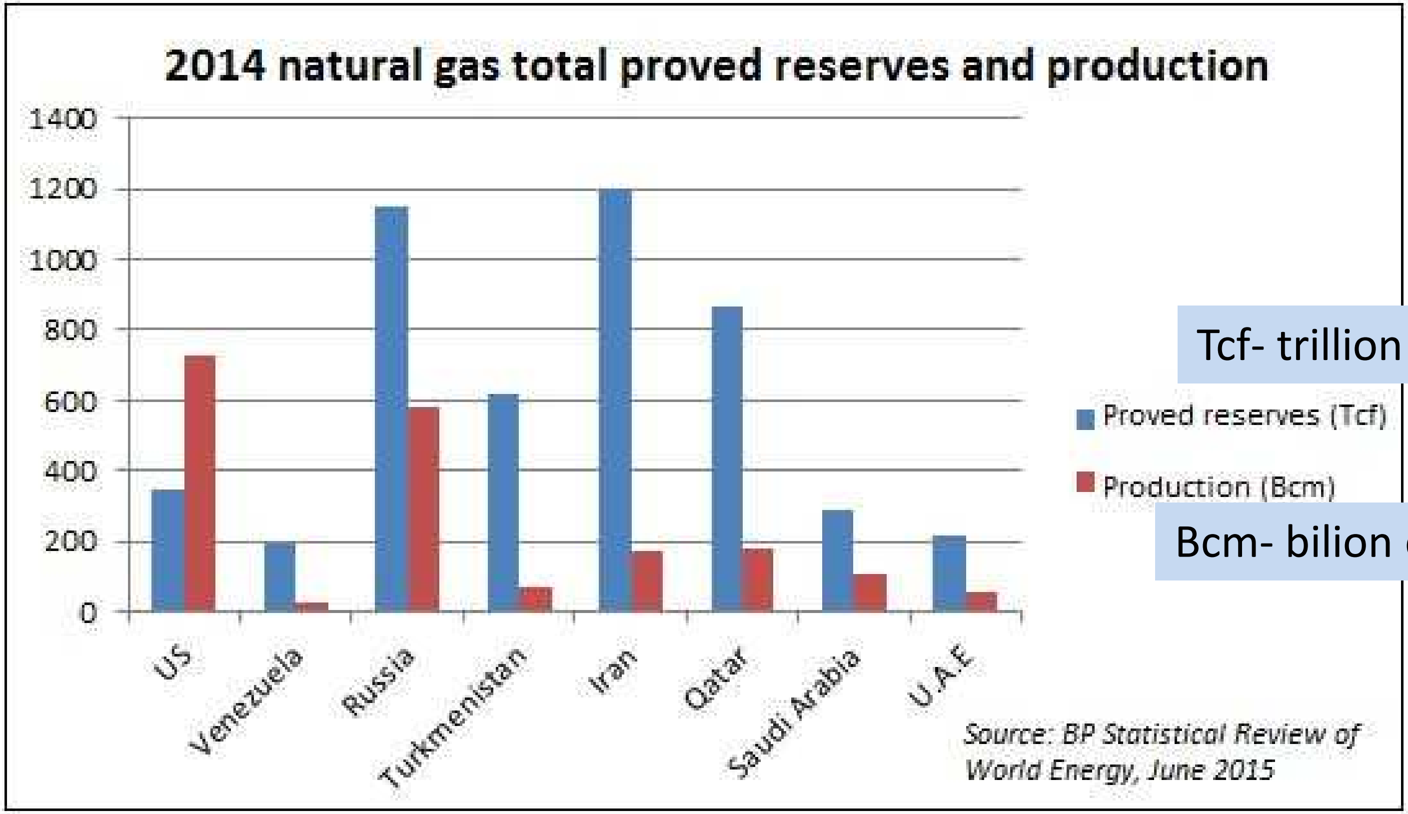

FUEL
PRIMARY OR NATURAL FUEL
SECONDARY OR ARTIFICIAL FUEL
SOLID
LIQUID
GAS

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

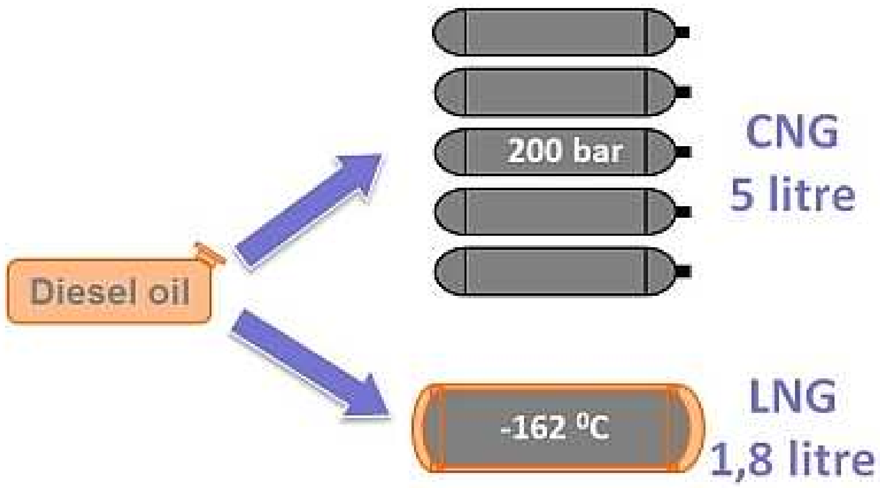


Tcf- trillion cubic feet

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

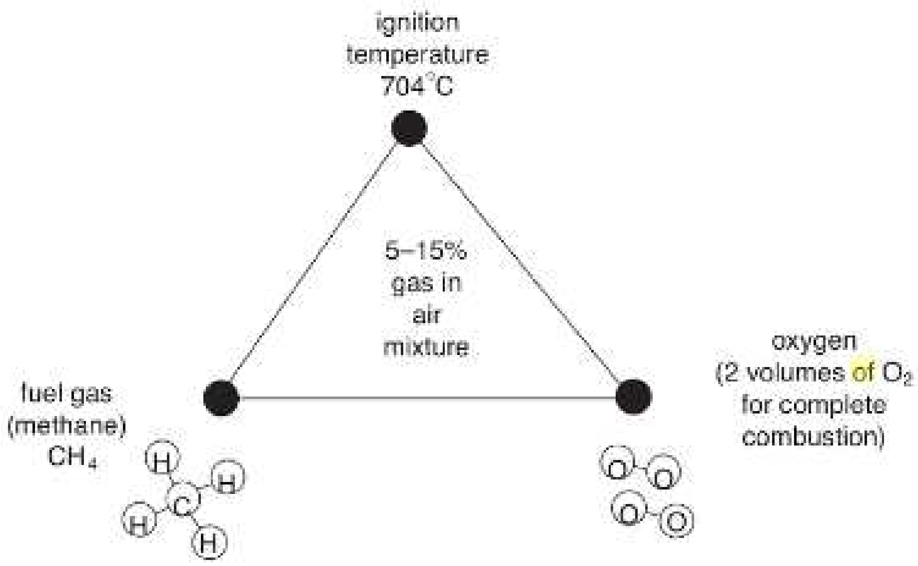
Natural gas network

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

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

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

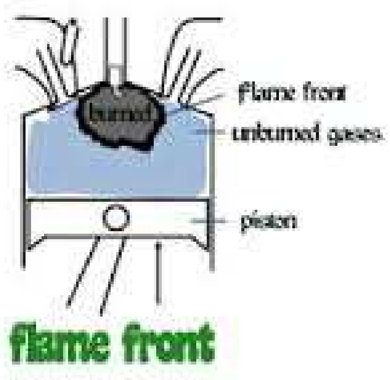
Gas fuel

Flame speed

Laminar

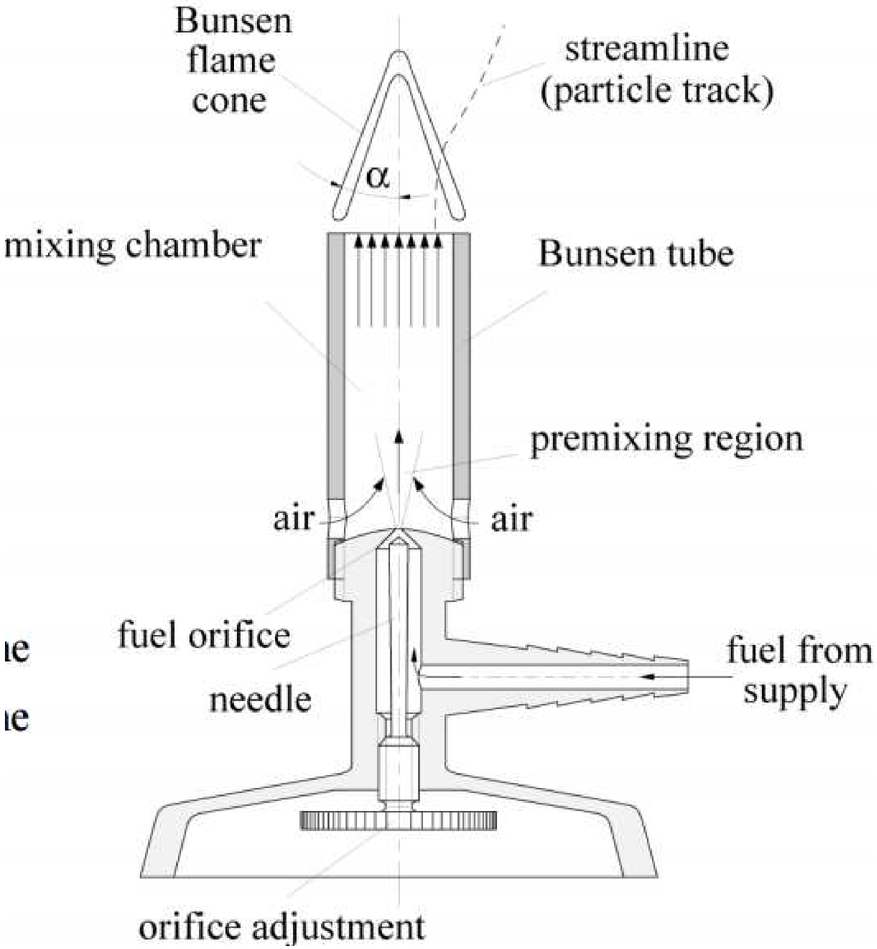
Turbulent

Pre-mixture



Difusion

Gas fuel

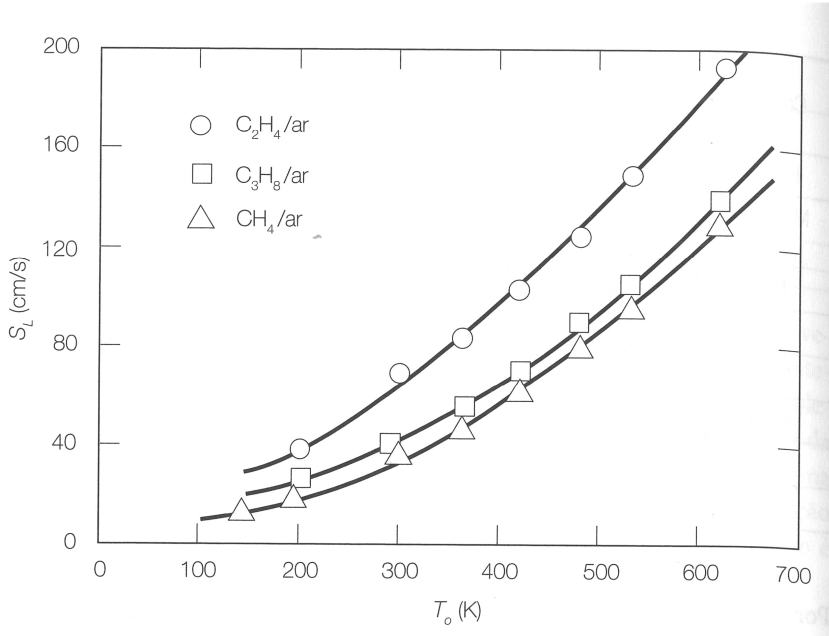

Bunsen
flame
cone
streamline
(particle track)
α
mixing chamber
Bunsen tube
premixing region
air
air
fuel orifice
fuel from
supply
needle
orifice adjustment

Gas fuel

Laminar Flame Speed

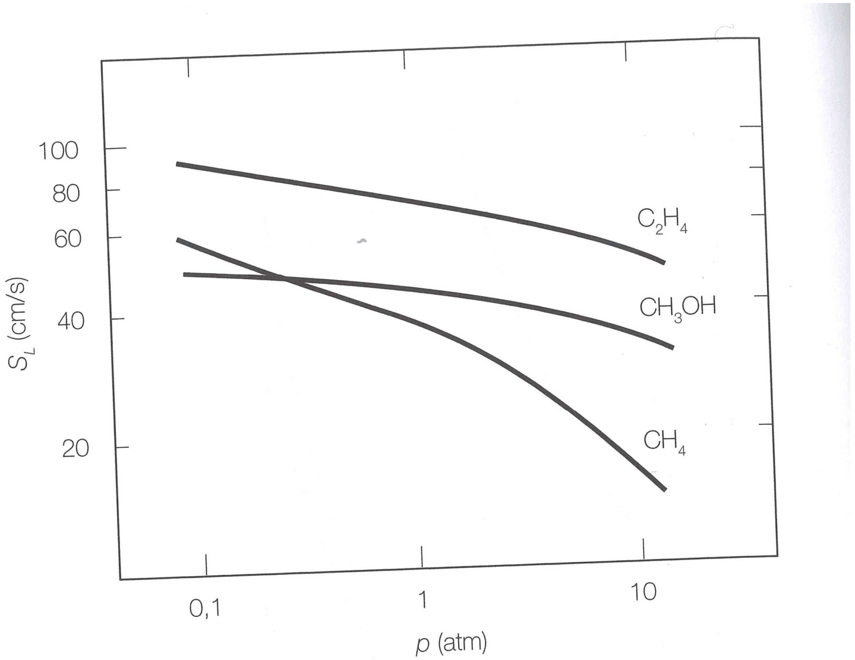
$$SL \propto T^m$$

Reactants initial temperature



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

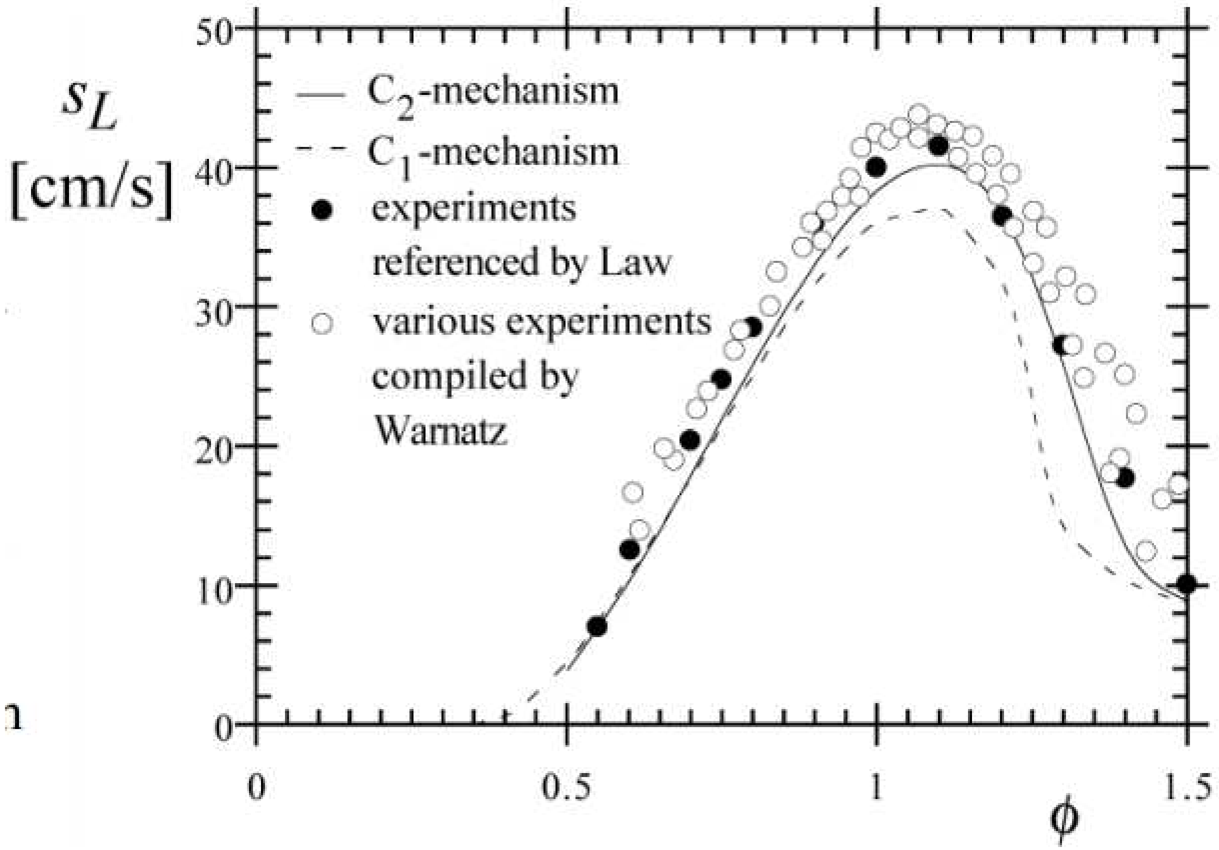
Laminar Flame Speed



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

p em atm

Gas fuel



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

1/λ

Gas fuel

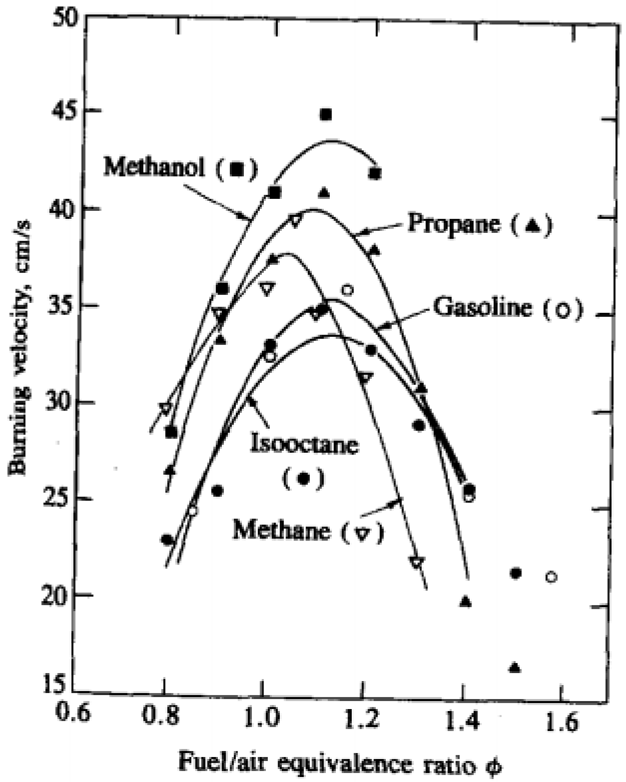
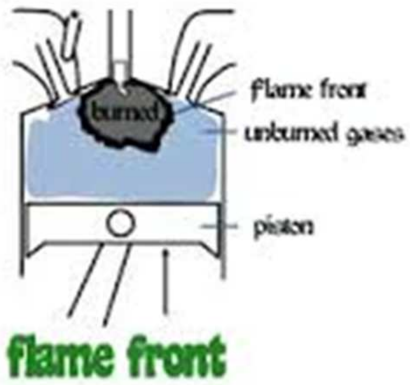


FIGURE 9-25
Laminar burning velocity for several fuels as function of equivalence ratio, at 1 atm and 300 K. Lines are least-squares polynomial fits to data.[29, 30]



$1/\lambda$

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.

$1/\lambda$

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 ($0{,}8 \leq \phi \leq 1{,}5$)	$0{,}34 - 1{,}38(\phi - 1{,}08)^2$	$2{,}18 - 0{,}8(\phi - 1)$	$-0{,}16 + 0{,}22(\phi - 1)$

$1/\lambda$

Gas fuel

Turbulence effect

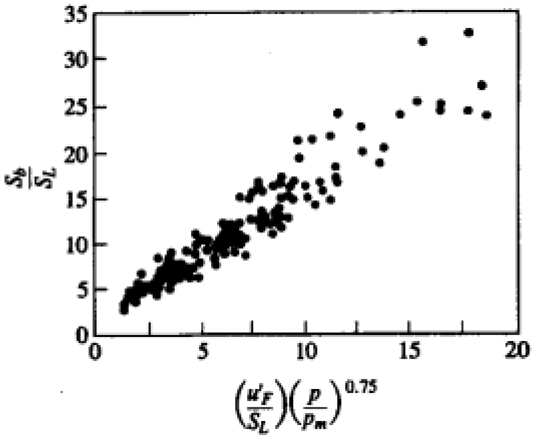
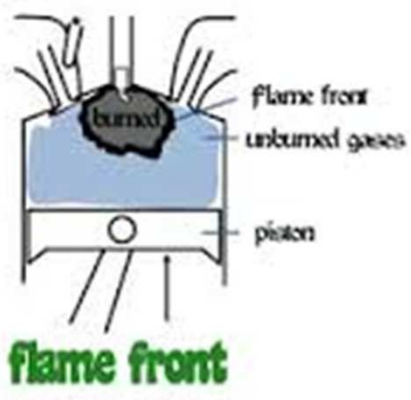
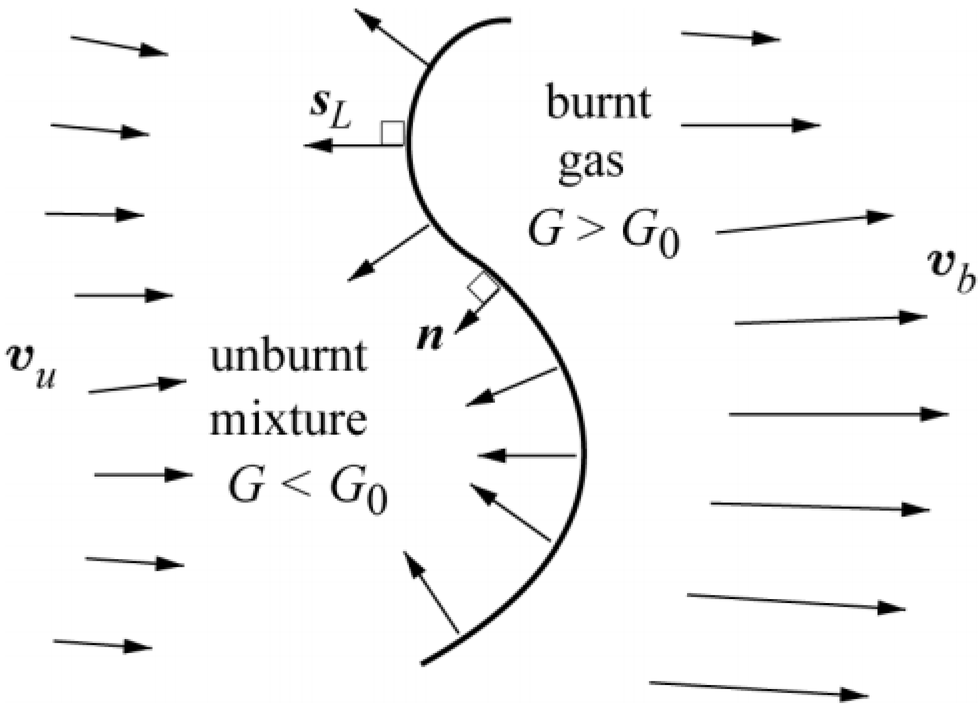


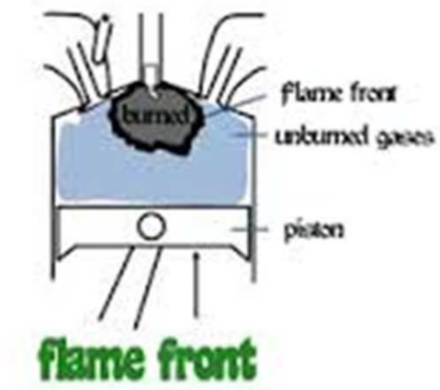
FIGURE 9-30
Variation of burning speed with turbulence intensity. The ensemble-averaged rms velocity fluctuation was measured during motoring engine operation. The ratio p/p_m (firing pressure/motoring pressure) corrects for the effect of additional compression on the turbulence intensity. Range of engine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



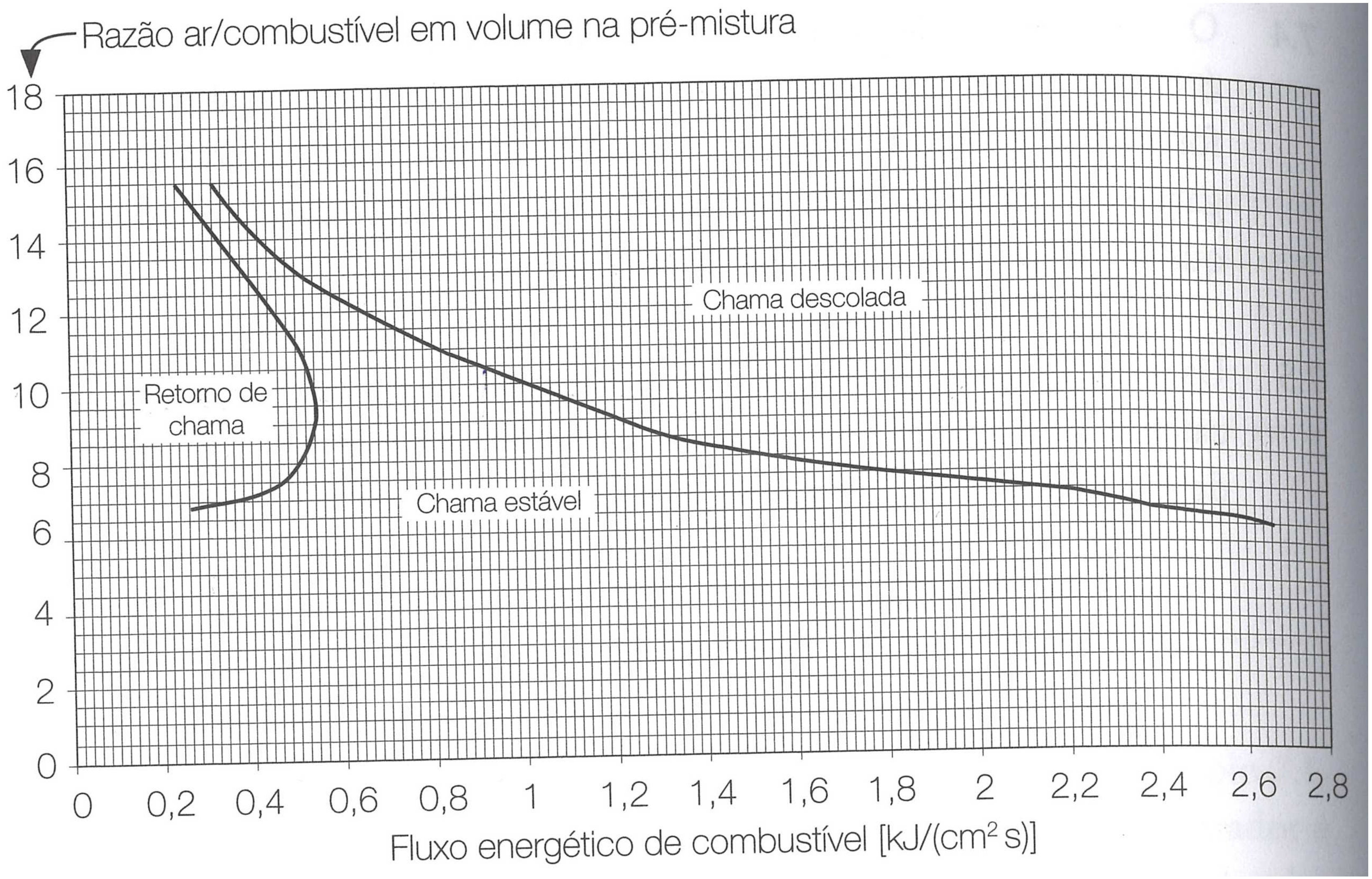
Gas fuel

Laminar Flame Speed and reactants flow





Gas fuel


Razão ar/combustível em volume na pré-mistura
18
16
14
12
10
8
6
4
2
0
Retorno de chama
Chama descolada
Chama estável
0
0,2
0,4
0,6
0,8
1
1,2
1,4
1,6
1,8
2
2,2
2,4
2,6
2,8
Fluxo energético de combustível [kJ/(cm2 s)]

Gas fuel

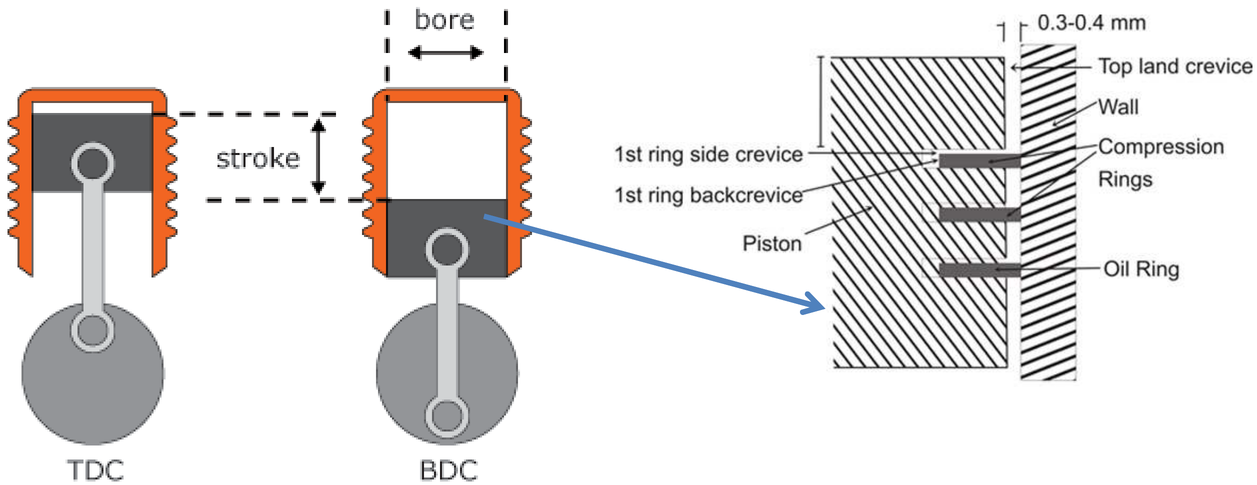
P#19 Pretende-se dimensionar os orificios de um queimador que é alimentado com uma mistura de metano e ar à temperatura de 300 K e pressão de 100 kPa. O queimador tem de satisfazer a seguinte condição de funcionamento: potência calorífica fixa de 3 kW e mistura pobre ou estequiométrica. Não está previsto qualquer dispositivo de controlo automático e/ou de estabilização de chama. Considere um queimador com doze orificios e procure maximizar a estabilidade das chamas.

a) Escolha a composição da mistura e calcule o seu caudal.
b) Dimencione os orificios.

Gas fuel

P#20 Imagine you are using LPG in a 4 cylinder, 1.4 liter internal combustion engine, compression ratio 12, bore=stroke. Assume a spherical centered flame front and cold start.

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.
e) Repeat for a natural gas with high content of methane.



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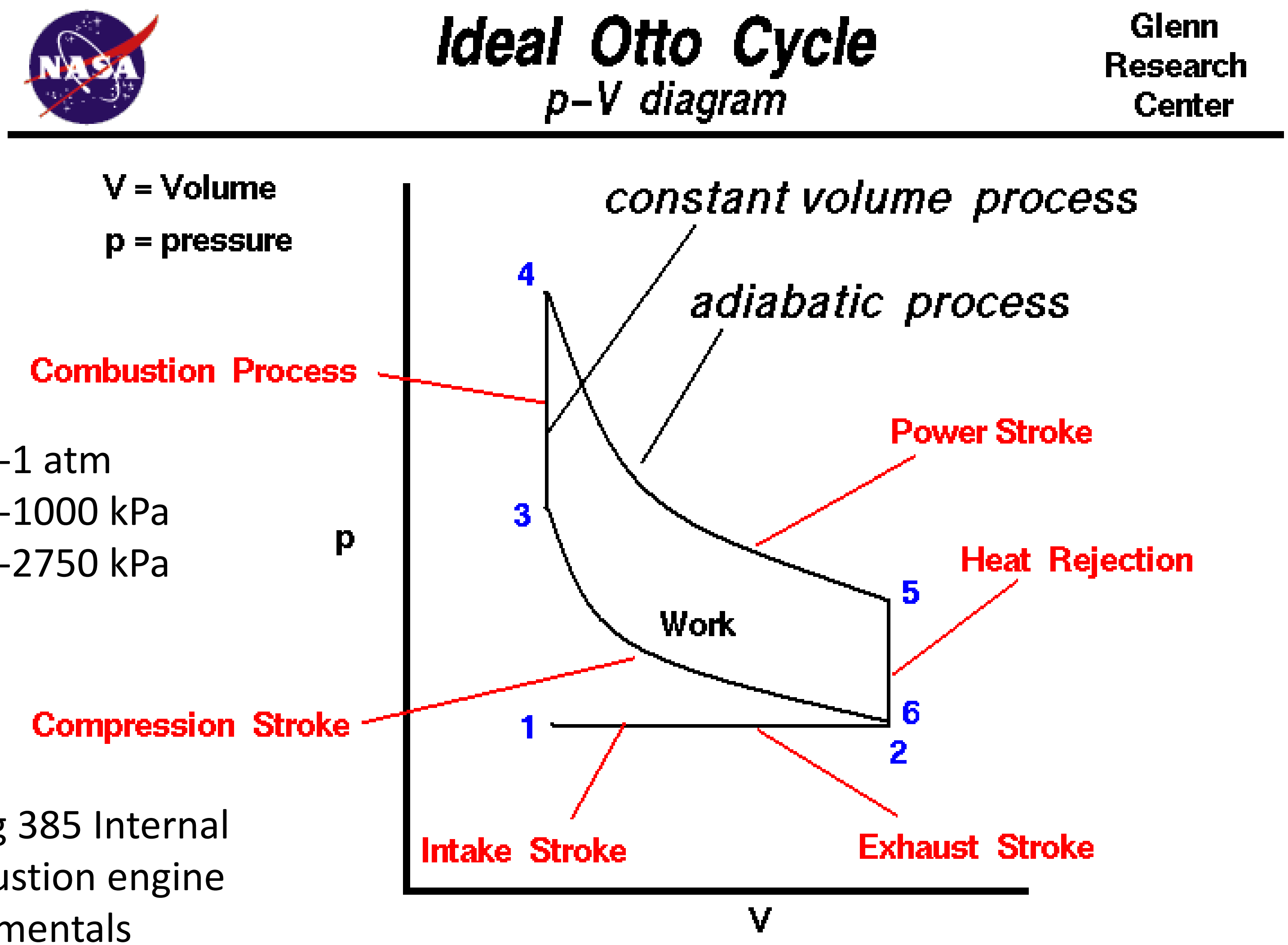
Gas fuel



Point 1 -1 atm
Point 3 -1000 kPa
Point 4 -2750 kPa

e.g. pg 385 Internal combustion engine fundamentals

Gas fuel

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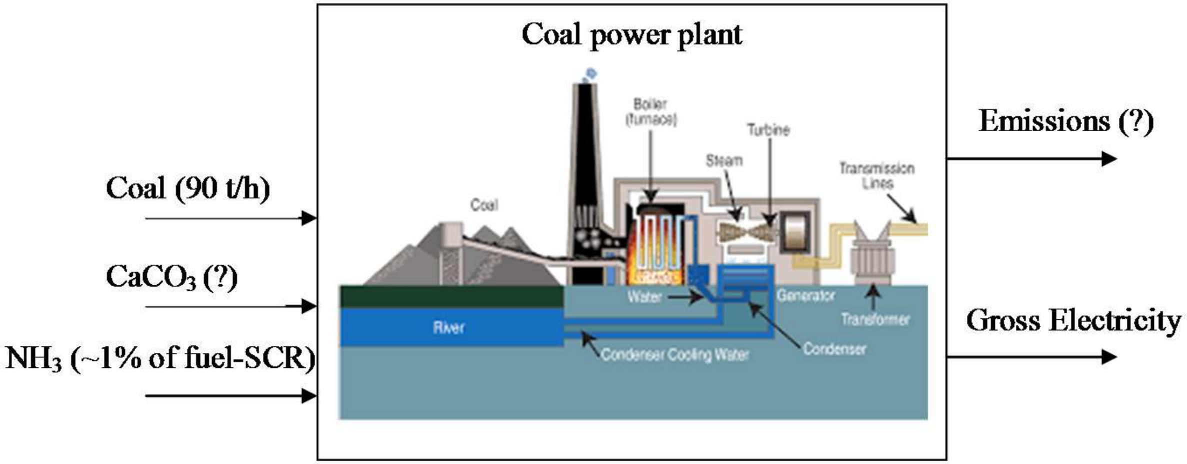
2^{nd} assignement-doubts



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