Ciências ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

DISCIPLINA MIEA 2019

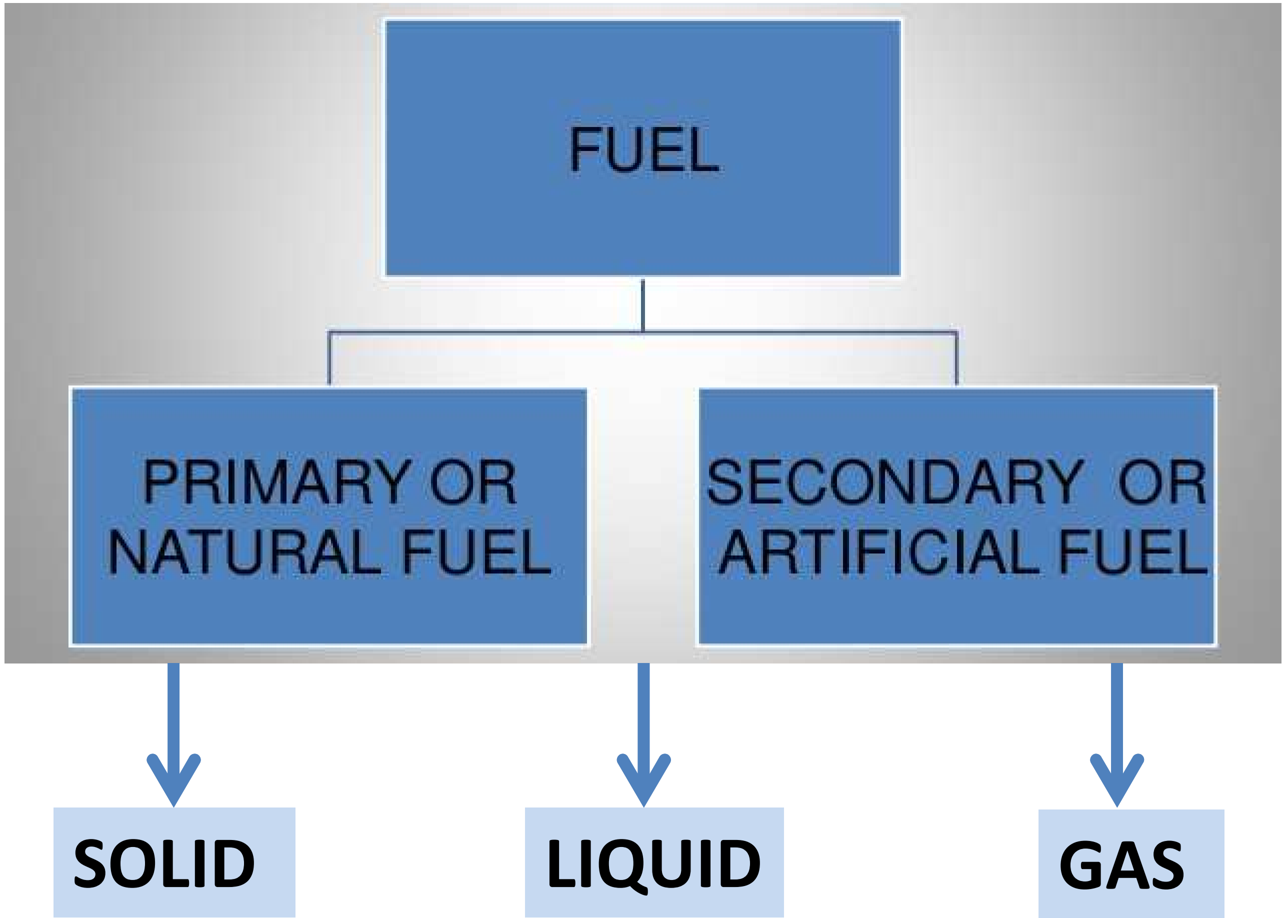
Technologies of combustion

Corpo docente

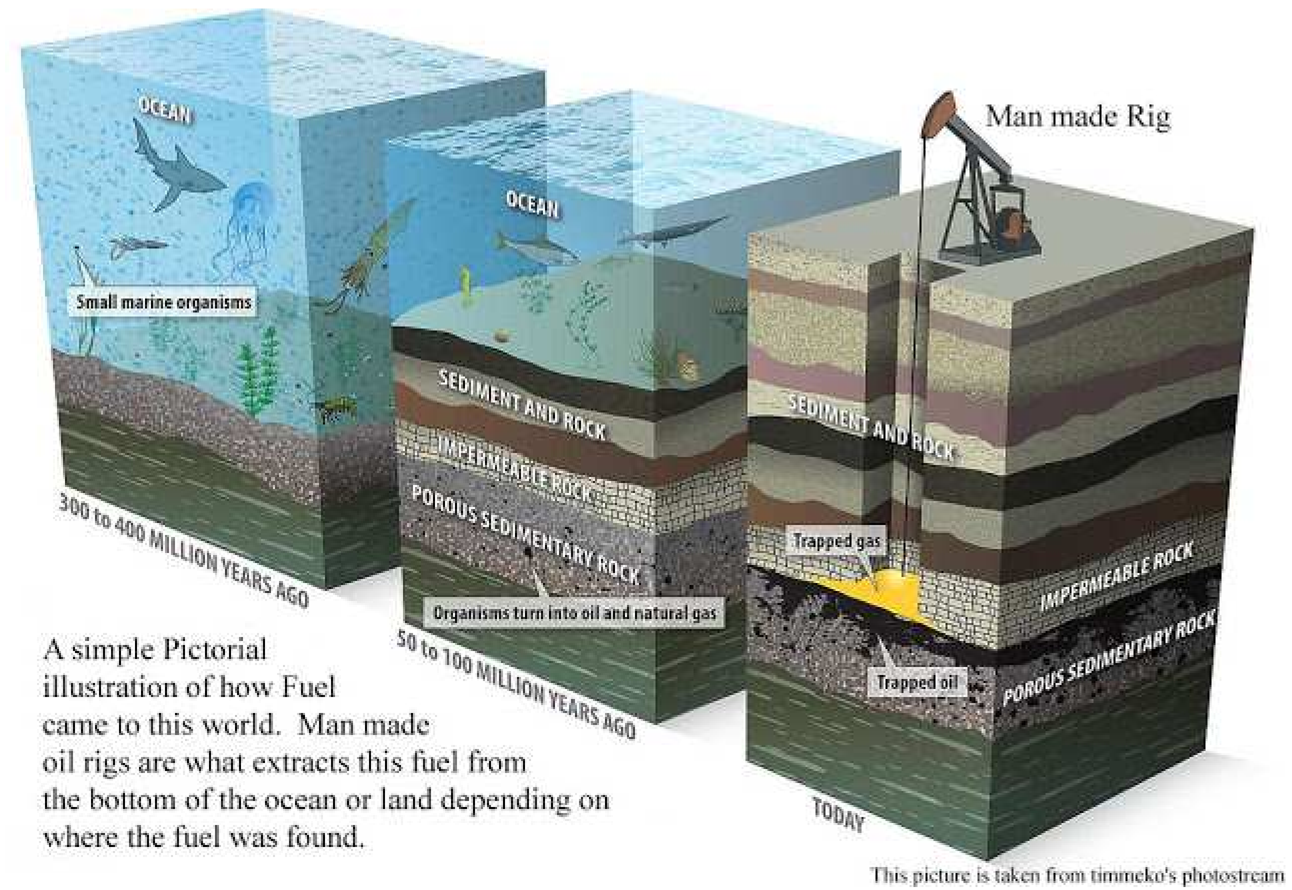
Carla Silva (Teóricas e práticas) /Theory and practice

camsilva@ciencias.ulisboa.pt

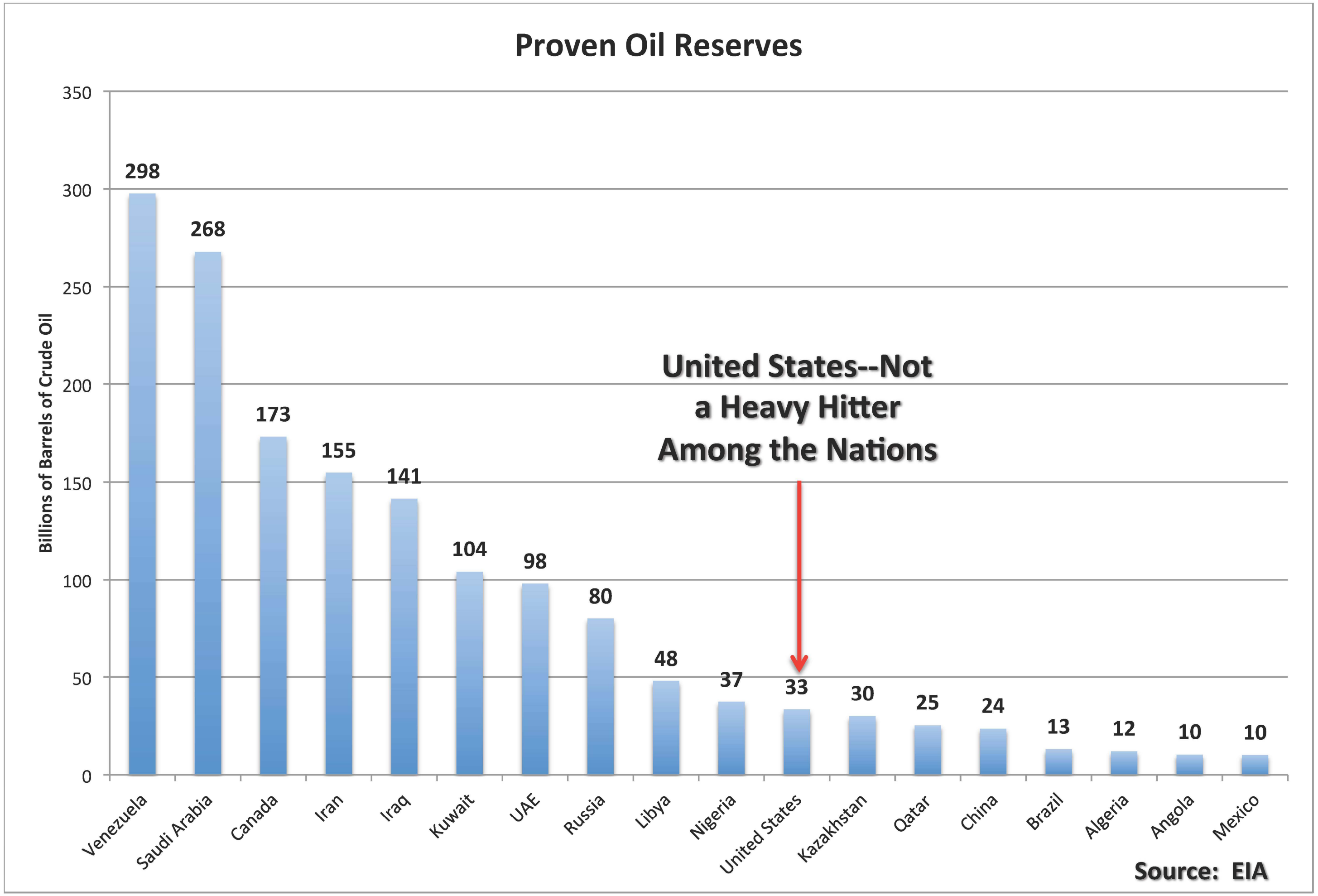
Fuel types


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

Crude oil

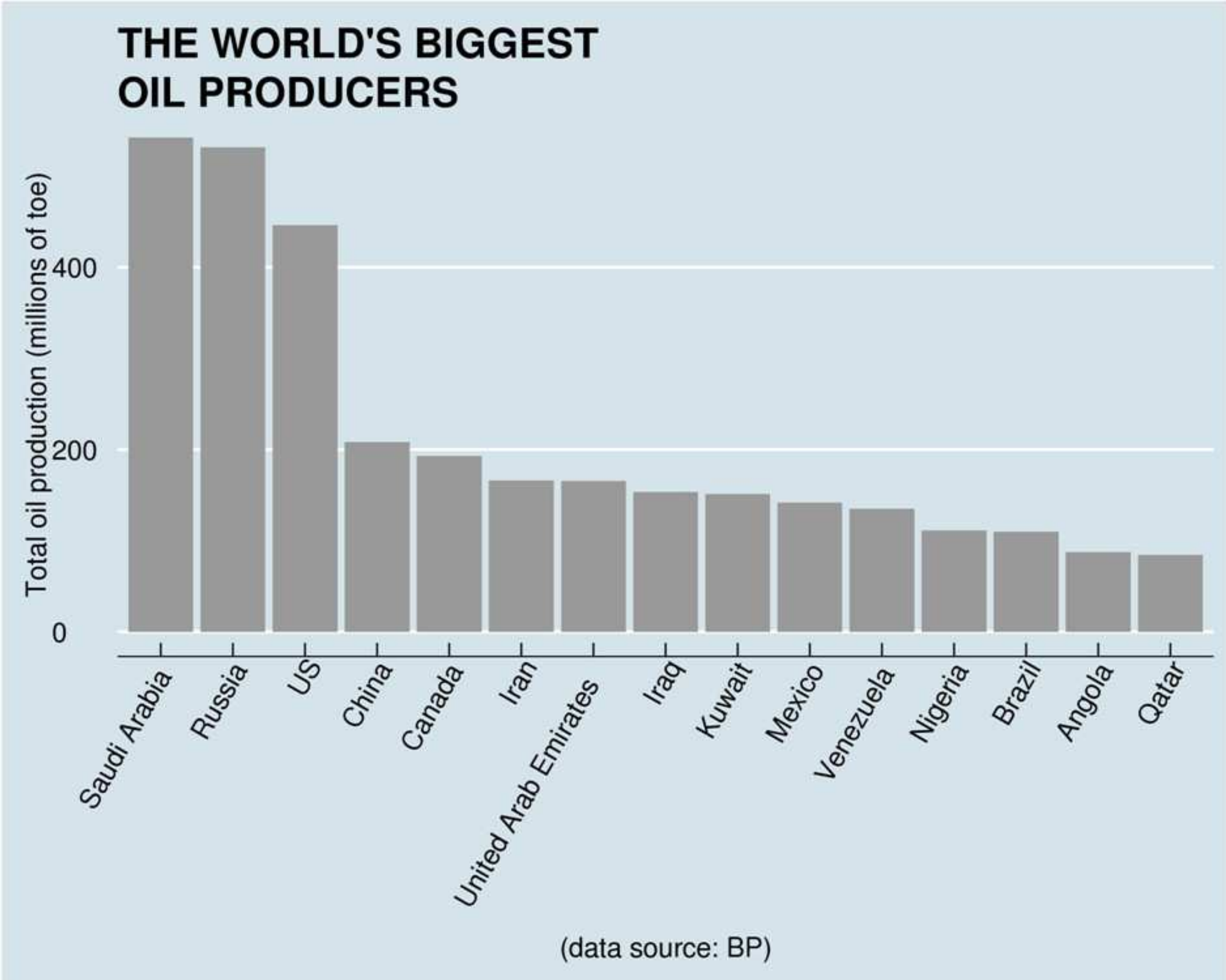

OCEAN
Small marine organisms
300 to 400 MILLION YEARS AGO
OCEAN
SEDIMENT AND ROCK
IMPERMEABLE ROCK
POROUS SEDIMENTARY ROCK
Organisms turn into oil and natural gas
50 to 100 MILLION YEARS AGO
Man made Rig
SEDIMENT AND ROCK
Trapped gas
IMPERMEABLE ROCK
POROUS SEDIMENTARY ROCK
Trapped oil
TODAY
A simple Pictorial illustration of how Fuel came to this world. Man made oil rigs are what extracts this fuel from the bottom of the ocean or land depending on where the fuel was found.
This picture is taken from timmeko's photostream

Crude oil



Proven Oil Reserves
Billions of Barrels of Crude Oil
350
300
250
200
150
100
50
0
298
268
173
155
141
104
98
80
48
37
33
30
25
24
13
12
10
10
Venezuela
Saudi Arabia
Canada
Iran
Iraq
Kuwait
UAE
Russia
Libya
Nigeria
United States
Kazakhstan
Qatar
China
Brazil
Algeria
Angola
Mexico
United States--Not
a Heavy Hitter
Among the Nations
Source: EIA

Crude oil


THE WORLD'S BIGGEST
OIL PRODUCERS
Total oil production (millions of toe)
0
200
400
Saudi Arabia
Russia
US
China
Canada
Iran
United Arab Emirates
Iraq
Kuwait
Mexico
Venezuela
Nigeria
Brazil
Angola
Qatar
(data source: BP)

Crude oil

Capacity:

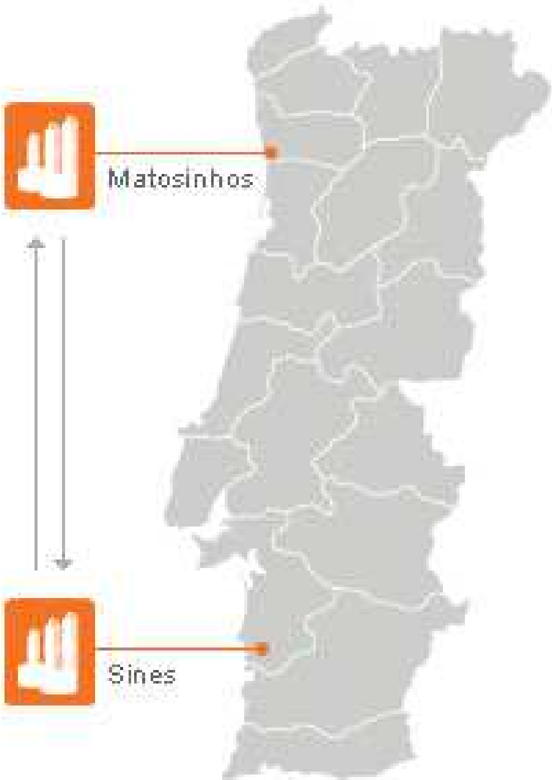
Sines refinery Portugal

220 thousand Barrel a day ~ 26 million litters

Matosinhos refinery Portugal

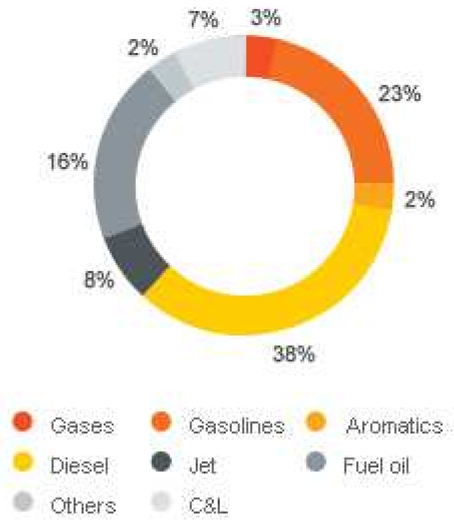
110 thousand Barrel a day ~ 13 million litters

Crude oil



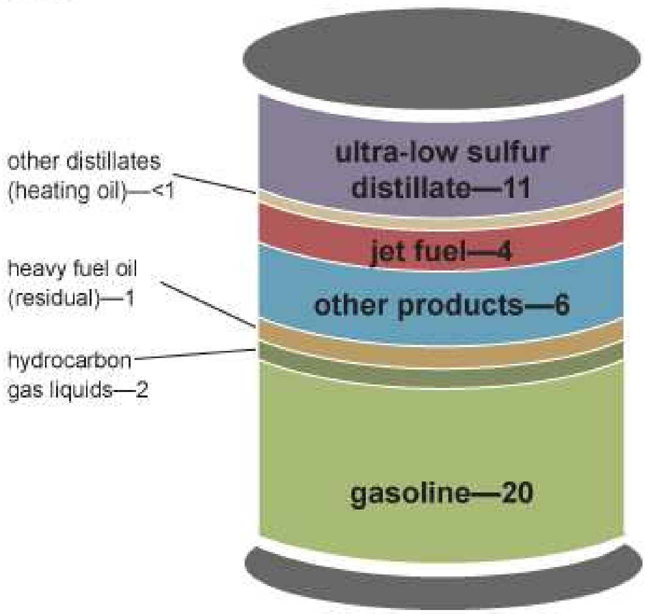
Installed capacity:

330 barrels a day



Crude oil

Petroleum products made from a barrel of crude oil, 2016
volumes



Note: A 42-gallon (U.S.) barrel of crude oil yields about 45 gallons of petroleum products because of refinery processing gain. The sum of the product amounts in the image may not equal 45 because of independent rounding.

Source: U.S. Energy Information Administration, *Petroleum Supply Monthly*, February 2017, preliminary data for 2016

- Liquified petroleum gas
- Gasoline
- Naphtha
- Jet/kerosene
- Diesel
- Fuels
- Base oils
- Lubricating oils
- Paraffin
- Aliphatic solvents and aromatics, benzene, toluene
and xylenes
- Bitumen

Crude oil

100% imported…….

Brazil, Angola, Saudi Arabia, Algeria, Cameroon
and Equatorial Guinea

Portuguese refinery

Crude oil

Direção Geral de Energia e Geologia
Direção de Serviços de Planeamento Energético e Estatística

IMPORTAÇÕES DE PRODUTOS DO PETRÓLEO E BIOCOMBUSTÍVEIS EM 2015
(toneladas)

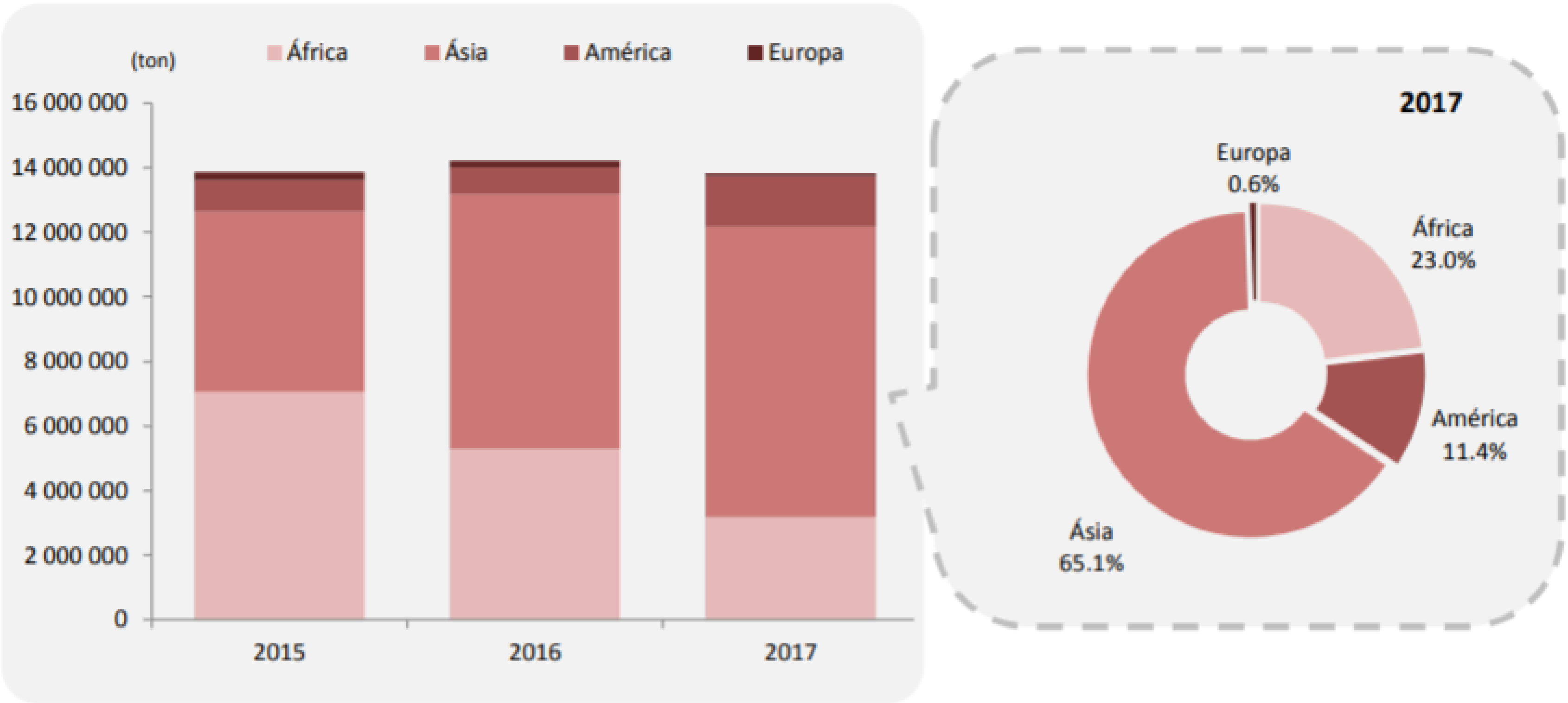
País	Produtos Intermédios	Produtos Energéticos											Produtos Não Energéticos						Total
		GPL	Gasolina	AV. Gas	Jets	Gasóleo	Petróleos	Fuel	Coque	Bio diesel[1]	Bio gasolina[2]	Sub-Total	Nafta	Lubrificantes	Asfaltos	Parafinas	Solventes	Sub-Total	
Alemanha		165	30			3						198		1.357			7	1.364	1.562
Argélia		22.808										22.808							22.808
Bélgica	161.632	834	5.574			20.378						188.418		2.462				2.462	190.880
Dinamarca		4.116										4.116							4.116
E.U.A.		128.182							231.220			359.402							359.402
Espanha	27.099	245.549	111.281	460	10.512	702.789	907	71.177	157.097		10.383	1.326.871	61.034	29.598	124.379	4.599	106	219.716	1.546.587
França	86.804	8.190		530							33.114	95.524		8.220			10	8.230	103.754
Grécia								29.924				29.924							29.924
Guiné		9.000										9.000							9.000
Guiné Equatorial		17.264										17.264							17.264
Holanda	76.979	5.696	19.905			20.495		171.819		24.201	15.565	319.095		45				45	319.140
Itália														81				81	81
Letónia						20.424						20.424							20.424
Noruega		106.308										106.308							106.308
Reino Unido		93.974		494		1						94.469		893				893	95.362
República do Congo		49.586										49.586							49.586
República Dominicana		49.454										49.454							49.454
Rússia	789.597											789.597							789.597
Suécia	13.575											13.575							13.575
Suiça						18.171						18.171		6				4	18.177
País não especificado	6.215									6.338	6.338	12.553							12.553
	1.161.901	741.126	136.790	1.484	10.512	782.261	907	272.920	388.317	30.539	65.400	3.526.757	61.034	42.662	124.379	4.599	123	232.797	3.759.554

30-01-2017

Notas:
os dados são provisórios
[1] Inclui HVO
[2] Inclui bioetanol e bioETBE

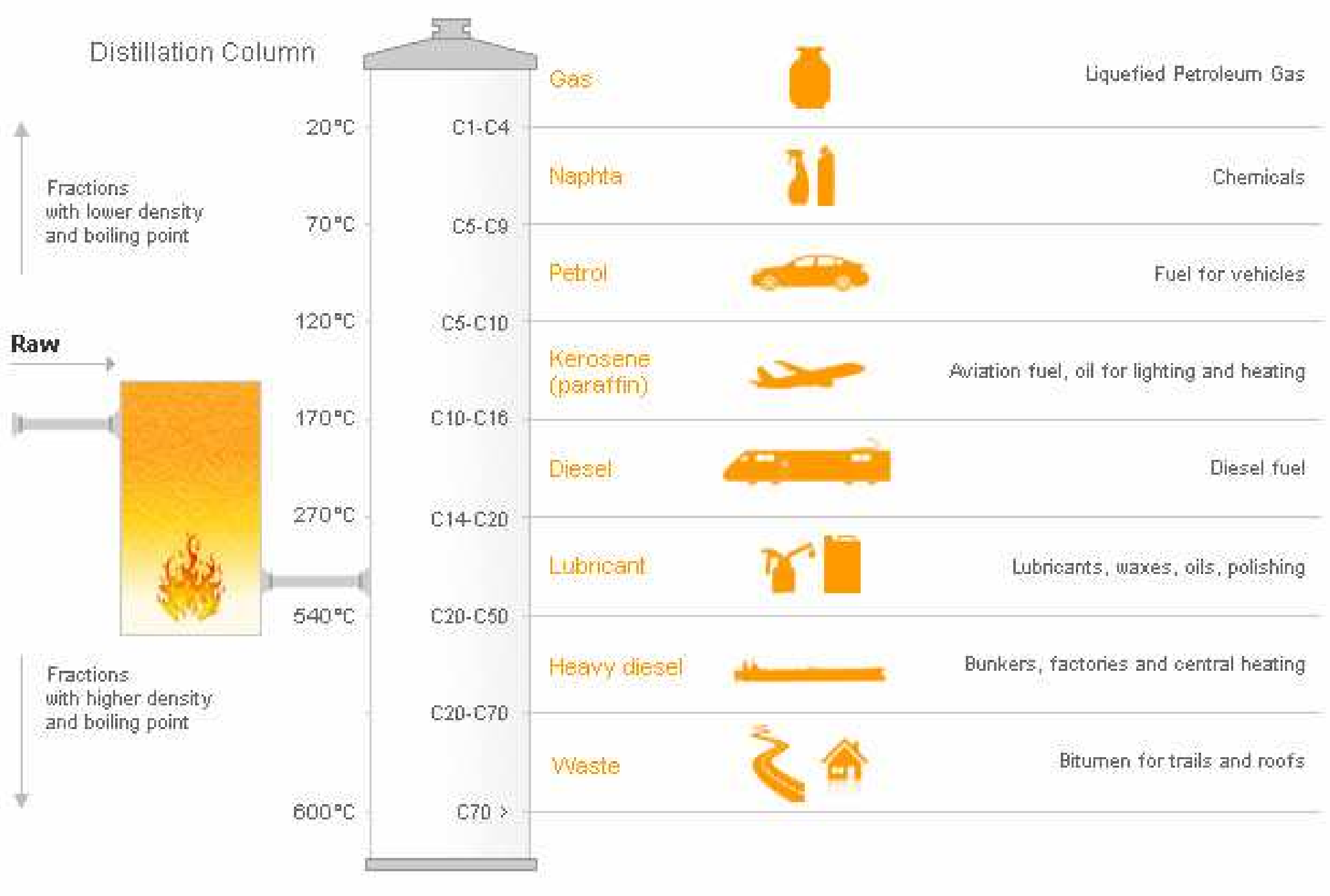
Crude oil

Figura 3 - Estrutura do Petróleo Bruto Importado, por Origens (2015 a 2017)



Fonte: DGEG

Crude oil



https://www.youtube.com/watch?v=o2xhmurpOtc

Crude oil

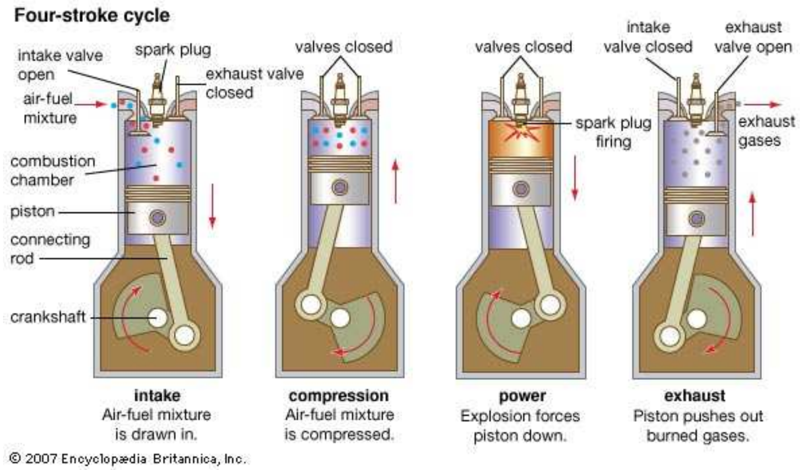
Liquid fuel properties

LPG (Propane) Properties Chart

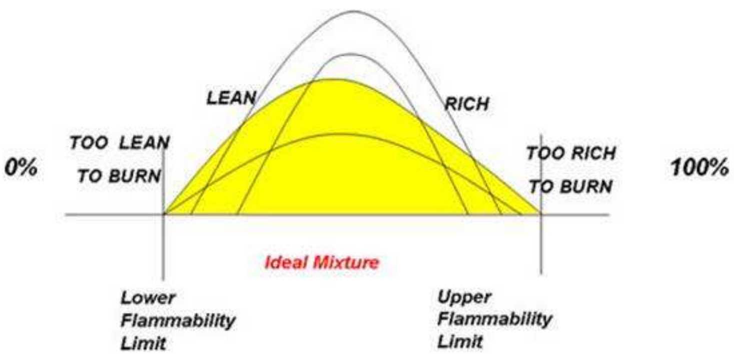
LPG Boiling Point	-42 °C or -44 °F
LPG Melting - Freezing Point	-188 °C or -306.4 °F
Specific Gravity of Liquid LPG	0.495 (25°C)
LPG Gaseous Density	1.898 kg/m^3 (15°C) or 0.1162 lb/ft^3
Energy Content of LPG	25 MJ/L or 91,547 BTU/Gal (60°F)
LPG Gaseous Expansion	1 L (liquid) = 0.27 M^3 (gas)
Flame Temperature	1967 °C or 3573 °F
Limits of Flammability	2.15% to 9.6% LPG/air
Autoignition Temperature	470 °C or 878 °F
Molecular Weight	44.097 kg/kmole

Note: Some numbers have been rounded.

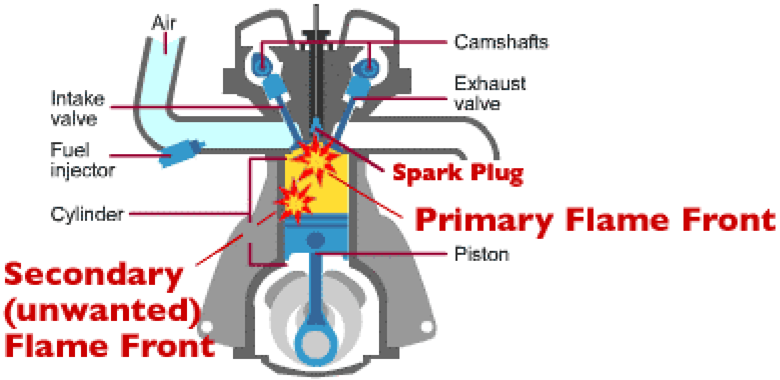
Octane number: ~ 110 (high resistance to autoignition)



Limits flammability:



Crude oil

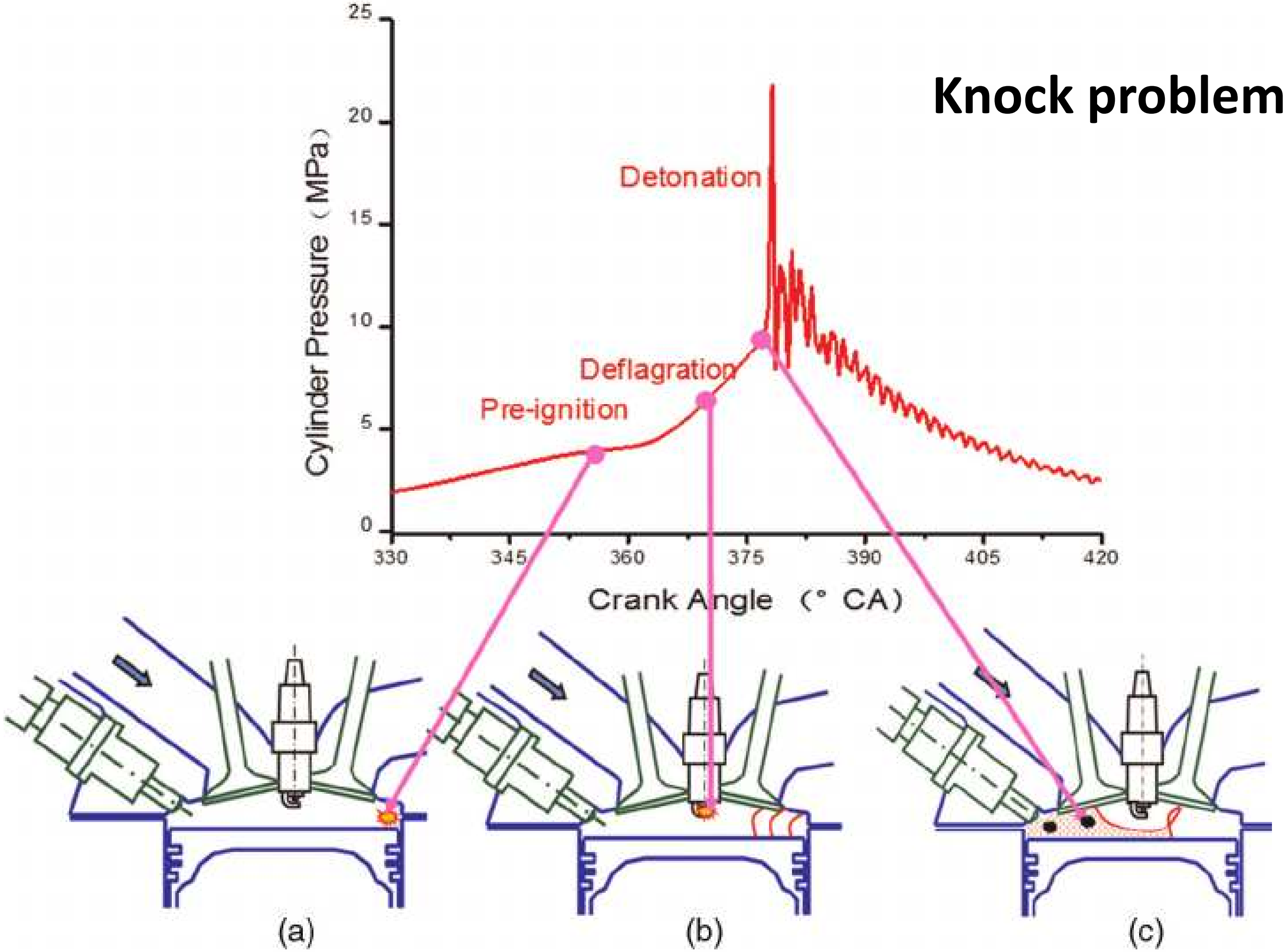


This photo of a badly damaged piston indicates the effects of long-term engine knock.

Octane number: ~ 110 (high resistance to autoignition)

Crude oil

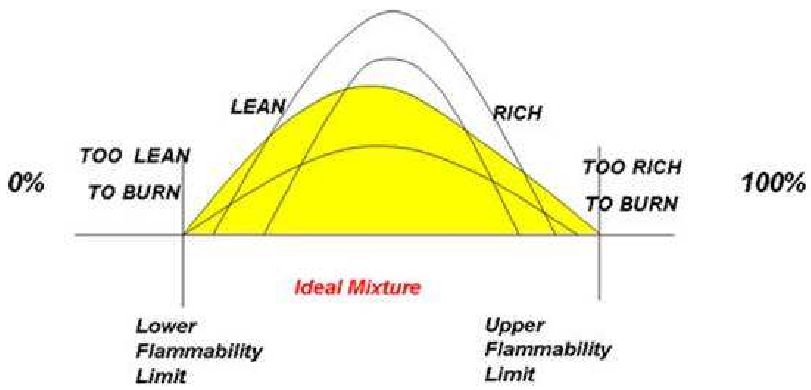
Knock problem



Crude oil

P#16 Calculate the (A/F)s of propane (C_3H_8). What is the mass A/F for each limit of flammability?

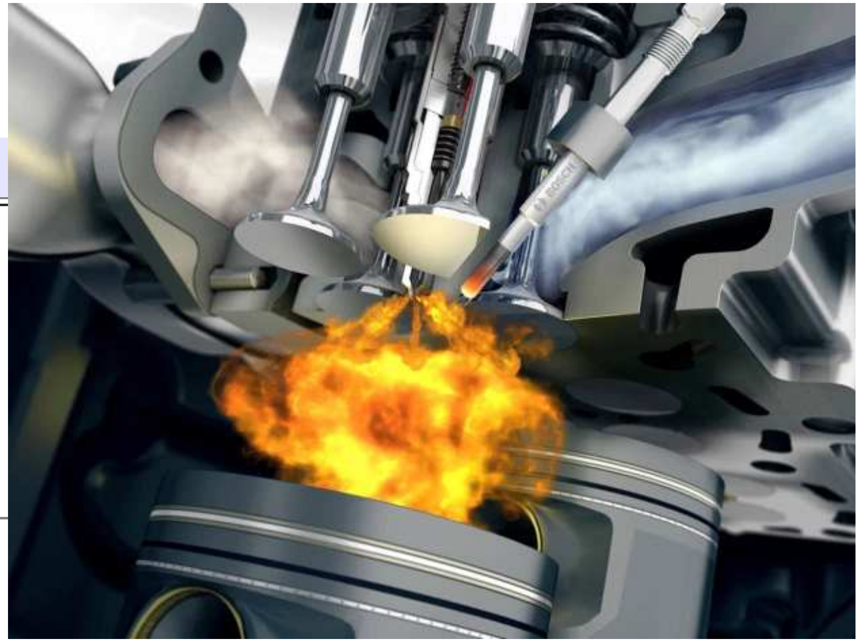
Limits flammability:
% volume in air



Crude oil

Diesel

PHYSICAL PROPERTIES
Boiling point: 282-338°C ←
Melting point: -30 - -18°C
Density: 0.87-0.95 g/cm³ ←
Solubility in water, g/100ml at 20°C: 0.0005
Flash point: 52°C c.c.
Auto-ignition temperature: 254-285°C ←
Explosive limits, vol% in air: 0.6-6.5
Octanol/water partition coefficient as log Pow: >3.3



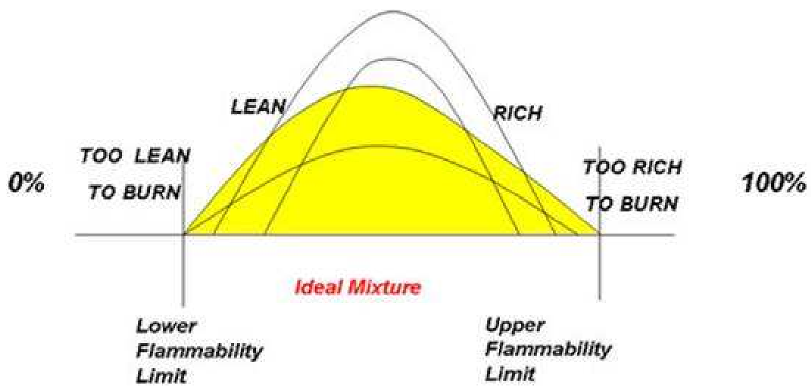
Cetane number=45 (between **40..55**); **60..65** for biodiesel.
This is a measure of a fuel's ignition delay; the time period between the start of injection and start of combustion (ignition) of the fuel, with larger cetane numbers having **lower ignition delays.**

↘ Remember ignition delay effect on emissions!!!!
Higher NOx for biodiesel

Crude oil

P#17 Calculate the (A/F)s of Diesel (C_7H_{14}). What is the mass A/F for each limit of flammability?

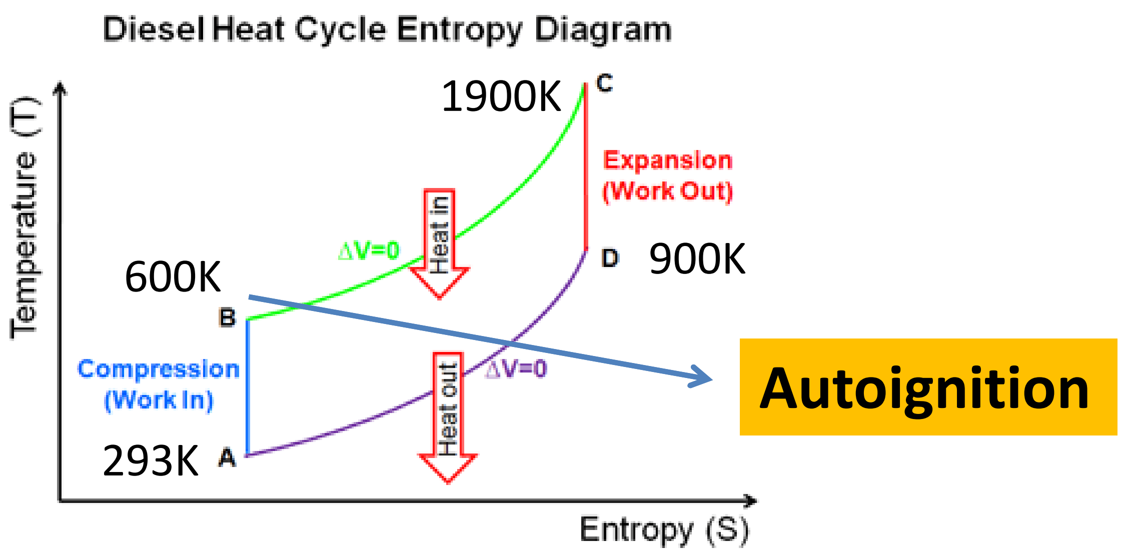
Limits flammability:
% volume in air



Crude oil

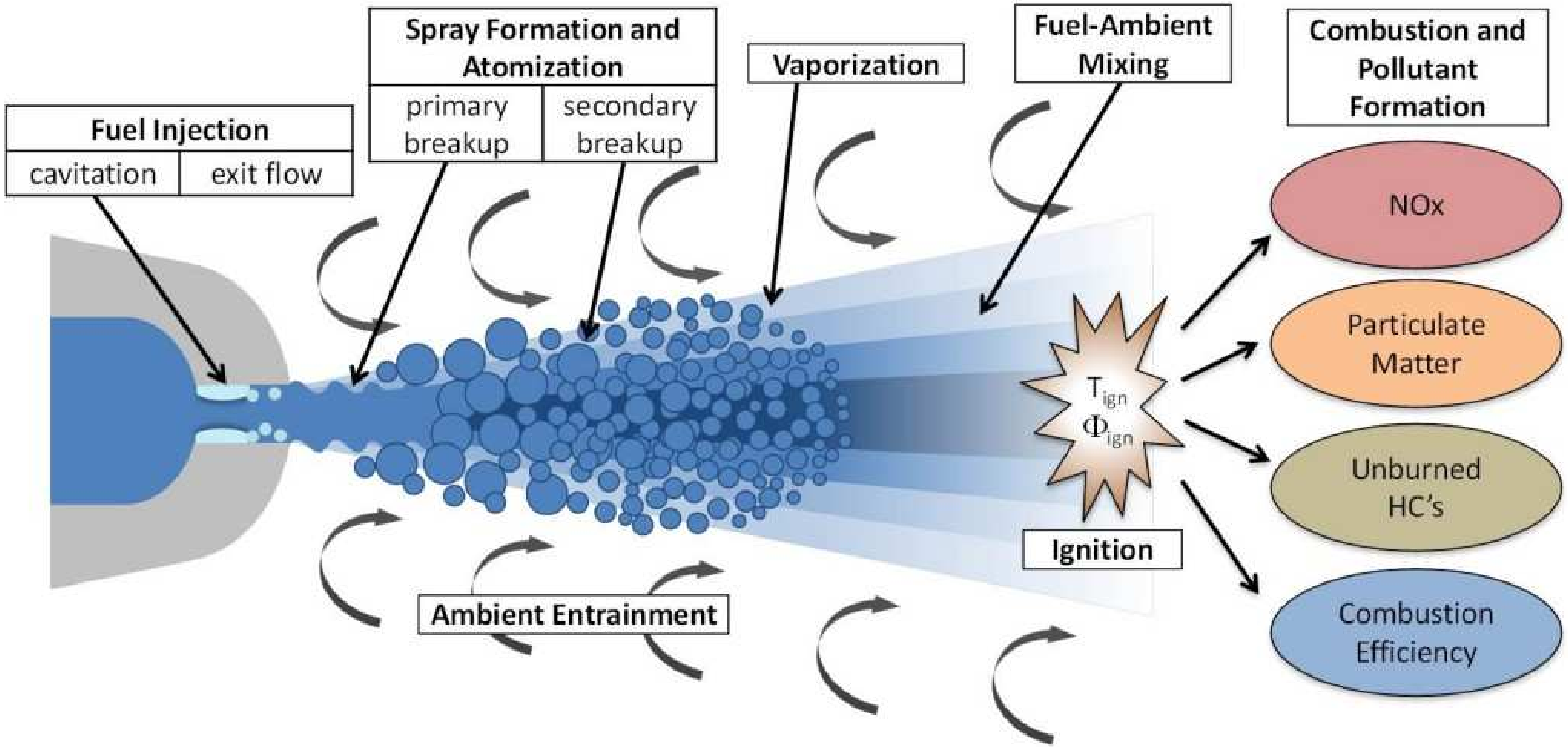
Diesel AUTOIGNITION

Compression ratio =18



Combustion of droplets

Droplets distribution range from few microns to around 500µm

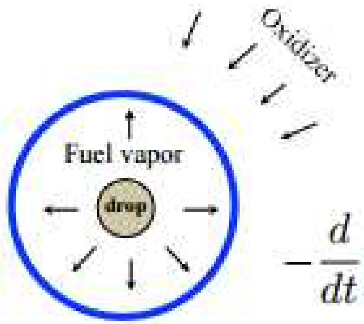


Combustion of droplets

Droplet Vaporization and Combustion:

Assumptions:

- droplet is a sphere
- single component fuel
- quiescent ambience
- no gravity
- spherical symmetry
- quasi-steady approximation
- one-step overall chemical reaction (F + O → Products)

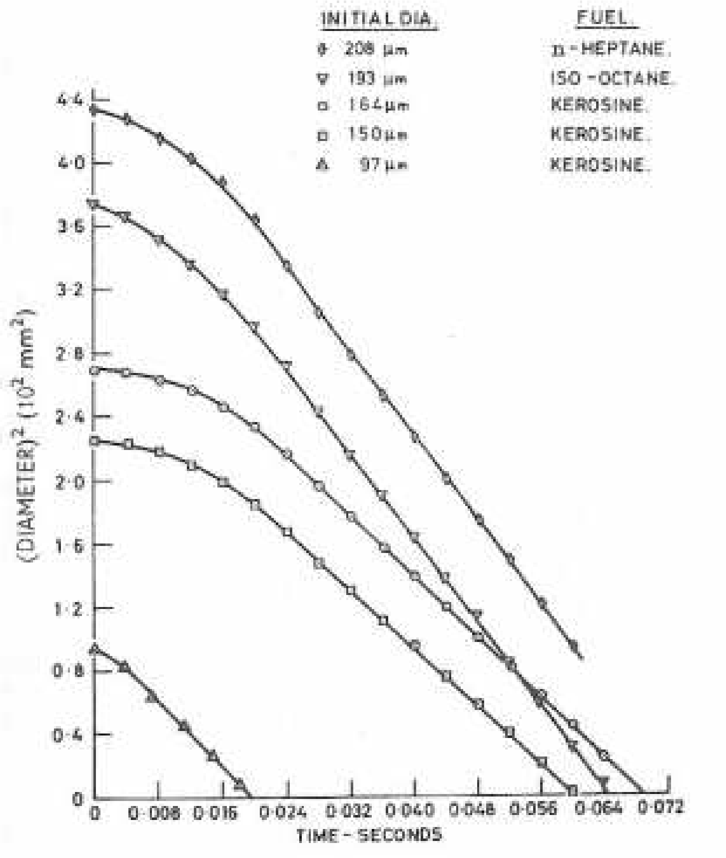


$$-\frac{d}{dt}\left(\frac{4}{3}\pi\rho_l r_s^3\right) = \dot{m}$$

mass flow rate

mass per unit time leaving the droplet

Combustion of droplets



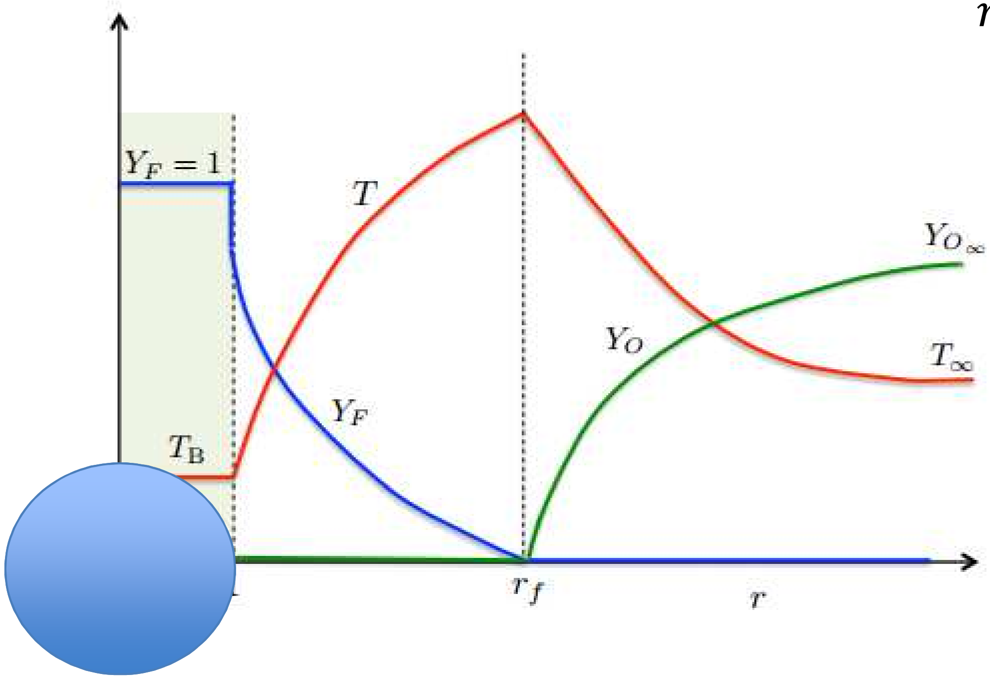
Nuruzzaman et al. PCI, 1971

D^2 law

Droplet lifetime = $\frac{D^2{}_0}{K}$

K~ $1\text{x}10^{-6}$ m^2/s

Combustion of droplets



Thermal conductivity

$$\dot{m}_{fu} = \frac{4\pi\lambda_g r_s}{c_{p,g}} \ln(B+1)$$

Heat capacity

D² law

$$t_d = \frac{D^2{}_0}{K}$$

droplet diameter

droplet life time

$$B = \left(\frac{LHV.y_{O2,\infty}}{s} + c_{p,g}(T\infty - Ts)\right)\frac{1}{h_{f,g}}$$

Heat of vaporization of the fuel

mO2/mfu stoichiometric

Combustion of droplets

Thermal conductivity

$$\dot{m}_{fu} = \frac{4\pi\lambda_g r_s}{c_{p,g}} \ln(B+1)$$

Heat capacity

PROPERTIES AT AVERAGE FLAME TEMPERATURE AND DROPLET BOILING POINT TEMPERATURE

$$\bar{T} = \frac{T_s + T_f}{2}$$

D² law

$$t_d = \frac{D^2{}_0}{K}$$

droplet diameter

droplet life time

$$cp,g = cp,fu(\bar{T})$$

$$\lambda g = 0.4\,\lambda fu(\bar{T}) + 0.6\,\lambda ox\,(\bar{T})$$

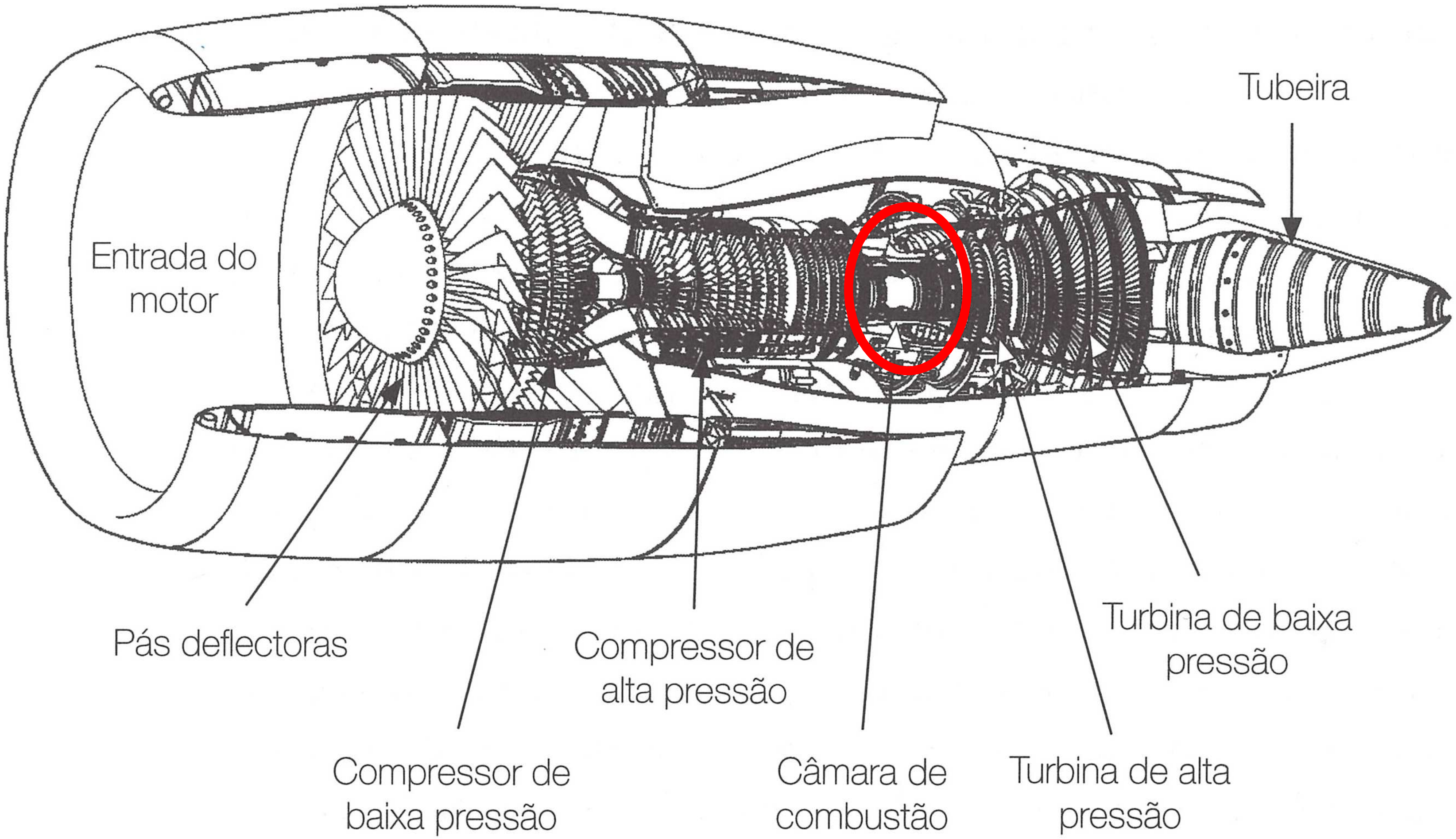
$$B = \left(\frac{LHV.y_{O2,\infty}}{s} + c_{p,g}(T\infty - Ts)\right)\frac{1}{h_{f,g}}$$

Heat of vaporization of the fuel

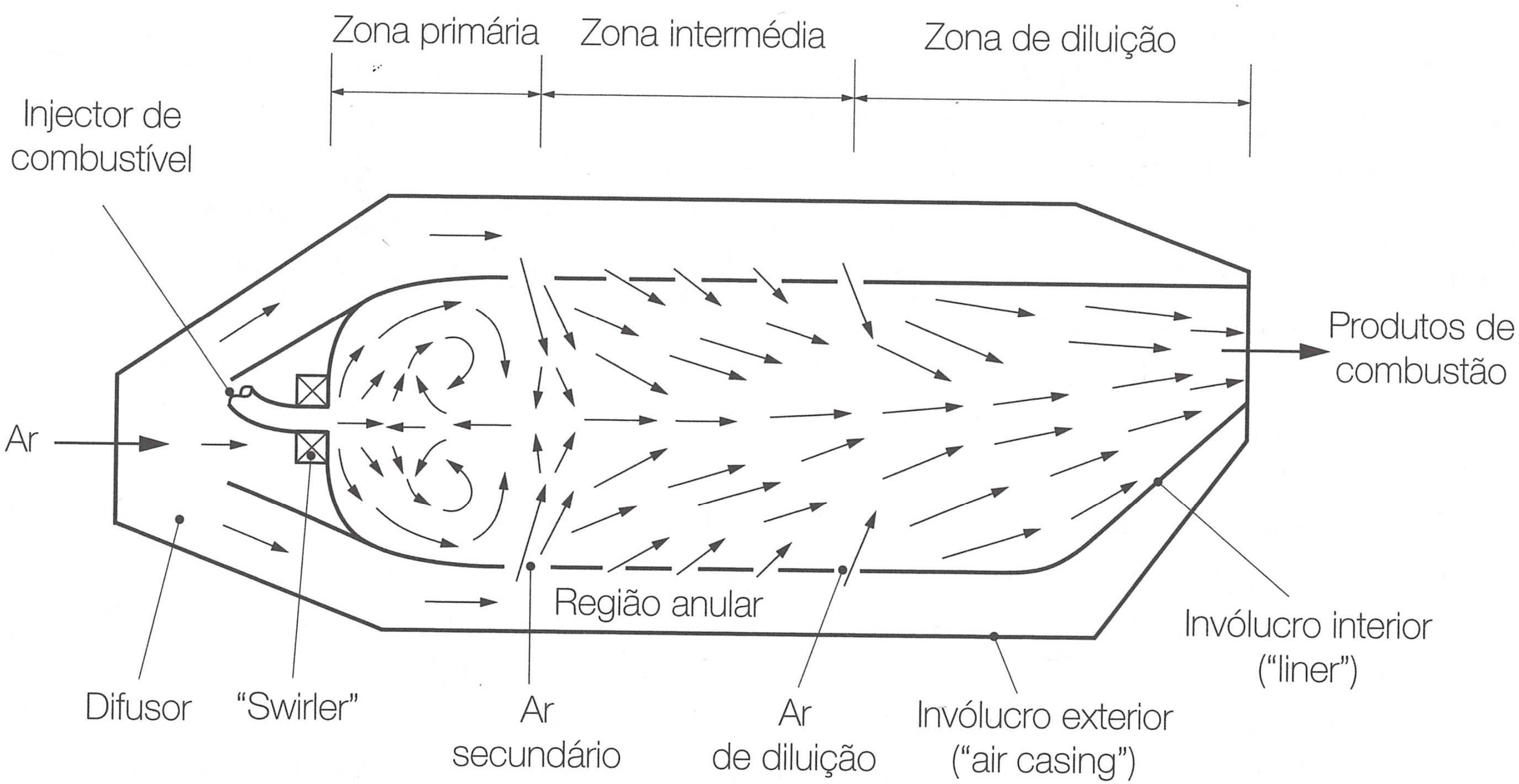
mO2/mfu stoichiometric

Combustion of droplets

Turbina a gás de um avião.

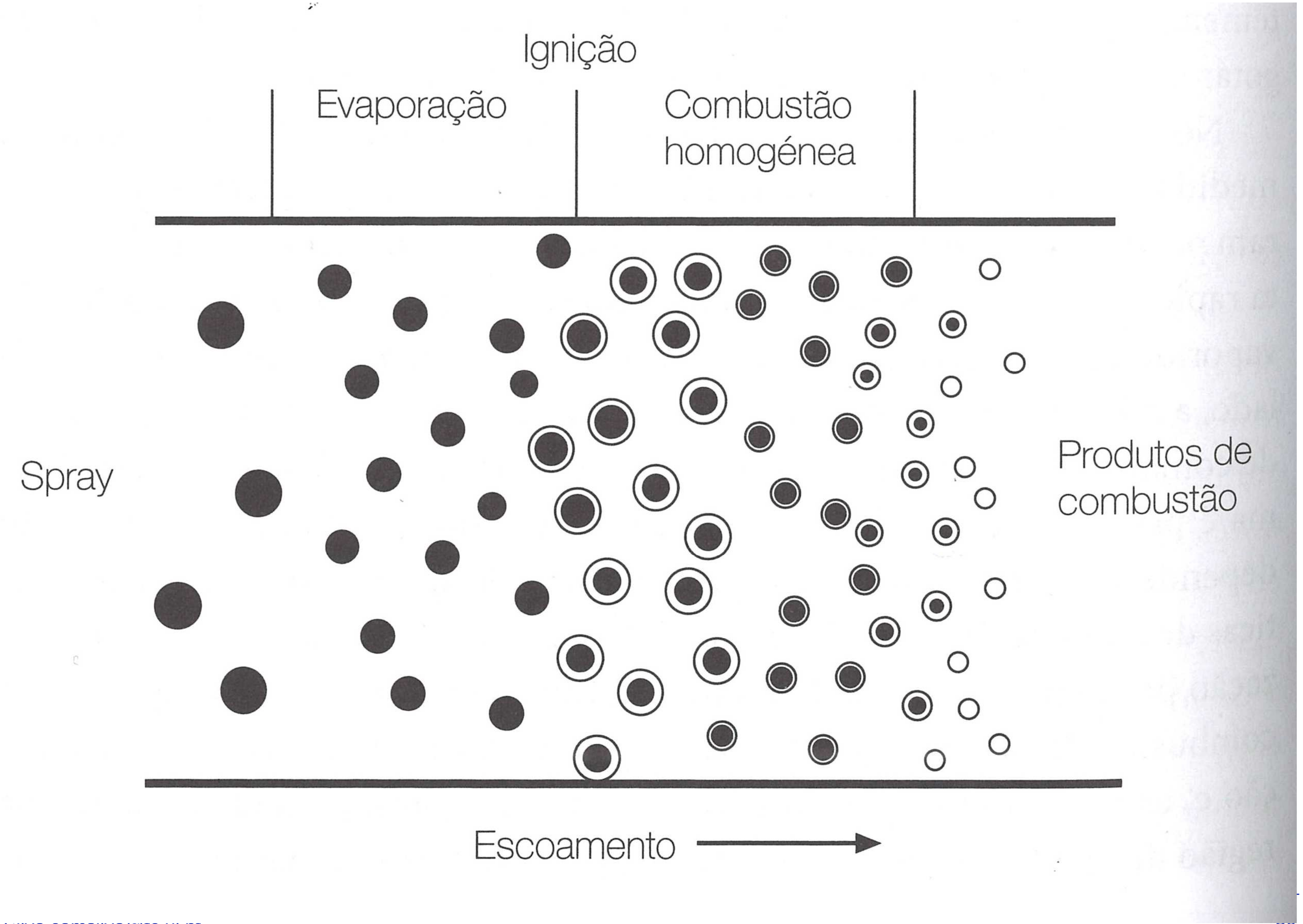


Combustion of droplets/sprays

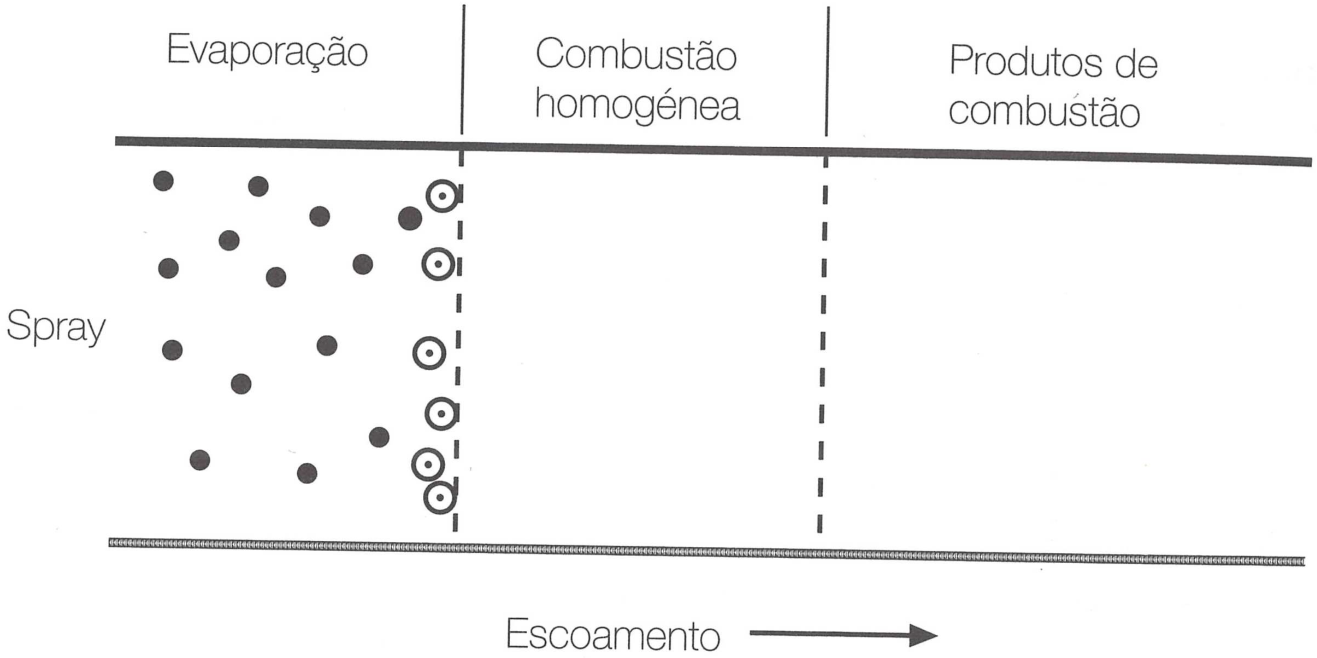


Representação esquemática da câmara de combustão de uma turbina a gás.

Combustion of droplets



Combustion of droplets



Exercice

P#18 Mono-dimensional spray Droplets of 200 µm. What should be the length of gas turbine combustion chamber for air and droplet speed of 30 m/s? and the fuel consumption rate?. Assume there is no heat transfer to the droplets interior, and that the droplet is at the boiling point. Air 300 K, 1 bar. Consider two fuels.

	T_{flame} (K)	PCI (MJ/kg)
n-hexane (C6H14)	1700	45.1
Propane (C3H8)	1900	46.4

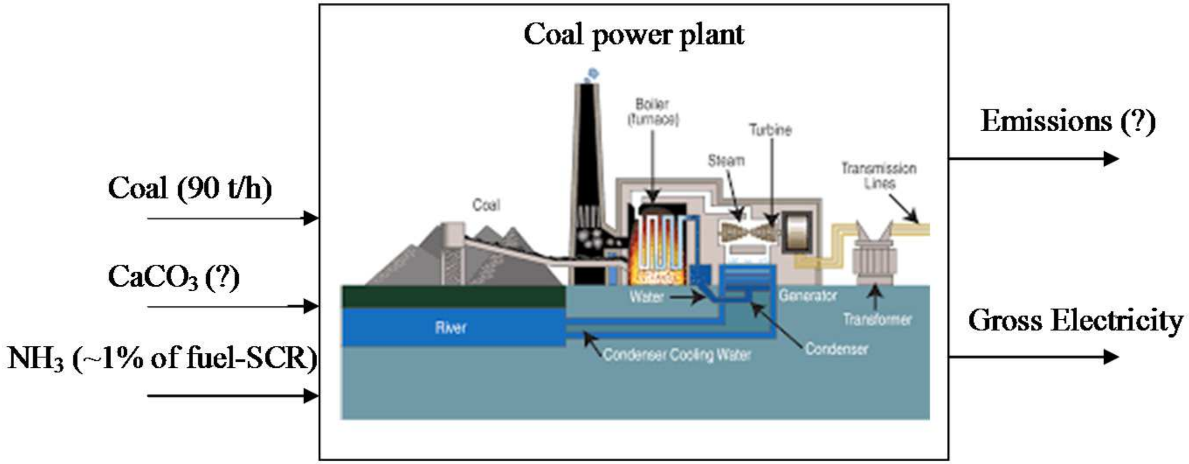
Emissions

Review#2 (exercicio 12.4 livro Português) Uma caldeira de uma central termoelétrica é alimentada com um fuel-óleo residual que apresenta a seguinte composição mássica elementar indicada na tabela. Considerando combustão completa com 25% de excesso de ar,

i) Estime a relação (A/F)st.
ii) Estime a concentração mássica de SO_2 nos produtos de combustão.
iii) Compare com o limite seco a 3% de O_2 de 200 mg/Nm^3.
iv) Pode estimar a concentração de partículas no escape? Como?
v) Introdução mínima de cal para remoção de S e cumprir limites:
$CaCO_3+SO_2+2H_2O+1/2O_2 \rightarrow CaSO_4.2H_2O+CO_2$ (M(ca)=40 kg/kmol)

C	86.4%
H	9.8%
N	0.35%
S	1.13%
O	2.28%
Cinzas/Ash	0.04%

2nd assignement-doubts



Obrigado

Ciências
ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa