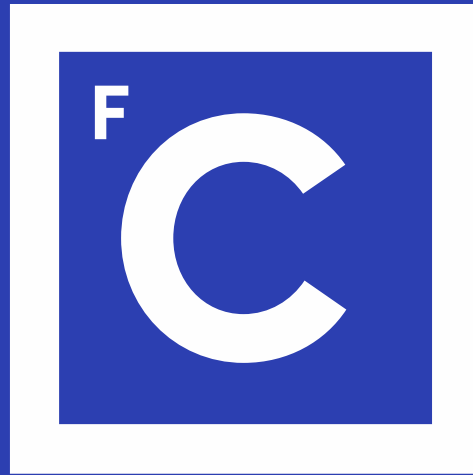




Ciências ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa

DISCIPLINA MIEA 2019

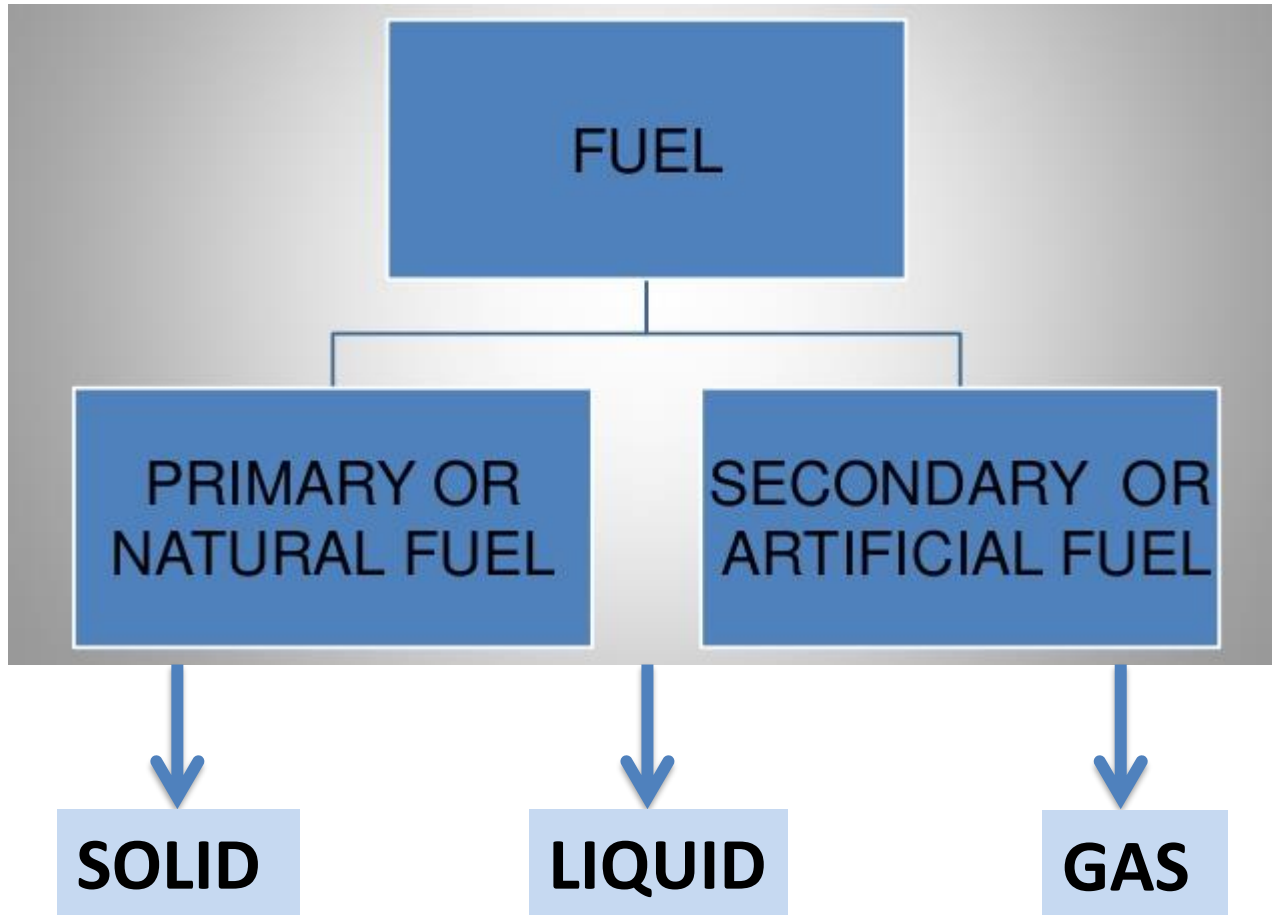


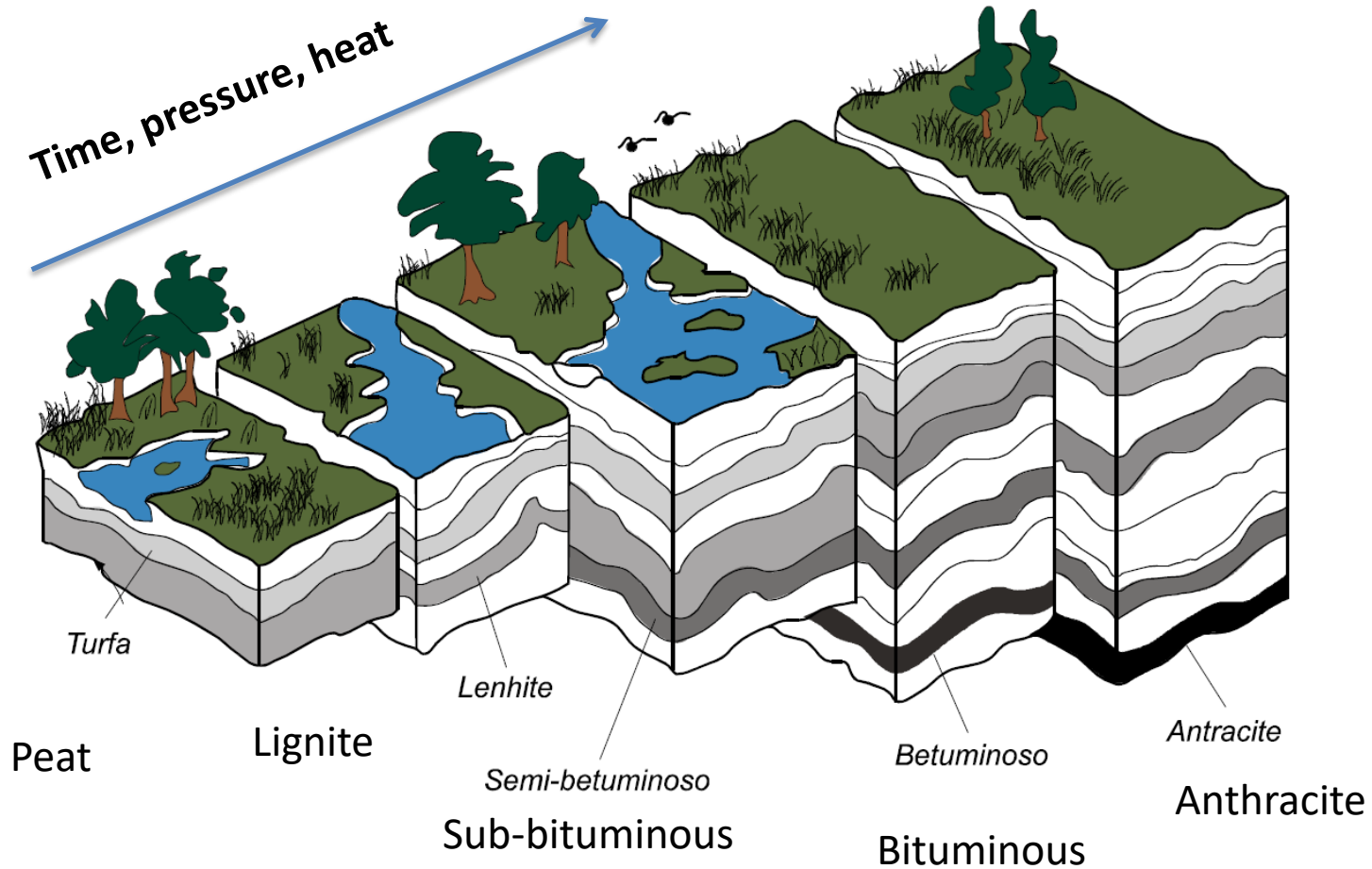
Technologies of combustion

Corpo docente

Carla Silva (Teóricas e práticas) /Theory and practice
camsilva@ciencias.ulisboa.pt

Fuel types





Time, pressure, heat



Peat

Lignite

Sub-bituminous

Bituminous

Anthracite

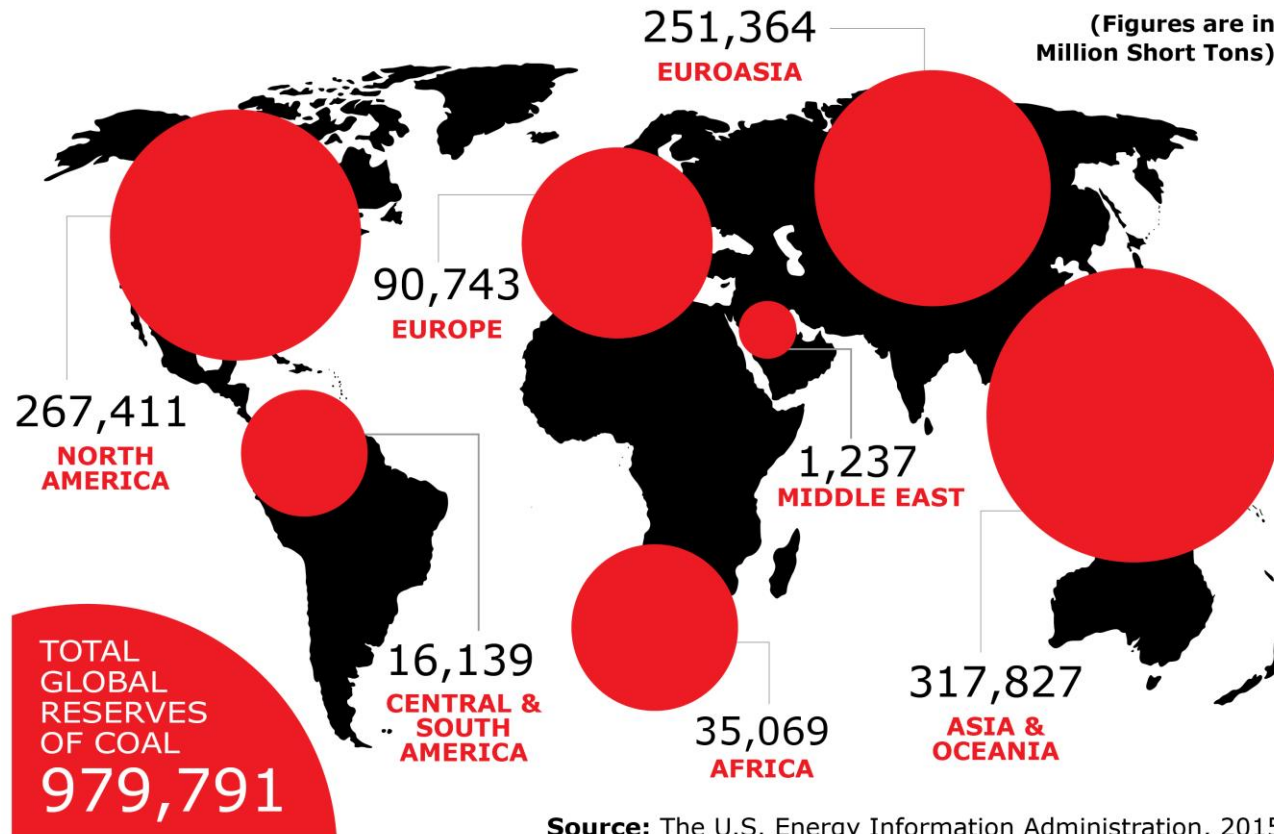
Fuel types

WORLD COAL RESERVES BY REGION

Coal reserves are available in almost every country. The biggest reserves are in the Asia & Oceania region.



(Figures are in
Million Short Tons)



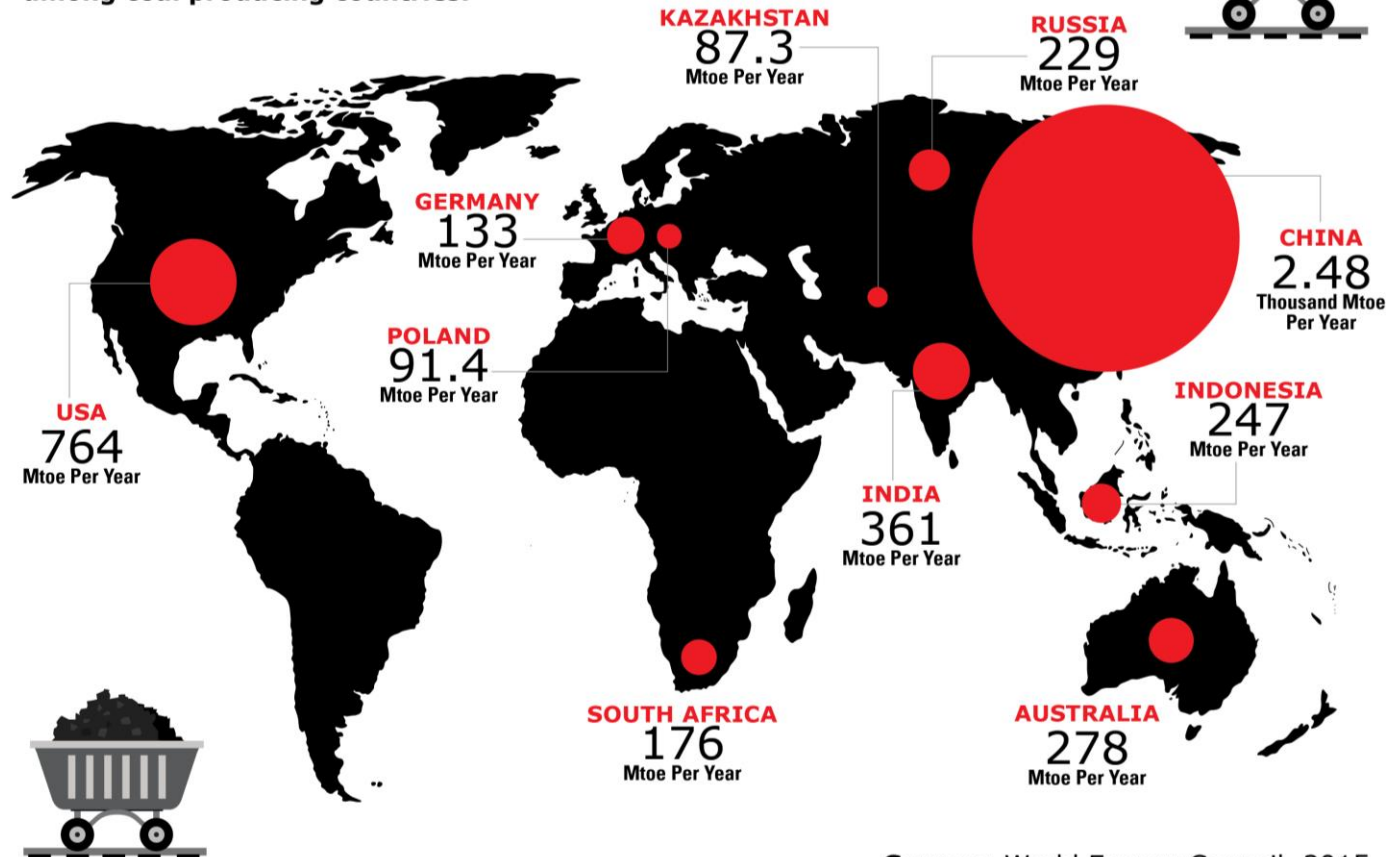
1 short ton
907.18474 kg

Source: The U.S. Energy Information Administration, 2015

Fuel types

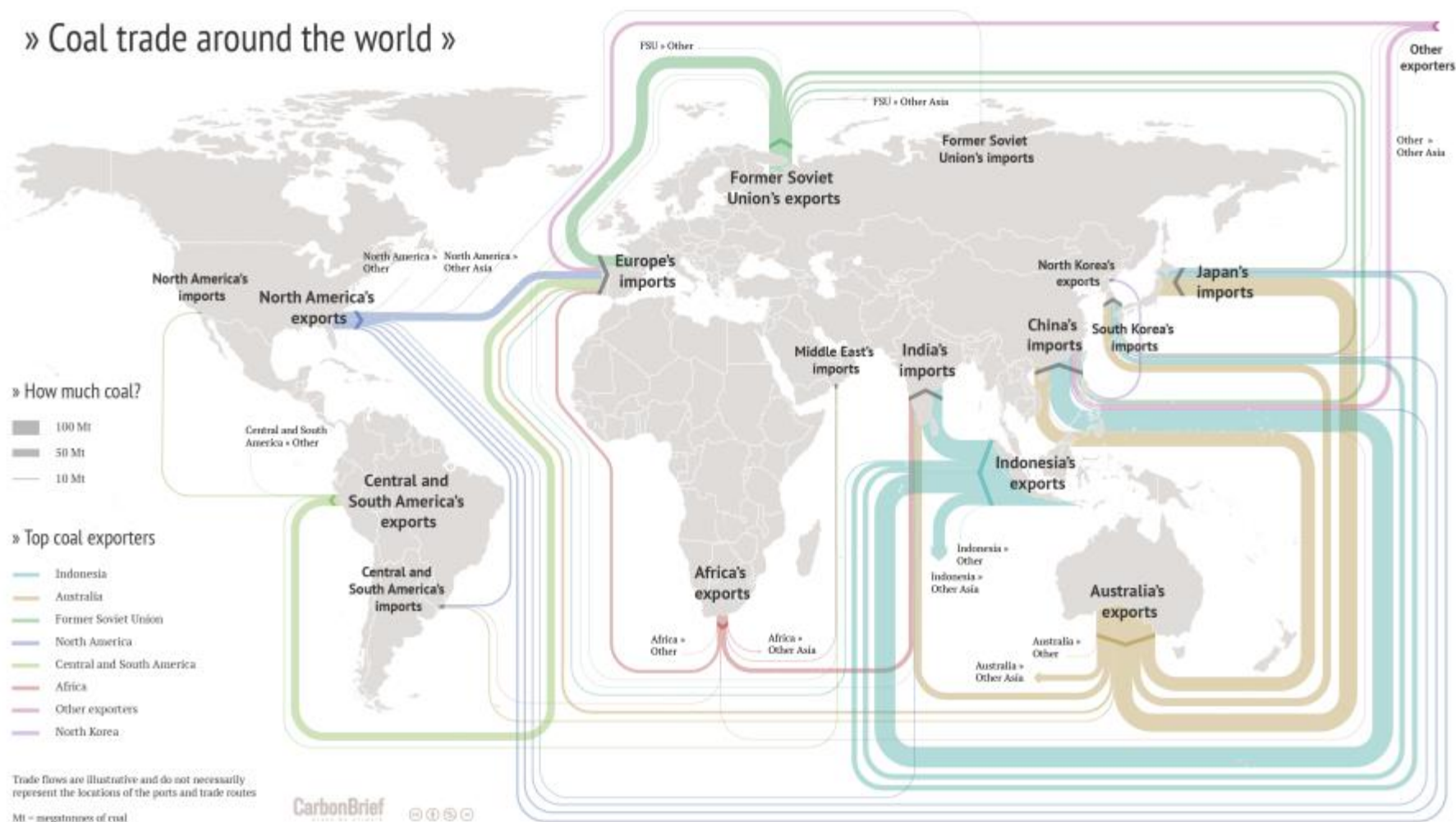
TOP COAL PRODUCING COUNTRIES

Coal is the world's largest source of electricity, accounting for around 40% of global electricity production. And China firmly holds the first place among coal producing countries.



Source: World Energy Council, 2015

» Coal trade around the world »



Ultimate and proximate analysis

A composição é caraterizada por dois tipos de análise

- Análise Elementar
- Análise Imediata

Análise Elementar - Frações mássicas dos elementos:

C, H, O, N, S e cinzas (atualmente inclui-se Cl, Ca, ...)
Azoto (NP1012), Enxofre (ASTM D3177)

Análise Imediata - Frações mássicas de acordo com decomposição:

Humidade (determinada a 110°C)
Matéria volátil (gases libertados em aquecimento a 950°C) - NP3423
Carbono fixo (obtido por diferença para os restantes valores)
Cinza (matéria restante após oxidação do resíduo carbonoso) - NP1019

Table 1.7 Relationship Between Ultimate Analysis and Proximate Analysis			
	%C	=	$0.97C + 0.7(VM - 0.1A) - M(0.6 - 0.01M)$
	%H	=	$0.036C + 0.086(VM - 0.1xA) - 0.0035M^2(1 - 0.02M)$
	%N ₂	=	$2.10 - 0.020 VM$
where			
	C	=	% of fixed carbon
	A	=	% of ash
	VM	=	% of volatile matter
	M	=	% of moisture

A entalpia de formação do carvão é próxima de zero

Tipo de carvão	Carbono % massa	Hidrogénio % massa	Idade (anos*10 ⁶)
Antracites	93 - 95	3.8 - 2.8	210 - 250
Carbonoso*	91 - 93	4.25 - 3.8	210 - 250
Bituminoso*	80 - 91	5.6 - 4.35	150 - 180
Sub-bitum.*	75 - 80	5.6 - 5.1	60 - 100
Lenhite	60 - 75	5.7 - 5.0	20 - 60
Turfa	50 - 60	6.1 - 5.8	1
Madeira**	46 - 51	6.2 - 5.9	0

* Hulhas

** Madeira é considerada renovável (não fóssil)

Fuel types

Correlations for Higher Heating Value (HHV or PCS)

$$\text{PCS} \sim 33,8 \, xC + 144,3 (xH - xO/8) + 9,4 \, xS \text{ (Dulong)}$$

$$\text{PCS} \sim 34,1 \, xC + 132,3 [xH - (xO + xN)/11] + 6,8 \, xS - 1,5 \, xAs$$

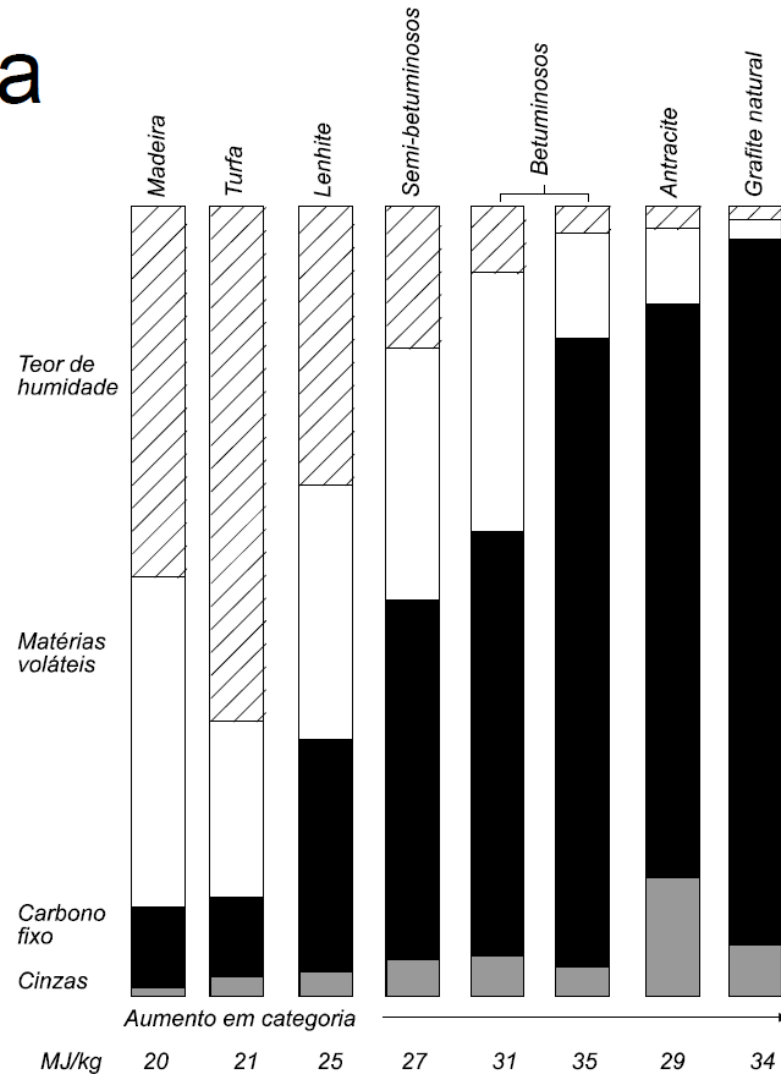
(Mason and Gandhi, 1983)

in MJ·kg⁻¹ and dry basis. Last includes ash effects xAs

Análise Imediata

Nesta análise caracteriza-se a composição do combustível em:

- Humidade
- Voláteis
- Carbono fixo
- Cinzas



Fuel types

A composição dos combustíveis sólidos para ambas as análises pode ser expressa em três bases:

- As received* (A_r - incluindo humidade e cinzas)
- Dry basis* (D_b - base seca, exclui a humidade)
- Dry ash free* (D_{af} - exclui humidade e cinzas)

Fuel types

Even with complete combustion the minimum particle emissions are limited by the ash content initially in the fuel



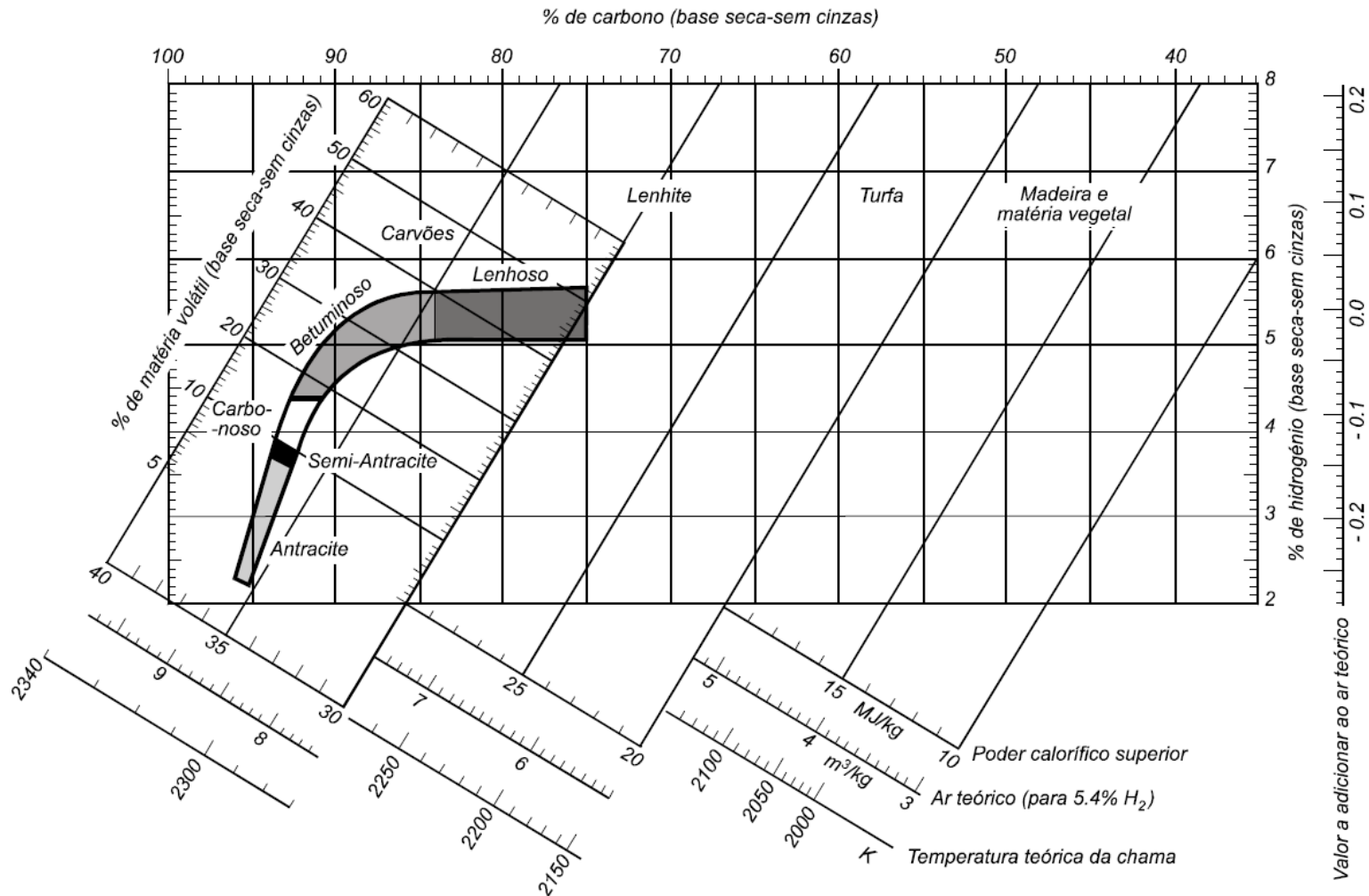
Ash is the general term used to describe the **inorganic** matter in a fuel, e.g. Fe, Ca, K, Si, etc



- There is an absence of carbon in its composition
- It is of a non-biologic origin

Fuel types

Diagrama de Seyler (adaptado)



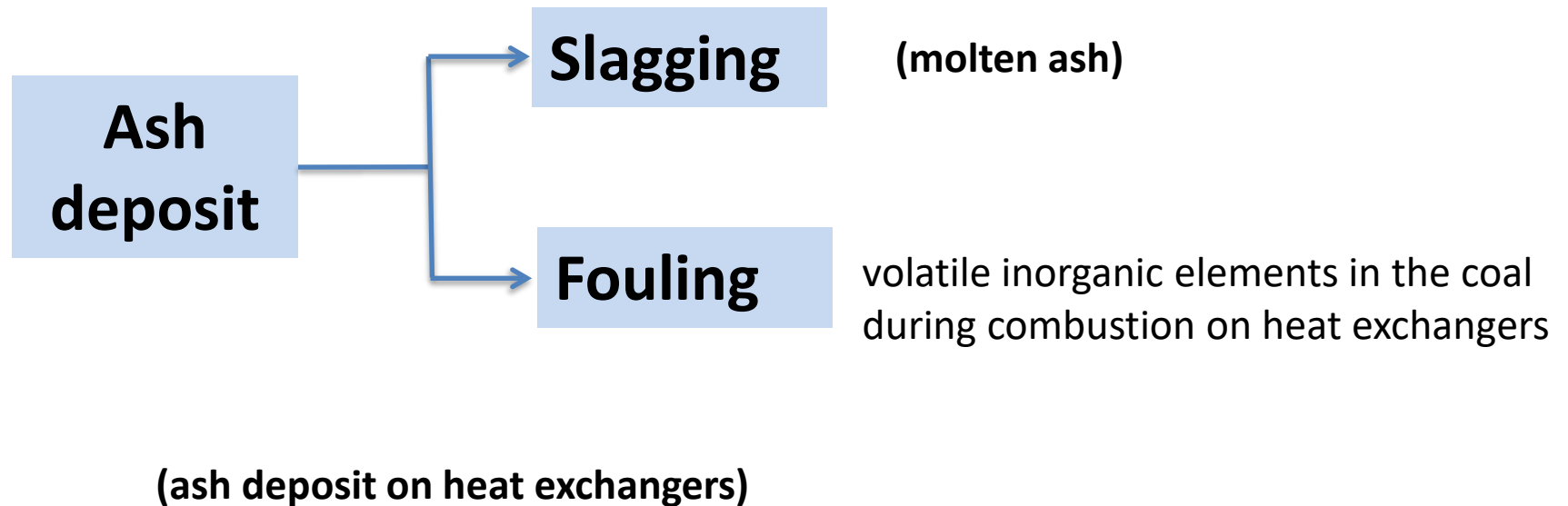
Fuel types

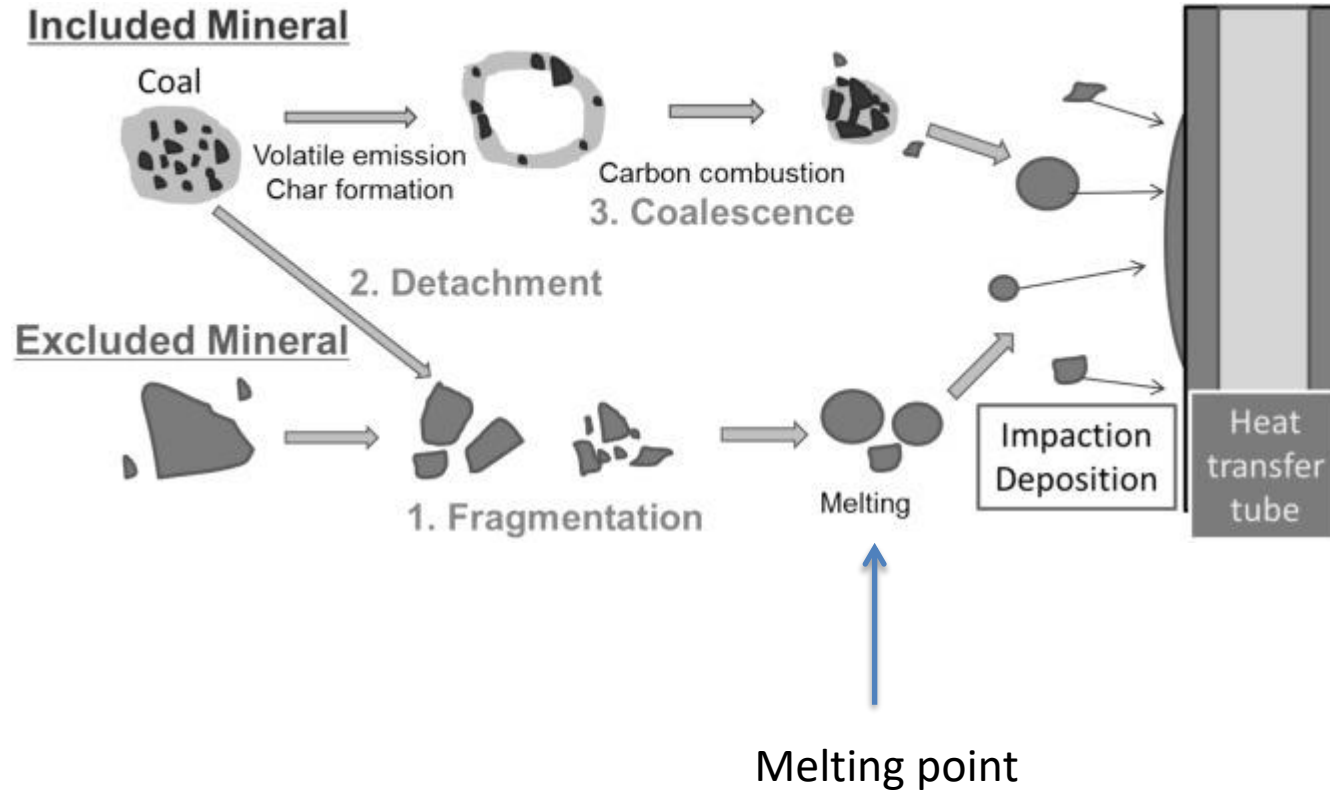
P#13 Consider this coal. Classify the coal according to the Seyler diagram. Identify lower heating value and adiabatic temperature.

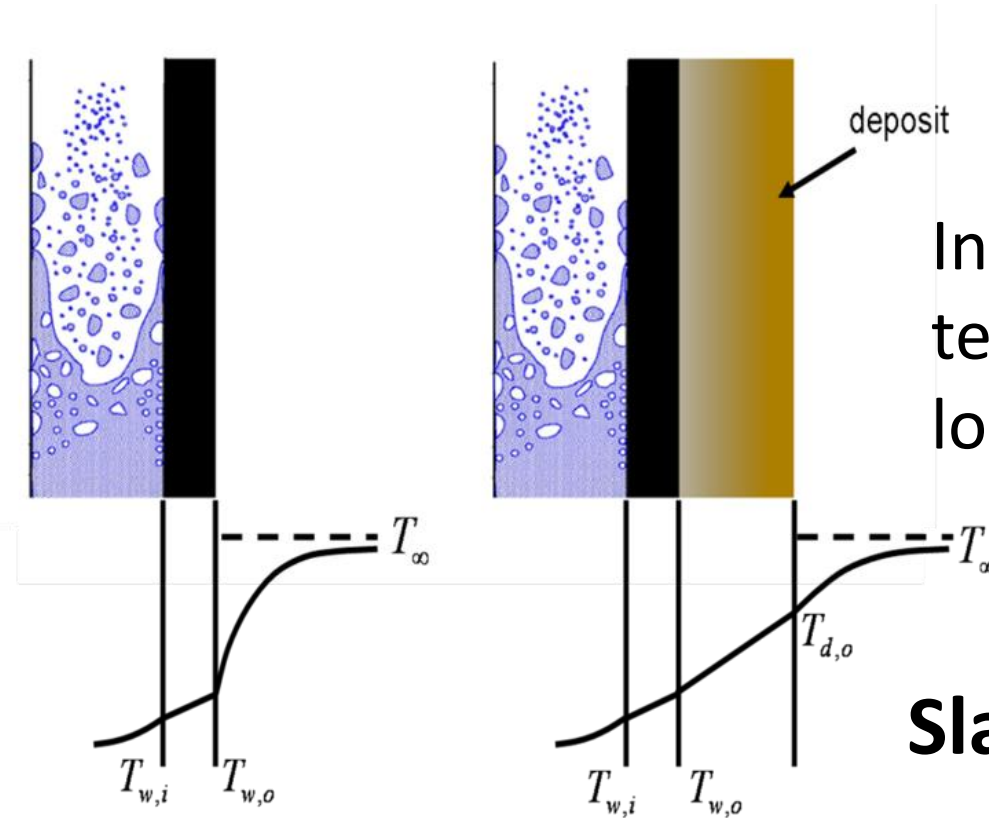
Coal composition by weight (%wt). Ash is the general term used to describe the inorganic matter in a fuel, e.g. Fe, Ca, K, Si, etc. Fixed carbon is 51% (volatile matter+fixed carbon+ash+moisture=100%). Moisture is water.

C	67.7
H	4.4
N	1.5
S	1.0
O	5.2
Ash	13.4

Problems with ash







Increase of combustion temperature!! Low heat loss to water!!!

Slagging (molten ash)

Fe-iron Melting temperature: 1538 °C (1811 K)

Magnesium: 650 °C (923 K)

SiO₂ (silica): 1710 °C (1983 K)

Al₂O₃=2072 °C (2345 K)



Problems with ash

TABLE 1.5 TYPICAL PROXIMATE ANALYSIS OF VARIOUS COALS (IN PERCENTAGE)			
Parameter	Indian Coal	Indonesian Coal	South African Coal
Moisture	5.98	9.43	8.5
Ash	38.63	13.99	17
Volatile matter	20.70	29.79	23.28
Fixed Carbon	34.69	46.79	51.22

Problems with ash

Biomass	Ash content (%)	Biomass	Ash content (%)
Corn cob	1.2	Coffee husk	4.3
Jute stick	1.2	Cotton shells	4.6
Sawdust (mixed)	1.3	Tannin waste	4.8
Pine needle	1.5	Almond shell	4.8
Soya bean stalk	1.5	Areca nut shell	5.1
Bagasse	1.8	Castor stick	5.4
Coffee spent	1.8	Groundnut shell	6.0
Coconut shell	1.9	Coir pith	6.0
Sunflower stalk	1.9	Bagasse pith	8.0
Jowar straw	3.1	Bean straw	10.2
Olive pits	3.2	Barley straw	10.3
Arhar stalk	3.4	Paddy straw	15.5
Lantana camara	3.5	Tobacco dust	19.1
Subabul leaves	3.6	Jute dust	19.9
Tea waste	3.8	Rice husk	22.4
Tamarind husk	4.2	Deoiled bran	28.2



Problems with ash

Table 4. Physical and chemical analysis of the coals of the Far East (Vdovichenko V. S et.al, 1991g)

<i>Continent</i>			<i>Eurasia</i>		
<i>Location</i>			<i>Far East (Primorsk region)</i>		
<i>Basin Name</i>			<i>Uglovskiy</i>		
<i>Deposit Name</i>			<i>Artemovskiy</i>	<i>Shkotovskiy</i>	<i>Tavrichanskiy</i>
<i>Proximate Analysis</i>	Moisture, 105°C	wt%, a.r.	23	37	20
	Volatiles, 900°C	wt%, dry	30	35	28.8
	Ash content, 815°C	wt%, dry	40	30	40
	Fixed carbon	wt%, dry	30	35	31.2
<i>Ultimate analysis</i>	Carbon	wt%, dry	40.2	48.65	42.3
	Hydrogen	wt%, dry	3.36	3.85	3.48
	Nitrogen	wt%, dry	0.78	1.05	1.2
	Sulphur	wt%, dry	0.4	0.3	0.5

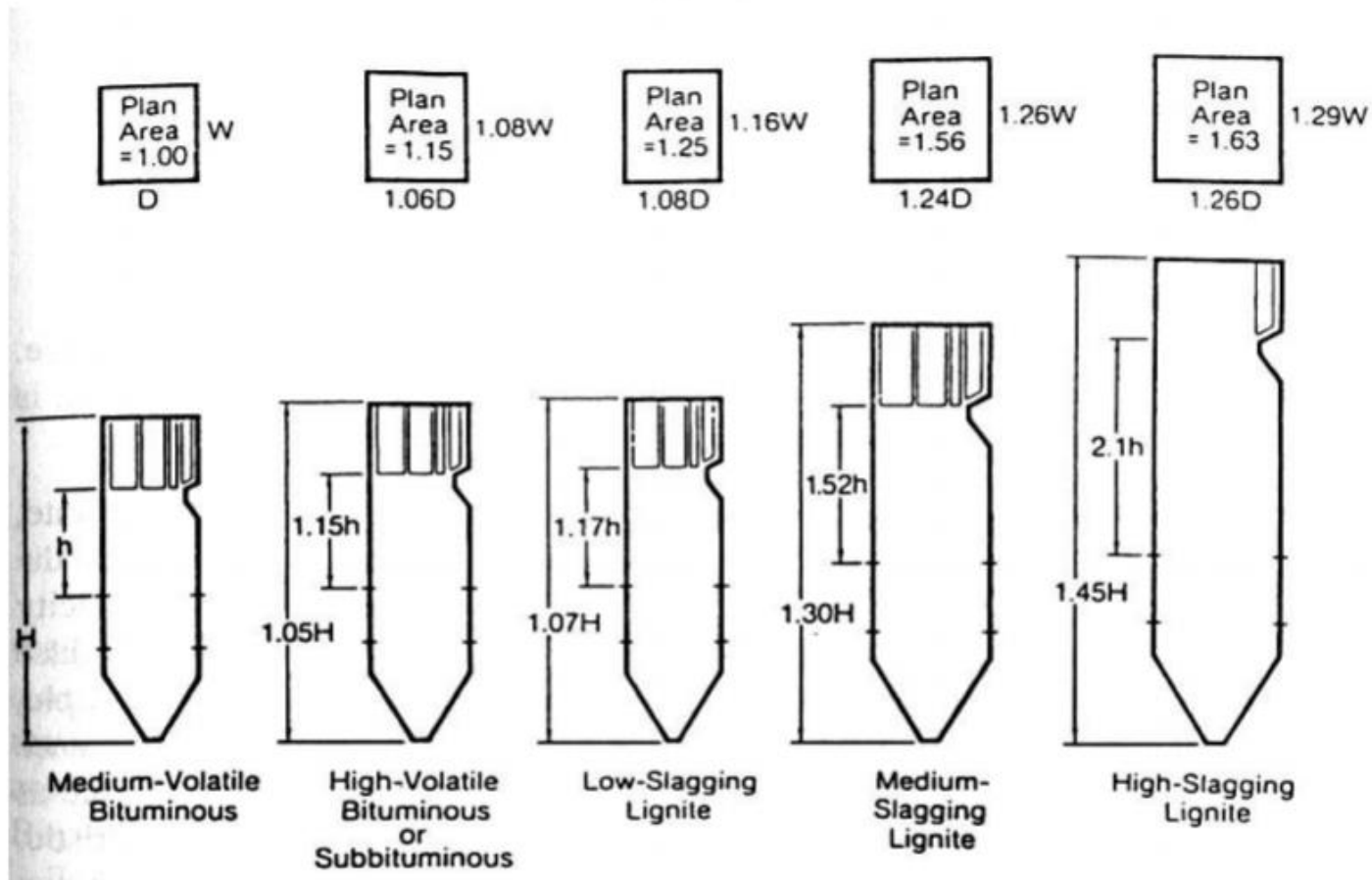
Problems with ash

**Coal low moisture; low ash
the better!!**



Problems with ash

Amount of flue gas, burning rate of fuel and slagging propensity also affects the furnace volume



Problems with ash

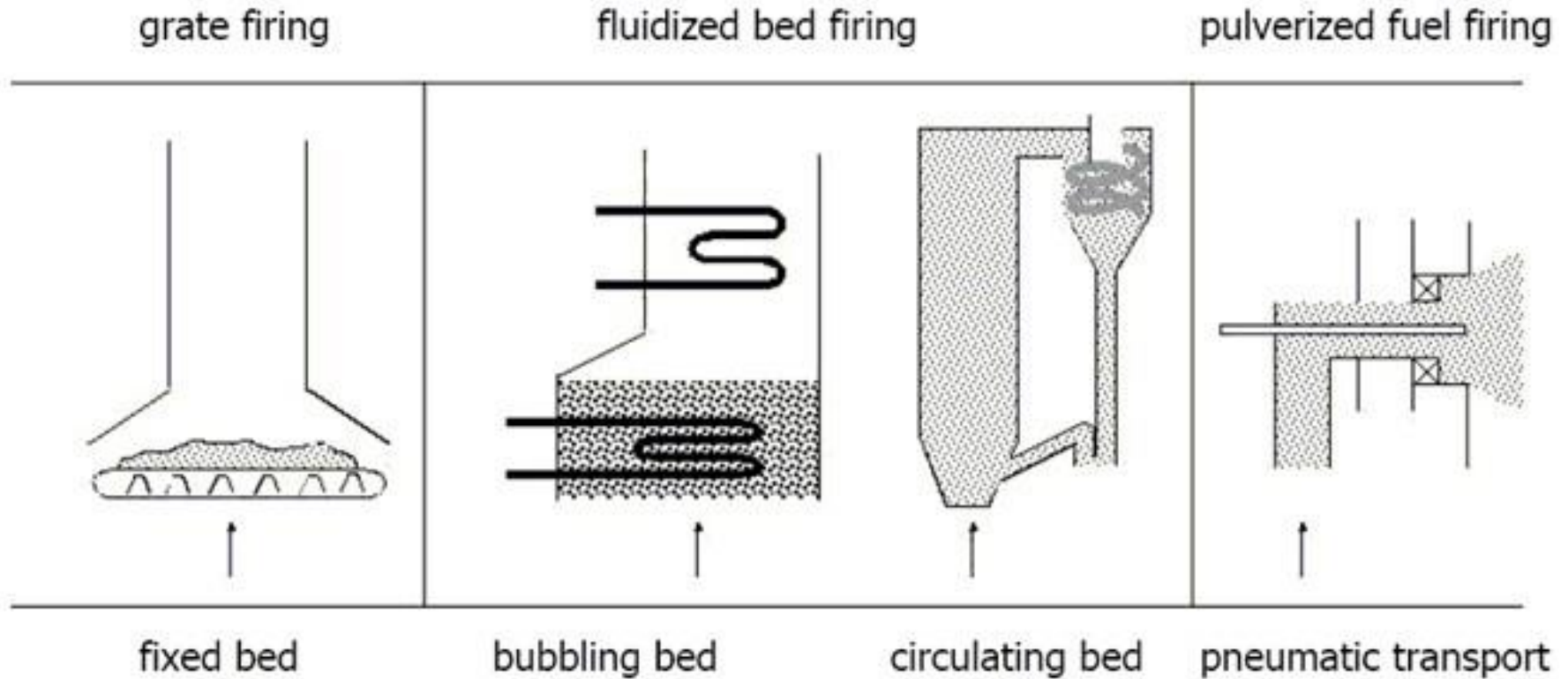
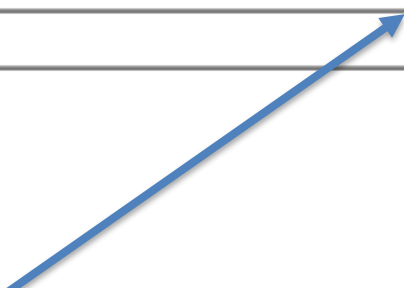


Table 1.8 Proper Size of Coal for Various Types of Firing System		
S. No.	Types of Firing System	Size (in mm)
1.	Hand Firing (a) Natural draft (b) Forced draft	25-75 25-40
2.	Stoker Firing (a) Chain grate i) Natural draft ii) Forced draft (b) Spreader Stoker	25-40 15-25 15-25
3.	Pulverized Fuel Fired	75% below 75 micron*
4	Fluidized bed boiler	< 10 mm

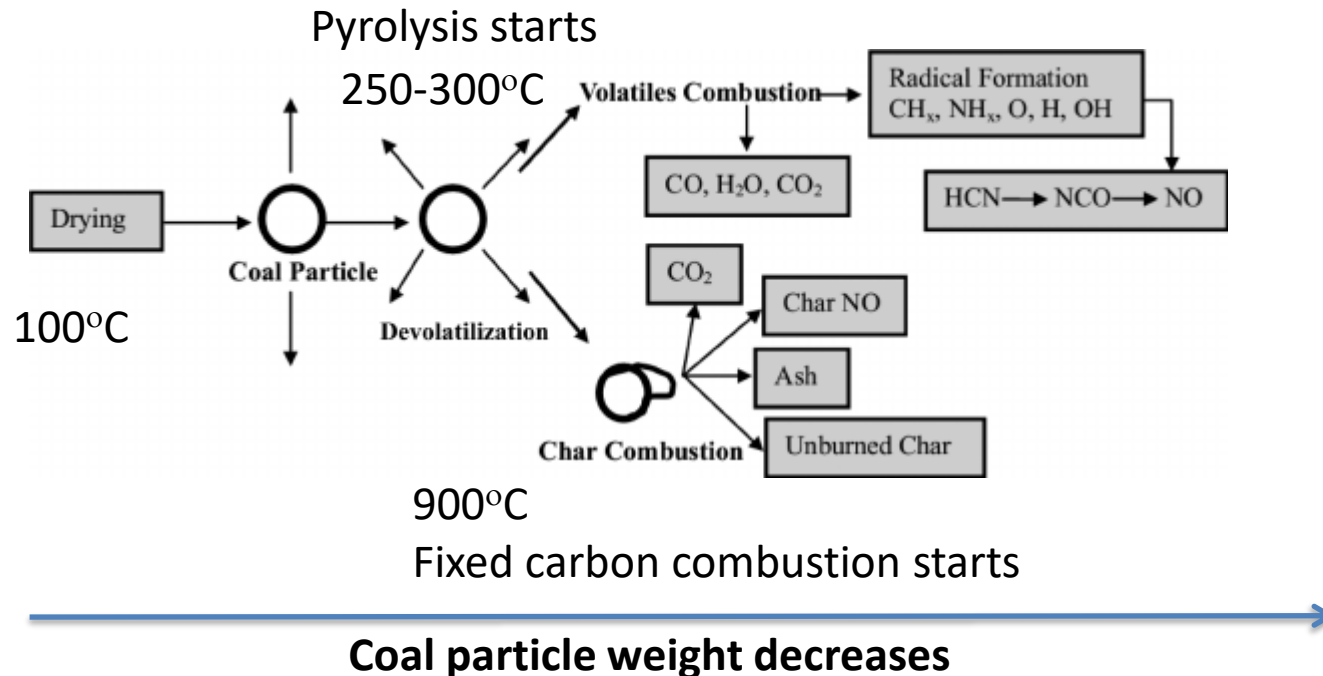
*1 Micron = 1/1000 mm



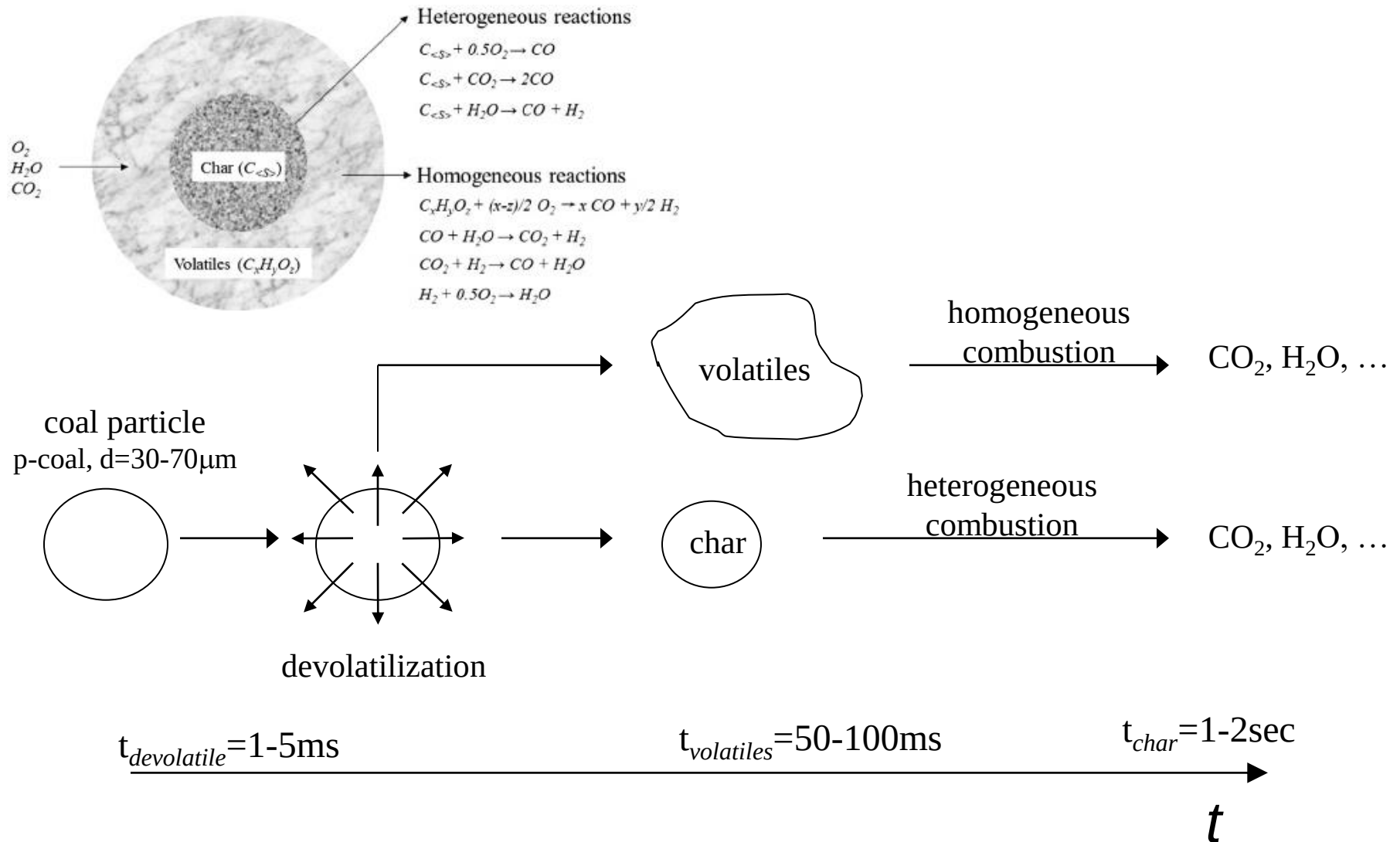
Combustion in solids

Three stages of mass loss:

- Drying (removal of water):endothermic;
- Devolatilization: vaporization of volatile organic compounds, gas-phase diffusion flames;
- Char combustion: heterogeneous (solid phase fuel, gas phase oxidizer) combustion of fixed carbon.



Coal combustion



Combustion in solids

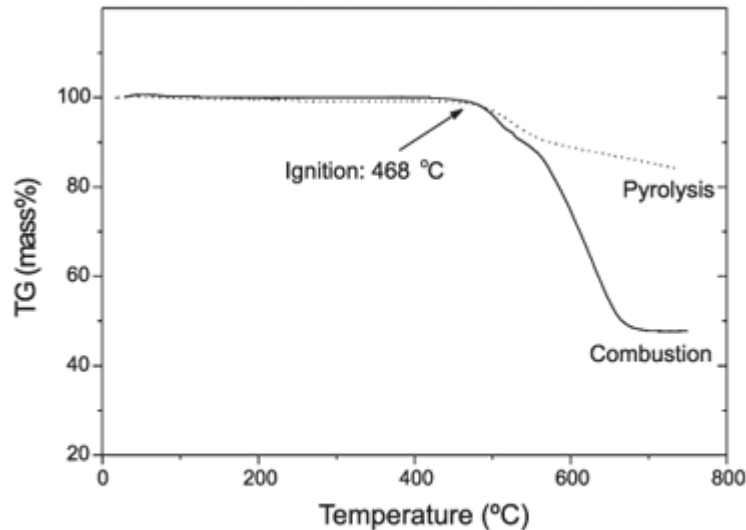


Figure 2. TG results for pyrolysis and combustion of the coal used for determining the ignition temperature

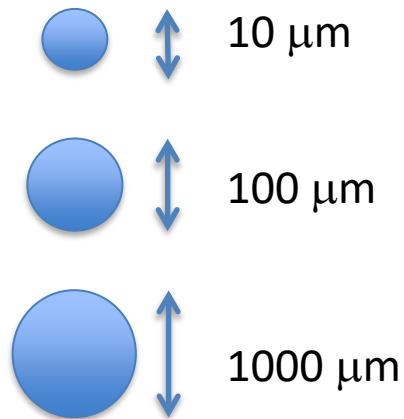
Material	Ignition Temperature
White Phosphorus	35 degree Celsius
Petrol	246 degree Celsius
Kerosene	220 degree Celsius
Diesel	210 degree Celsius
Wood	300 degree Celsius
Coal	454 degree Celsius
Piece of paper	233 degree Celsius

Thermogravimetric analysis or **thermal gravimetric analysis** (TGA) is a method of thermal analysis in which the mass of a sample is measured over time as the temperature changes.



Combustion in solids

COMBUSTION MODEL – 1 layer

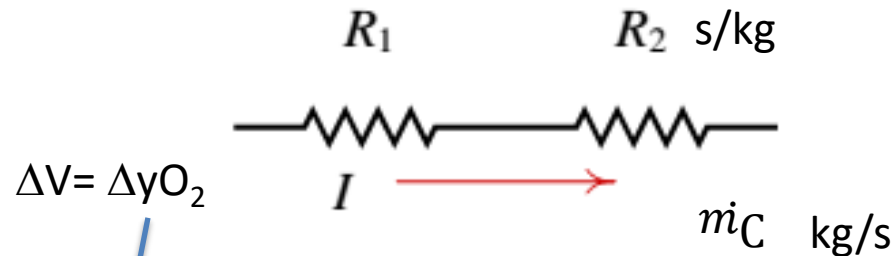


$$R_{kin} = \frac{M_{O_2} R T_s}{4\pi r_s^2 k_c M_C M_{mist} P}$$

Kinetic
mechanism

$$R_{diff} = \frac{s + y_{O_2, s}}{4\pi r_s \rho D^M}$$

Diffusion
mechanism



Combustion in solids

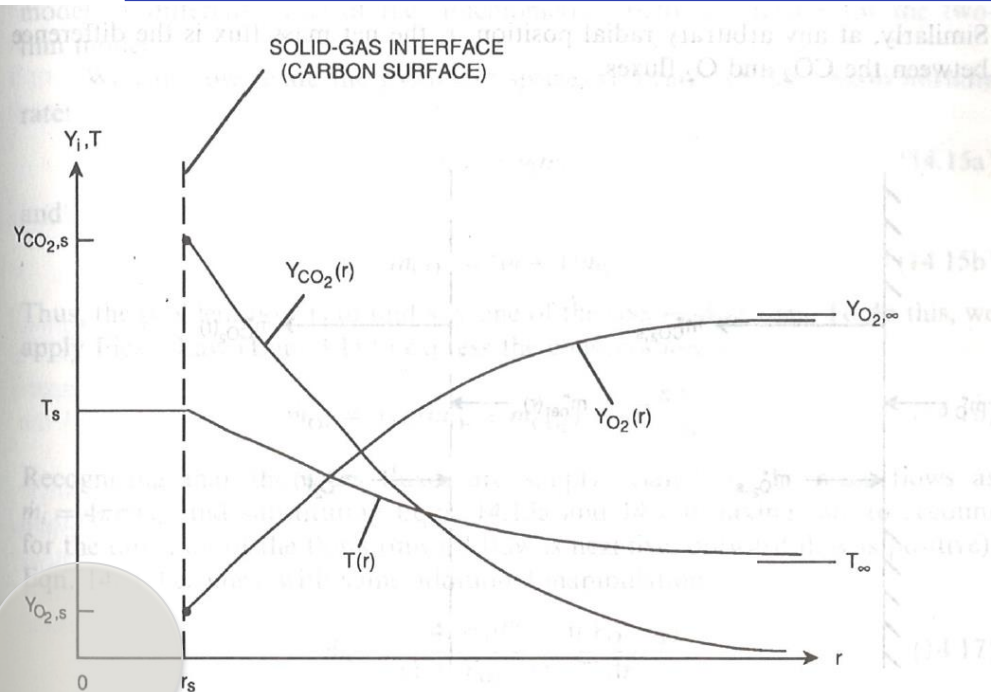
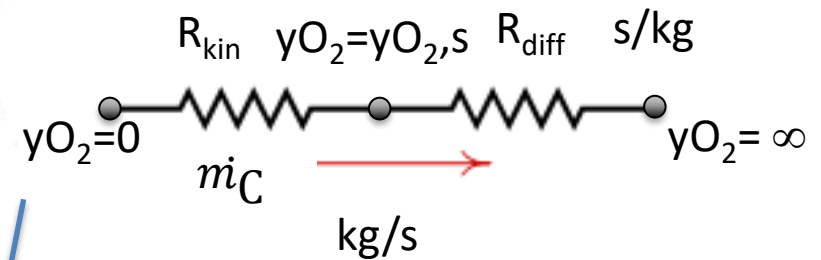


FIGURE 14.3

Species and temperature profiles for one-film model of carbon combustion assuming that CO_2 is the only product of combustion at the carbon surface.

COMBUSTION MODEL – 1 layer



y = mass fraction

Combustion in solids

$$R_{kin} = \frac{s}{4\pi r_s^2 \rho k_c} \xrightarrow{\text{A.exp } (-E_A/R.T_s)} \text{Kinetic rate} \sim 3 \cdot 10^5 \exp(-17966/T_s) \text{ m/s}$$

$\rho \xrightarrow{\text{Mixture density } \rho = P/(R/M \cdot T_s)}$
 Mixture molar mass $\sim 29 \text{ kg/kmol}$

$$s = M_{O_2}/MC$$

$$R_{diff} = \frac{s + y_{O_2}, s}{4\pi r_s \rho D^M} \xrightarrow{\text{Diffusion rate}} \sim 1.2 \cdot 10^{-4} \text{ m}^2/\text{s}$$

$\xrightarrow{\text{0.5 x Particle Diameter}}$

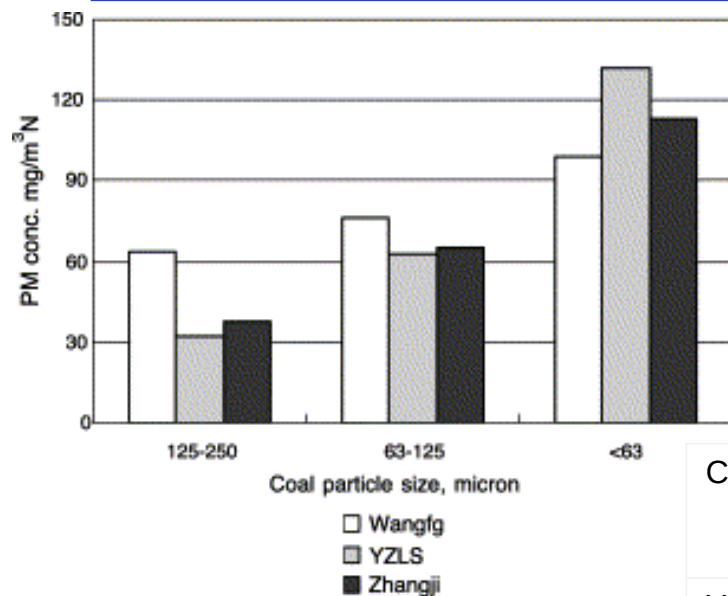
Combustion in solids

Time for burning = D^2/K_B

$$K_B = \frac{8\rho D^M}{\rho_C} \ln\left(1 + \frac{y_{O_2,\infty}}{s}\right)$$

Residence time in the boiler is typically 2-5 seconds

Combustion in solids



**Less coal particle size
more PM emissions**

Coal type	Coal particle size, μm	Ultimate analysis, wt.%, daf			
		C	H	N	S+O ^a
YZLS	125–250	81.89	5.59	2.31	10.20
	63–125	80.13	5.30	2.08	12.49
	<63	79.45	5.10	2.07	13.37
Zhangji	125–250	81.46	5.97	1.88	10.69
	63–125	80.15	5.64	1.68	12.53
	<63	79.58	5.50	1.73	13.19
Wangfg	125–250	85.60	5.38	2.13	6.89
	63–125	87.96	6.06	2.19	3.79
	<63	88.52	5.48	2.22	3.79

<http://www.sciencedirect.com/science/article/pii/S0378382003003060>

Combustion in solids

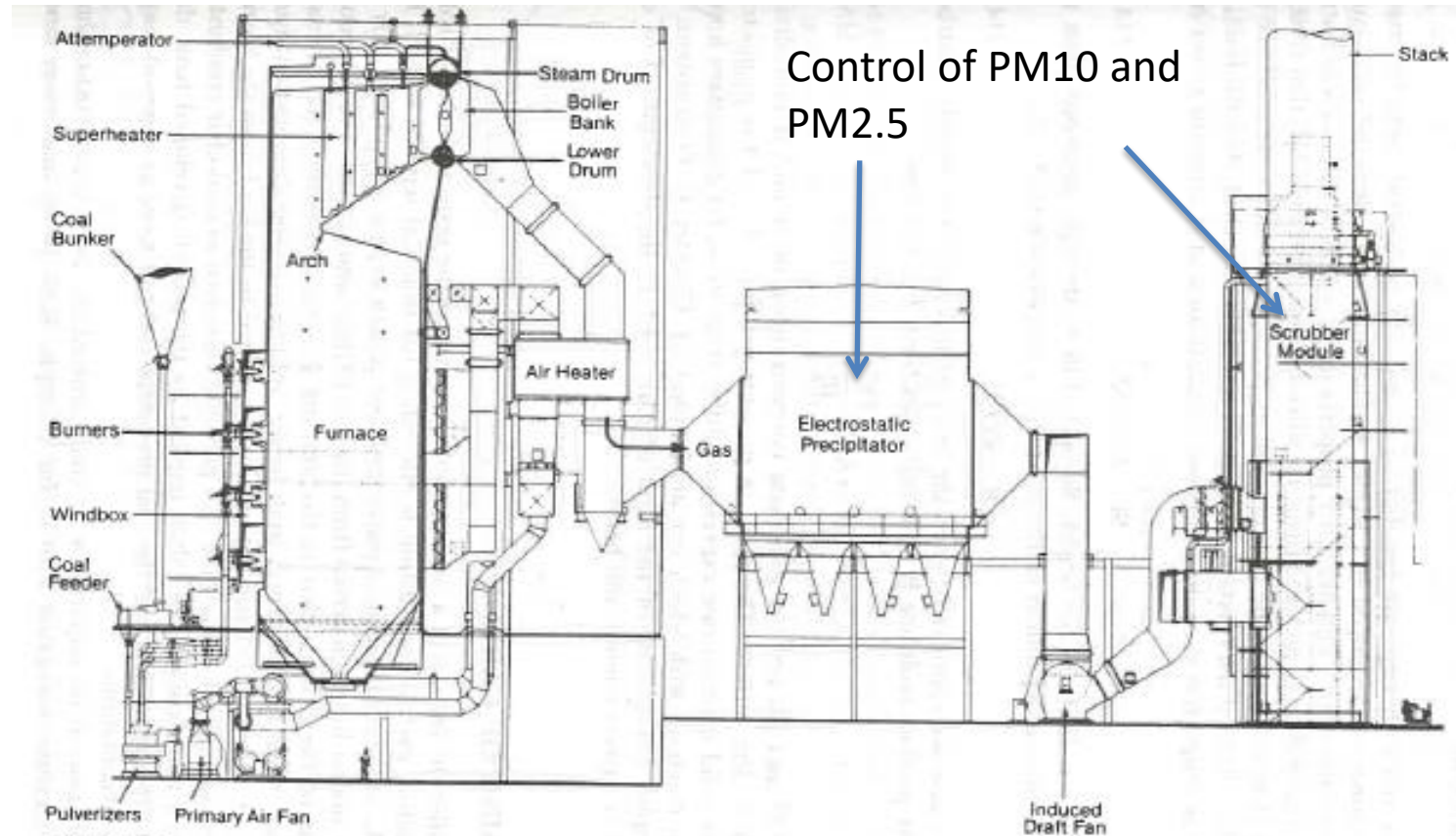


FIGURE 14.1

Pulverized-coal boiler. (Reprinted from Ref. [1] with permission of Babcock and Wilcox Co.)

Scrubber “Spray tower”

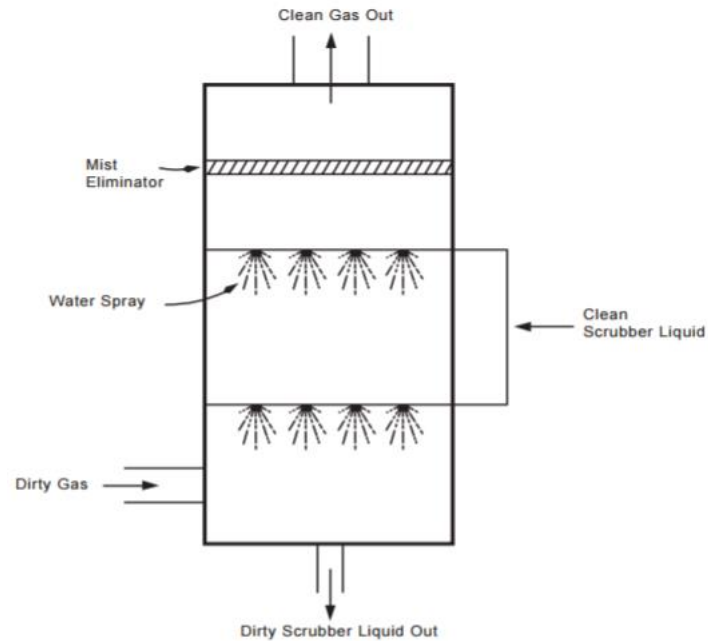


Figure 2.1: Spray Tower [4]

“Cyclonic Spray”

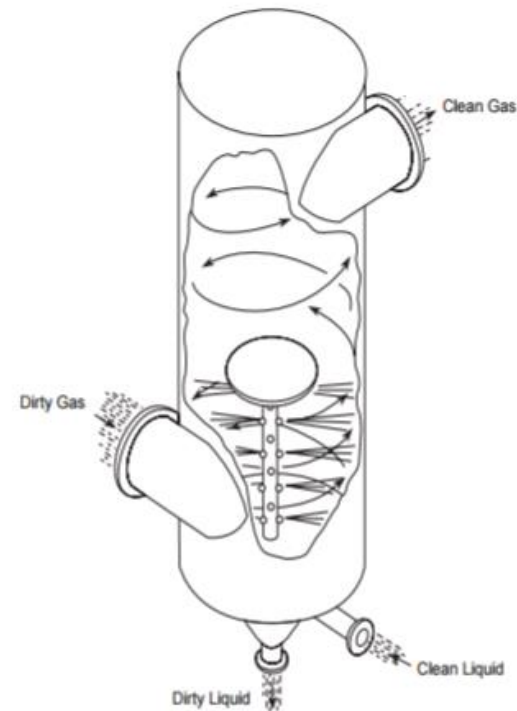


Figure 2.2: Cyclonic Spray Scrubber [3]

Combustion in solids

**Combustion of coal main
pollutants:
NO_x, SO₂ and PM!!!**

P#14 A boiler from a power plant is fed by residual fuel-oil. Mass ultimate analysis in the table. Consider complete combustion with 25% de excess air.

- i) Estimate (A/F)_{st}.
- ii) Estimate SO₂ concentration in the flue gas.
- iii) Compare [SO₂] with the legislation limits, 3% O₂ 200 mg/Nm³.
- iv) Estimate PM emissions.

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

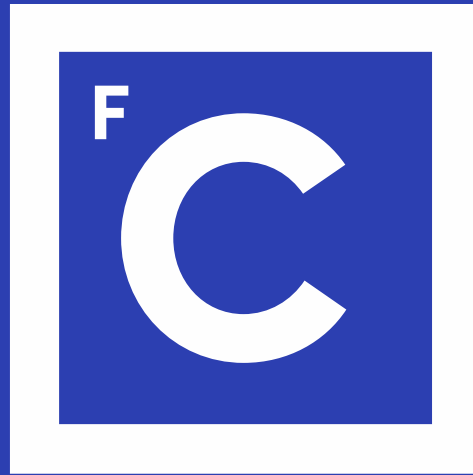
P#15 Ultimate analysis (dry basis wt%)

C	H	O
52.30	7.00	40.10

Proximate analysis			ar	dry	daf
	Moisture content	wt%	3.87		
	Volatile matter	wt%	76.90	80.00	80.48
	Ash content	wt%	0.58	0.60	
	Fixed carbon	wt%	18.65	19.40	19.52

- Determine the **ar** and **daf** ultimate analysis.
- What is the fuel according to the Seyler diagram?
- What would be the (A/F)s in mass and molar basis?
- What will be the first thing that is burned? Estimate its chemical formula.
- What would be the colour of the flame in a forest fire situation? Justify.

Obrigado



Ciências ULisboa

Faculdade
de Ciências
da Universidade
de Lisboa