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DISCIPLINA MEEA

Combustion

Corpo docente

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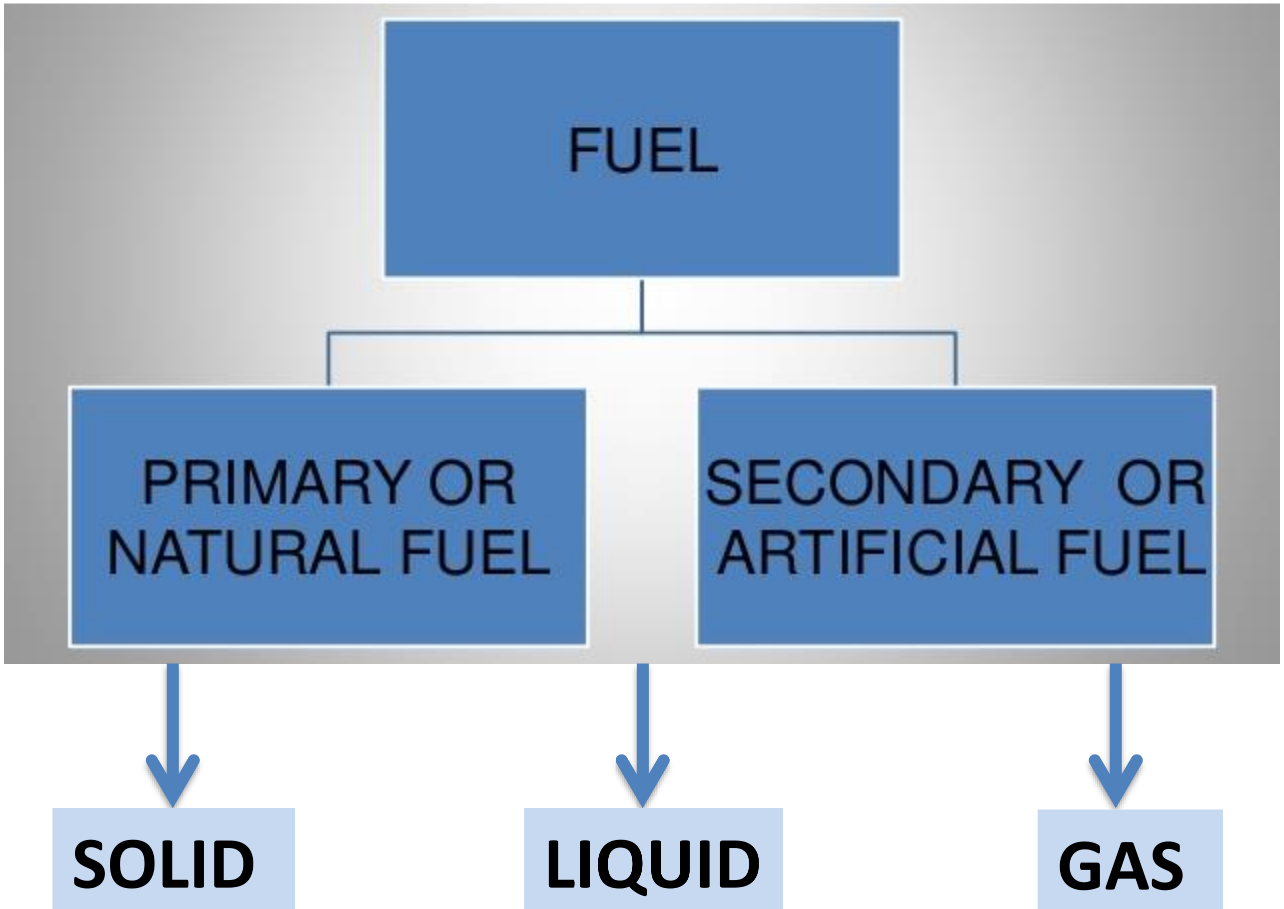
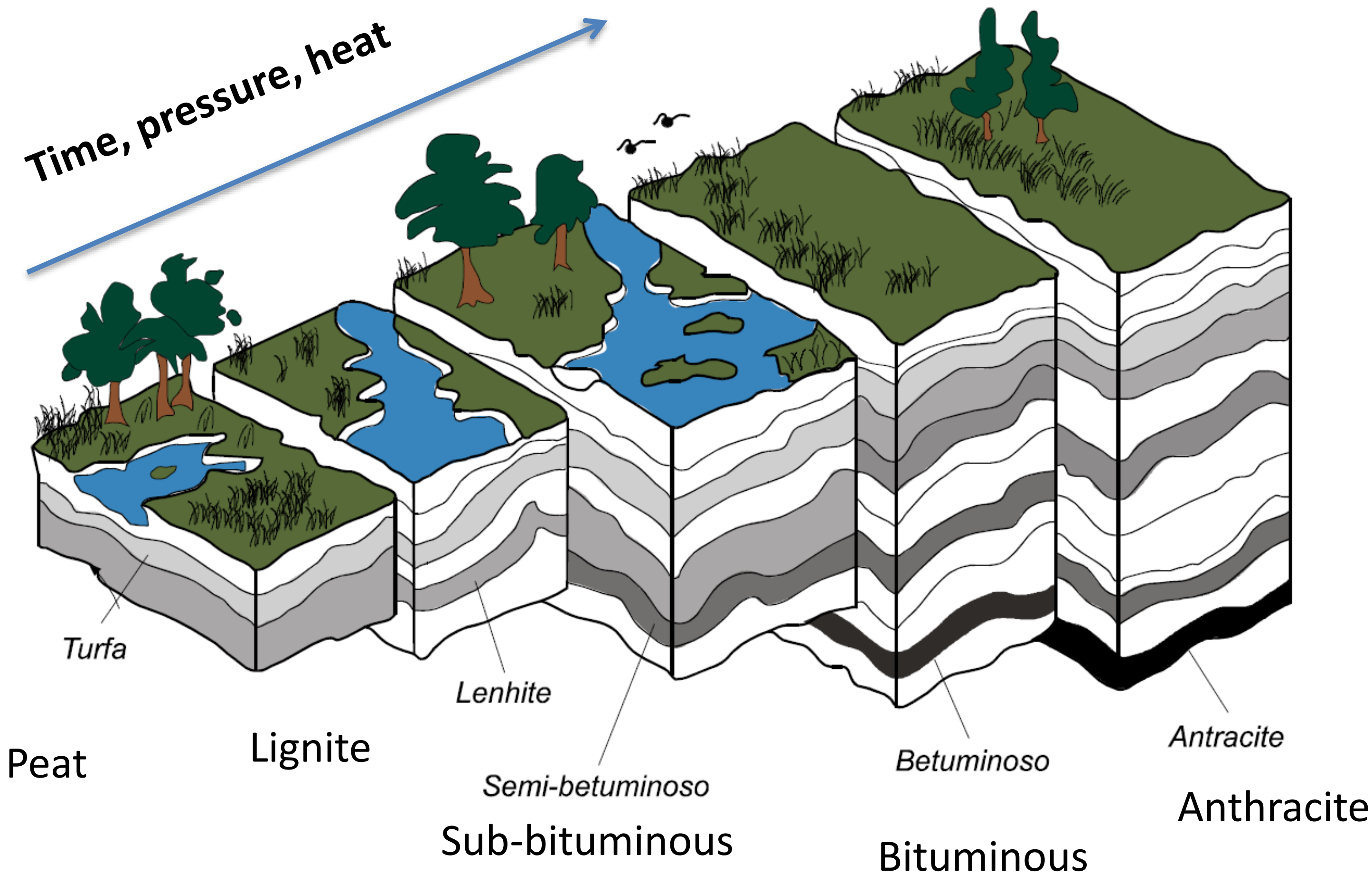
Fuel types


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

Fuel types


Time, pressure, heat
Turfa
Lenhite
Semi-betuminoso
Betuminoso
Antracite
Peat
Lignite
Sub-bituminous
Bituminous
Anthracite

Fuel types

Time, pressure, heat

Peat

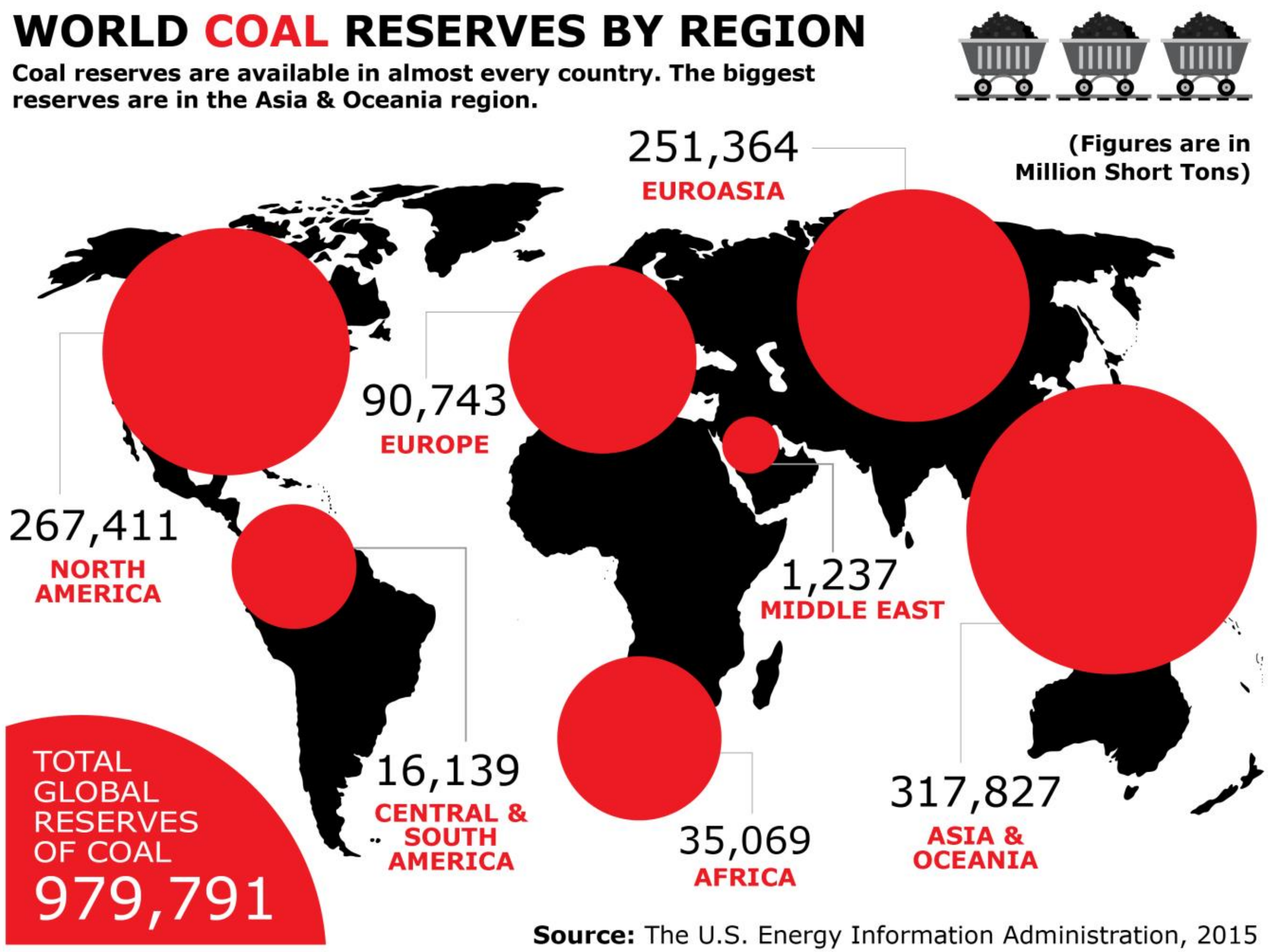
Lignite

Sub-bituminous

Bituminous

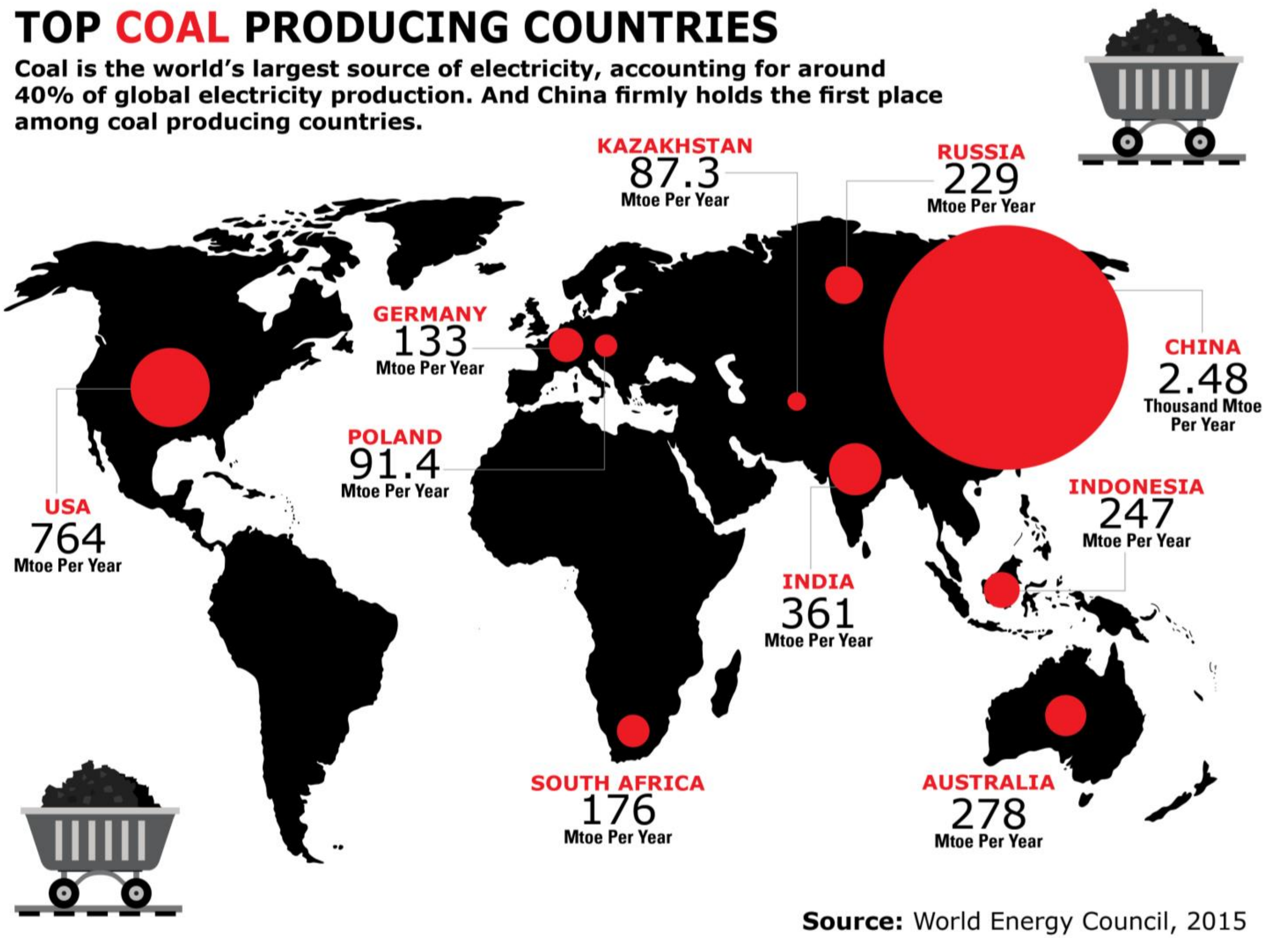
Anthracite

Fuel types



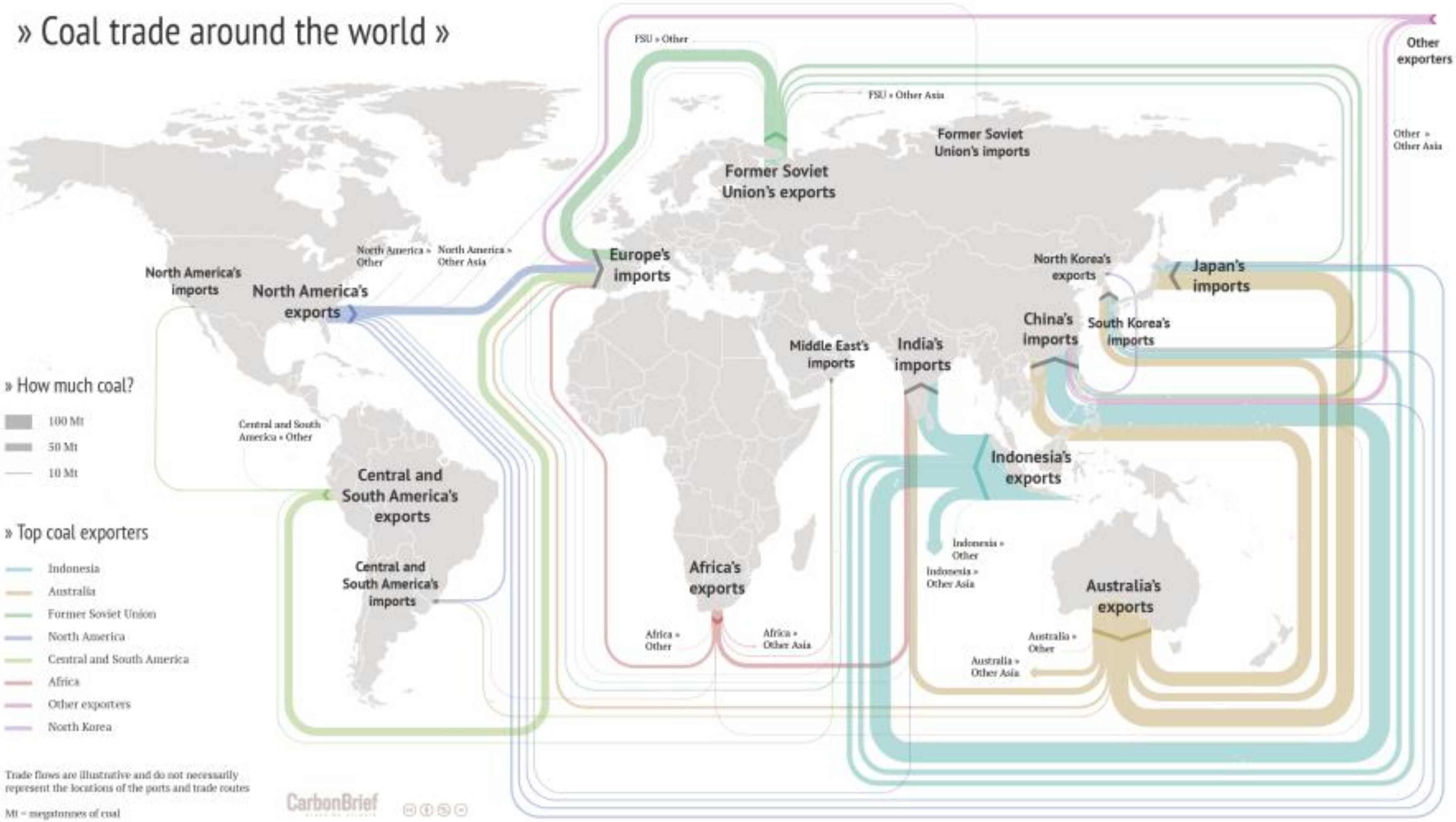
1 short ton
907.18474 kg

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.
KAZAKHSTAN 87.3 Mtoe Per Year
RUSSIA 229 Mtoe Per Year
GERMANY 133 Mtoe Per Year
CHINA 2.48 Thousand Mtoe Per Year
POLAND 91.4 Mtoe Per Year
INDONESIA 247 Mtoe Per Year
USA 764 Mtoe Per Year
INDIA 361 Mtoe Per Year
SOUTH AFRICA 176 Mtoe Per Year
AUSTRALIA 278 Mtoe Per Year
Source: World Energy Council, 2015

Coal trade


» Coal trade around the world »
FSU » Other
FSU » Other Asia
Other exporters
Other » Other Asia
Former Soviet Union's imports
Former Soviet Union's exports
Europe's imports
North America's imports
North America's exports
North America » Other
North America » Other Asia
North Korea's exports
Japan's imports
China's imports
South Korea's imports
Middle East's imports
India's imports
» How much coal?
100 Mt
50 Mt
10 Mt
Central and South America » Other
Central and South America's exports
Indonesia's exports
» Top coal exporters
Indonesia
Australia
Former Soviet Union
North America
Central and South America
Africa
Other exporters
North Korea
Central and South America's imports
Africa's exports
Indonesia » Other
Indonesia » Other Asia
Australia's exports
Africa » Other
Africa » Other Asia
Australia » Other
Australia » Other Asia
Trade flows are illustrative and do not necessarily represent the locations of the ports and trade routes
Mt = megatonnes of coal
CarbonBrief

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

Fuel types

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

Ultimate analysis

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)

PCS ~ 33,8 xC + 144,3 (xH - xO/8) + 9,4 xS (Dulong)

PCS ~ 34,1 xC + 132,3 [xH - (xO + xN)/11] + 6,8 xS – 1,5 xAsh
(Mason and Gandhi, 1983)

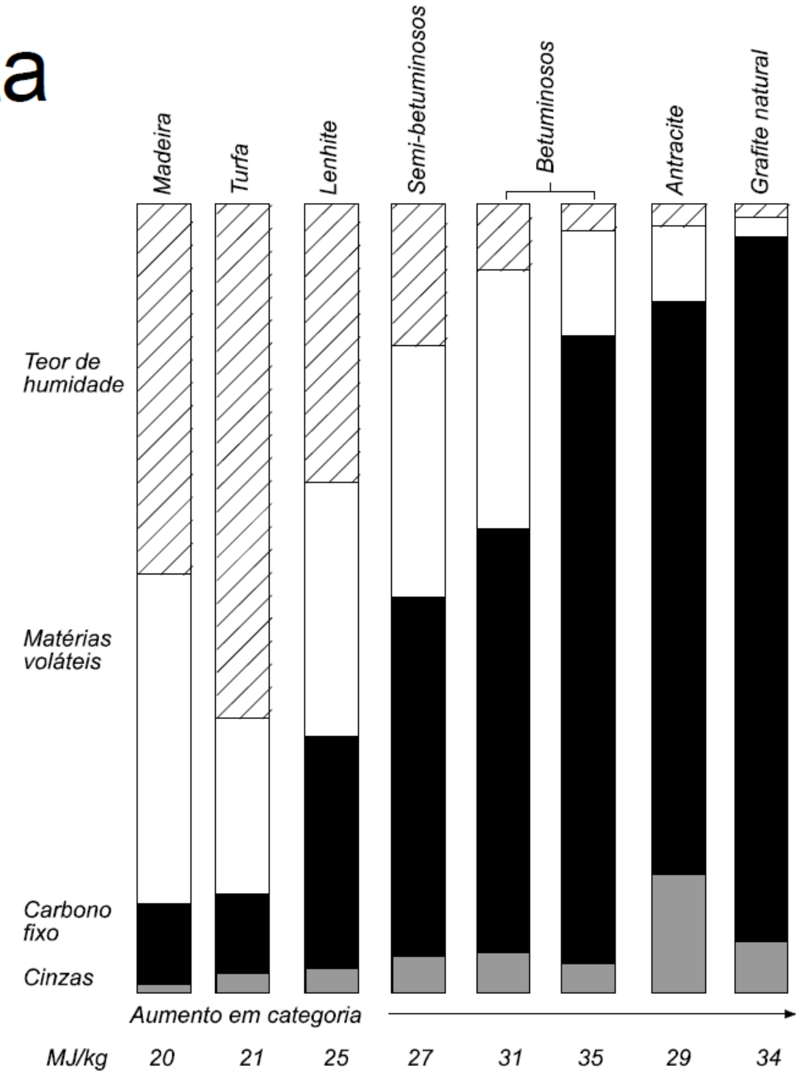
in MJ·kg-1 and dry basis. Last includes ash effects xAsh

Proximate analysis

Análise Imediata

Nesta análise carateriza-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* (Ar - incluindo humidade e cinzas)
- *Dry basis* (Db - base seca, exclui a humidade)
- *Dry ash free* (Daf - exclui humidade e cinzas)

Fuel types

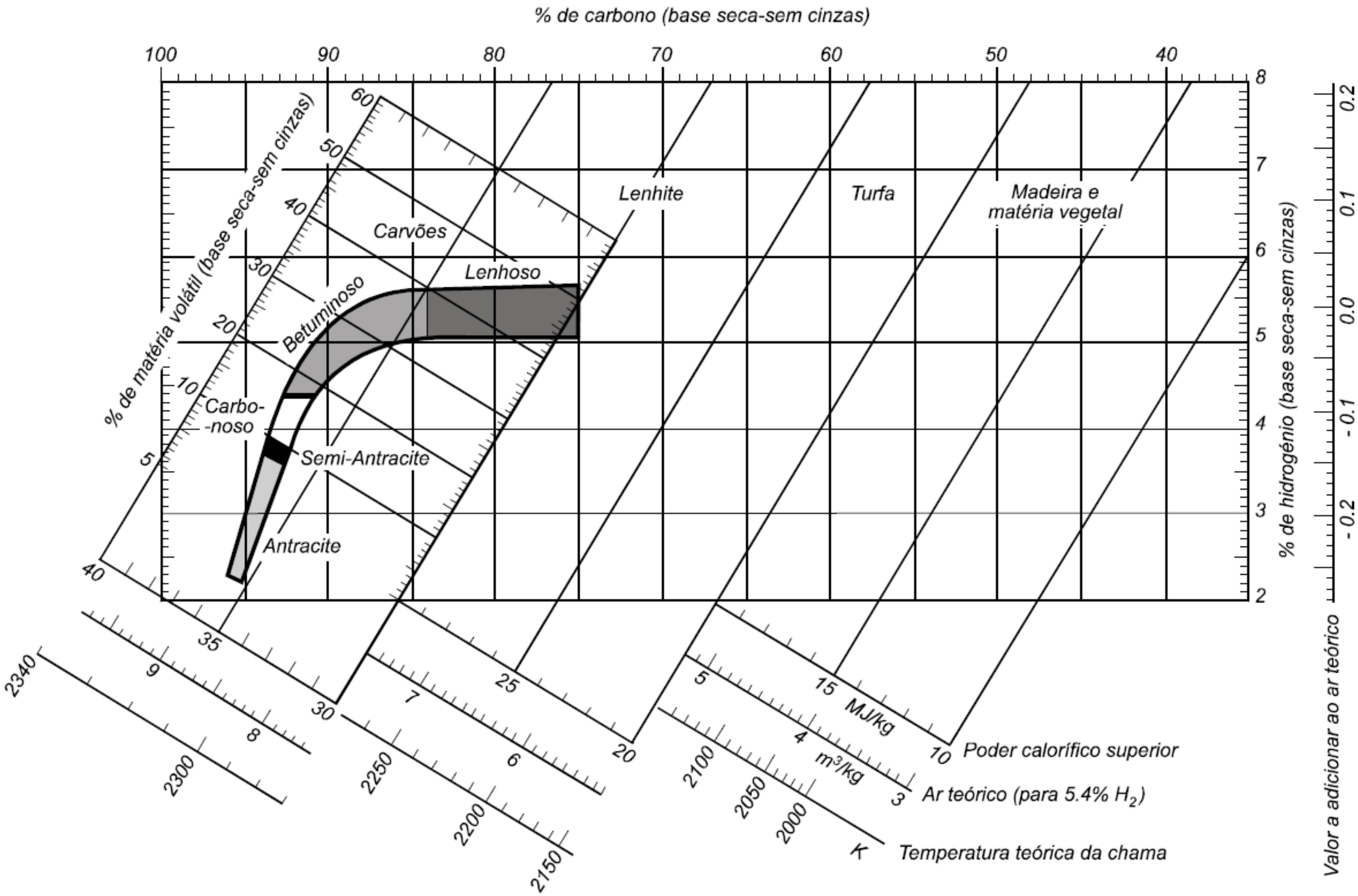
Even with complete combustion the minimum particle emissions are limited by the ash content inicially in the fuel

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

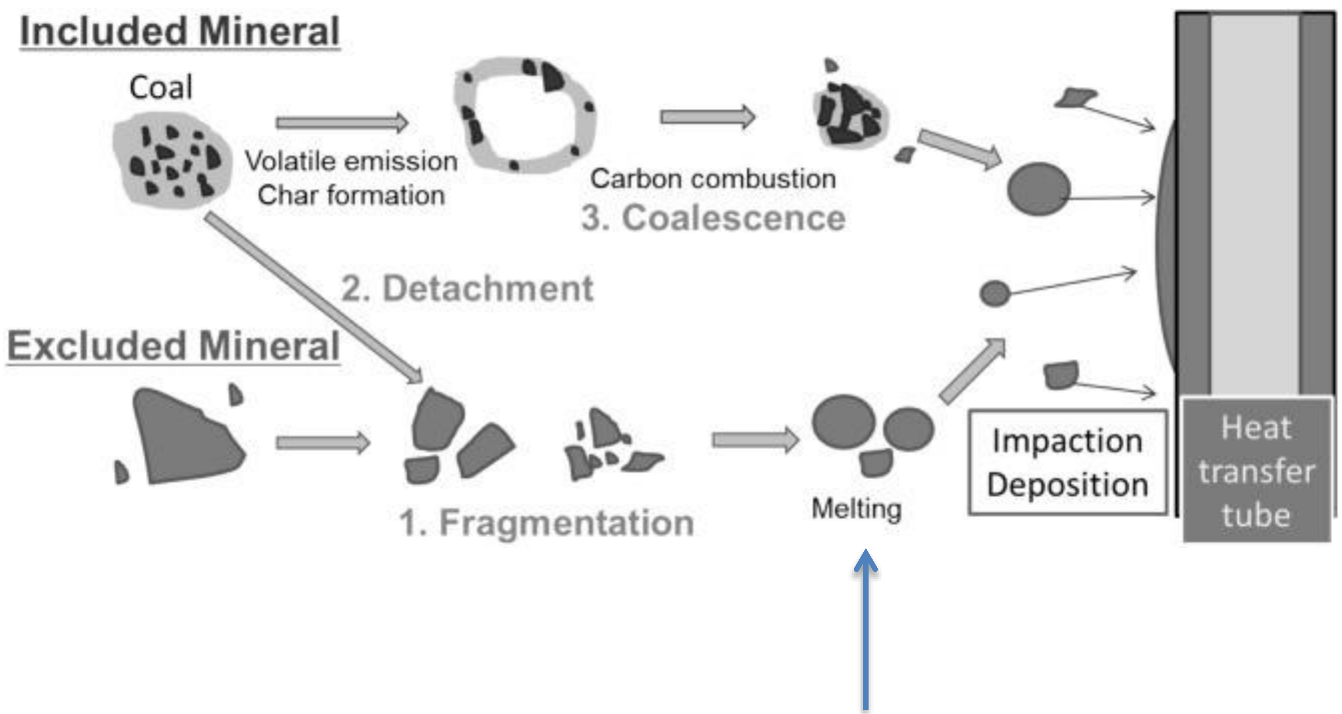
Problems with ash

Ash deposit

- **Slagging** — **(molten ash)**
- **Fouling** — volatile inorganic elements in the coal during combustion on heat exchangers

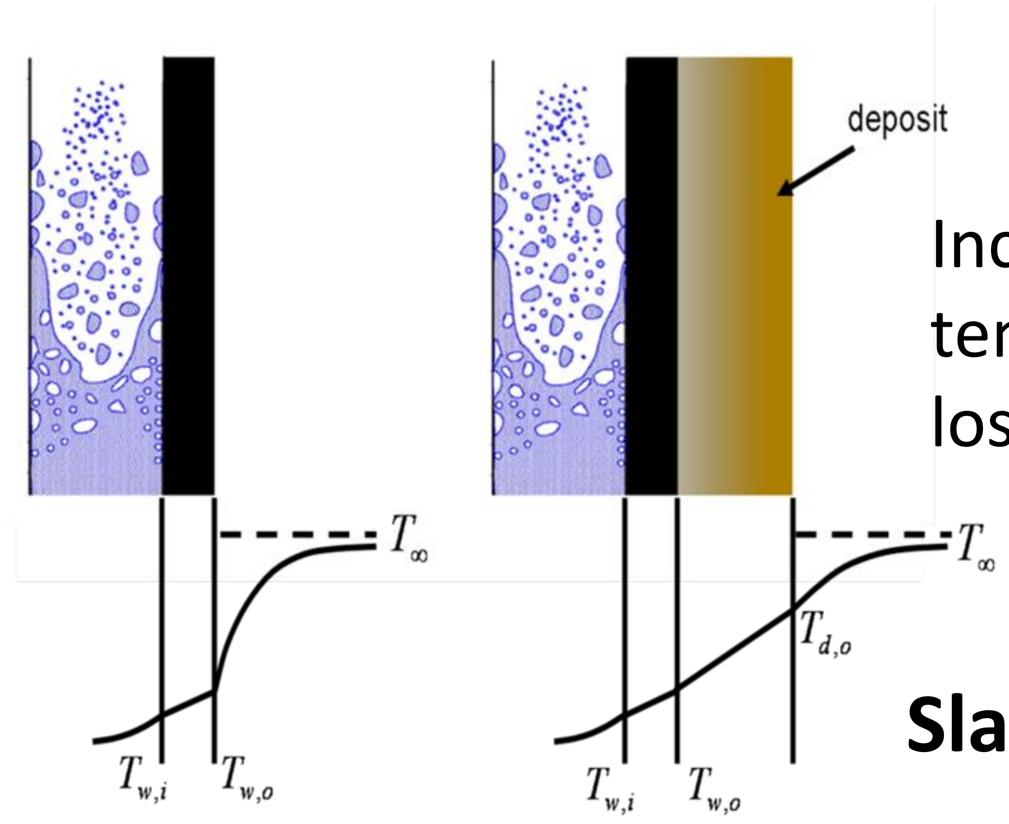
(ash deposit on heat exchangers)

Fuel types



Melting point

Problems with ash



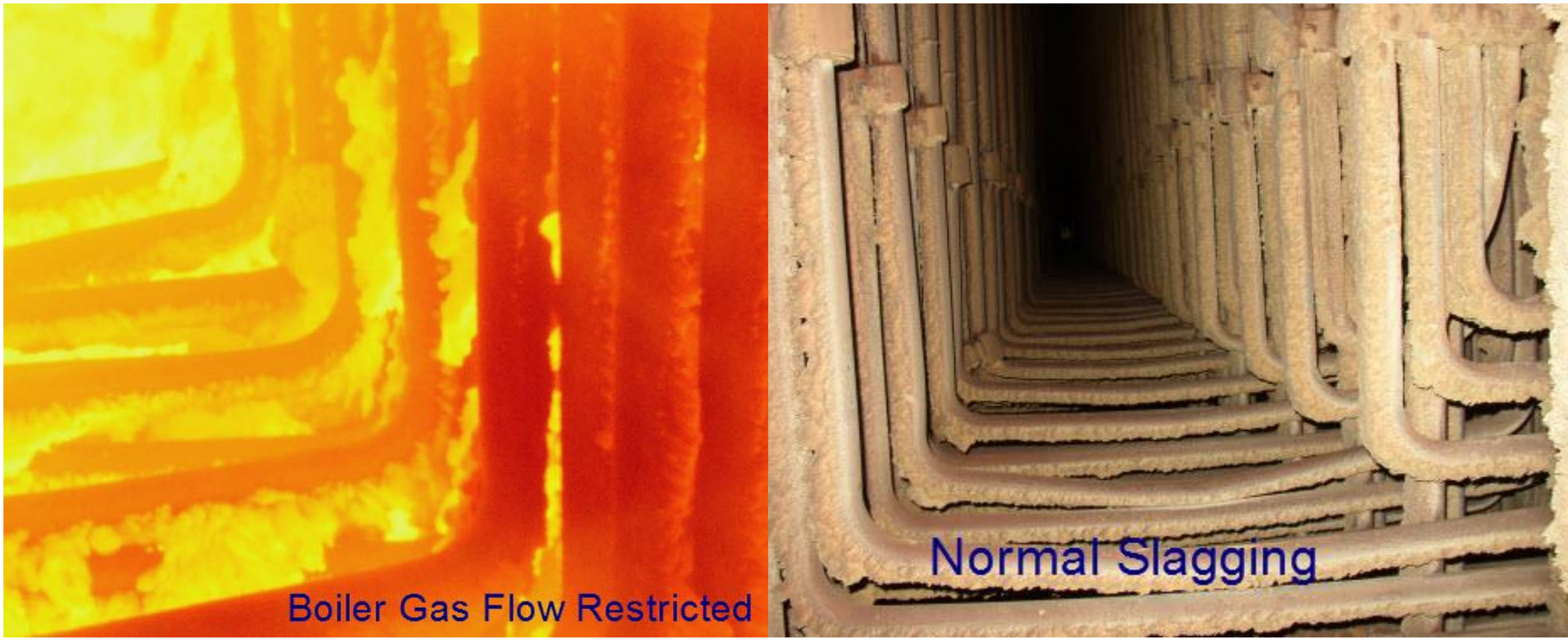
Increase of combustion temperature!! Low heat loss to water!!!

Slagging (molten ash)

Fe-iron Melting temperature: 1538 ºC (1811 K)
Magnesium: 650 ºC (923 K)
SiO2 (silica): 1710 ºC (1983 K)

Al_2O_3=2072 ºC (2345 K)

Problems with ash



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)

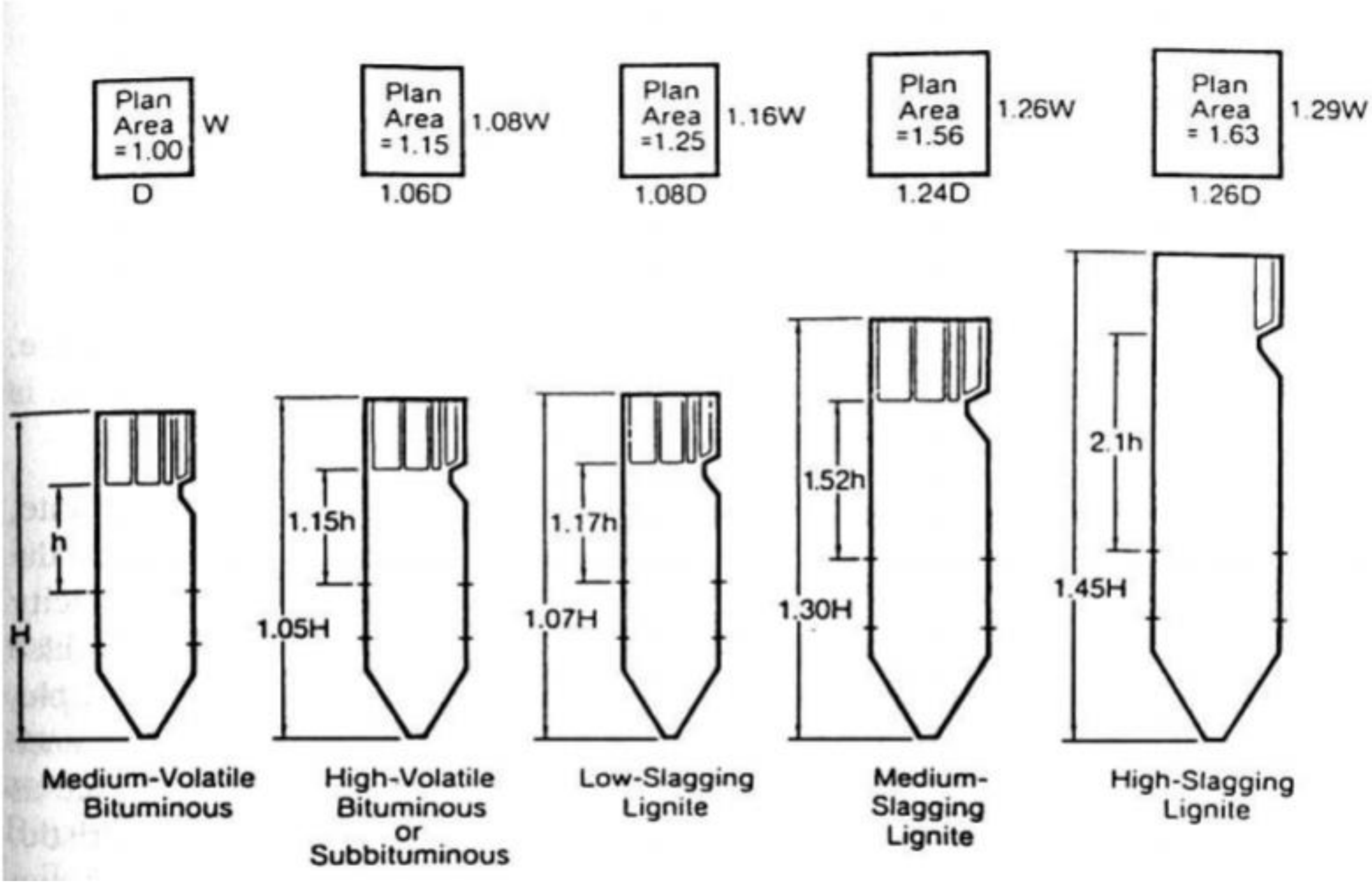
Continent			*Eurasia*		
Location			*Far East (Primorsk region)*		
Basin Name			*Uglovskiy*		
Deposit Name			*Artemovskiy*	*Shkotovskiy*	*Tavrichanskiy*
Proximate Analysis	Moisture, 105°C	wt%, a.r.	23	37	20
	Volatiles, 900°C	wt%, dry	30	35	28.8
	Ash content, 815°C	wt%, dry	40	30	40
	Fixed carbon	wt%, dry	30	35	31.2
Ultimate analysis	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

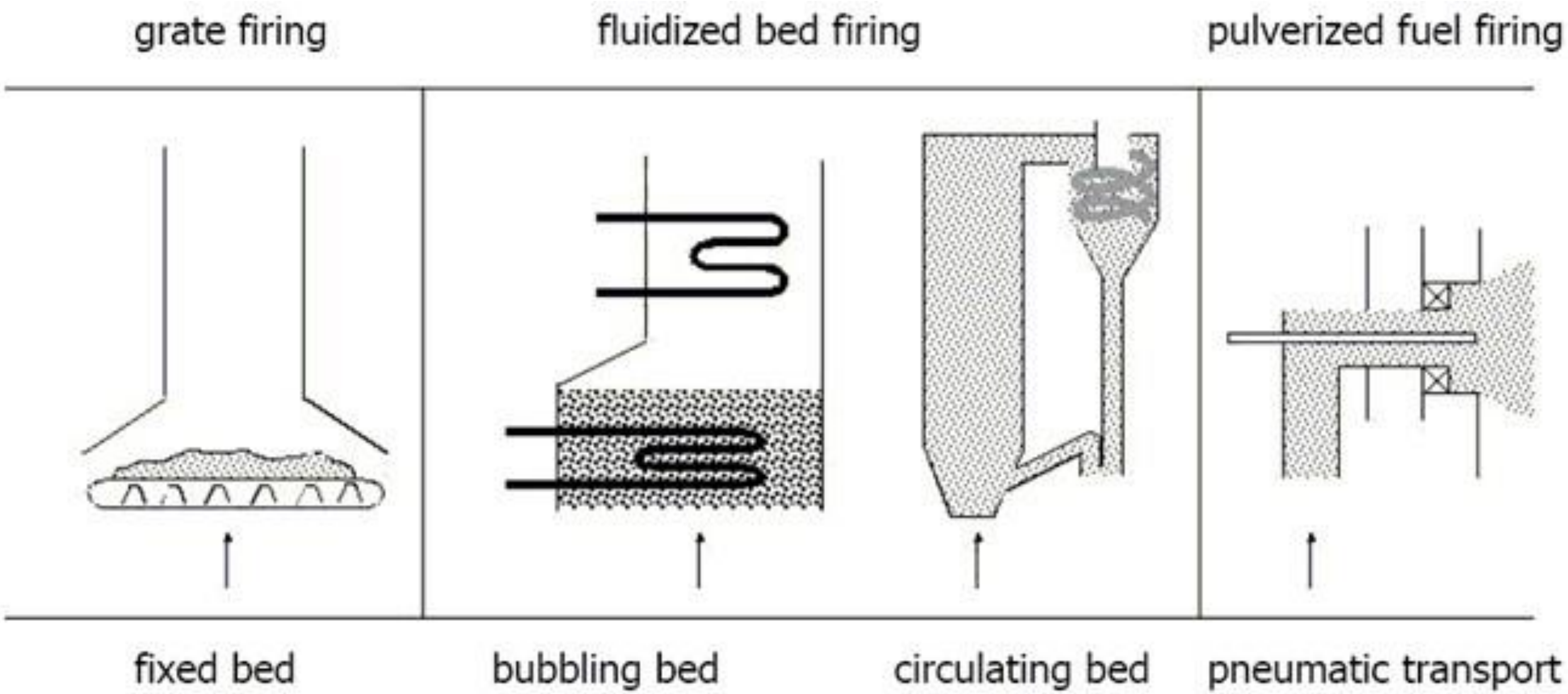
Coal low moisture; low ash the better!!

Problems with ash

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



Problems with ash



Fuel types

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	25-75
	(b) Forced draft	25-40
2.	Stoker Firing	
	(a) Chain grate	
	i) Natural draft	25-40
	ii) Forced draft	15-25
	(b) Spreader Stoker	15-25
3.	Pulverized Fuel Fired	75% below 75 micron*
4	Fluidized bed boiler	< 10 mm

*1 Micron = 1/1000 mm

Combustion in solids

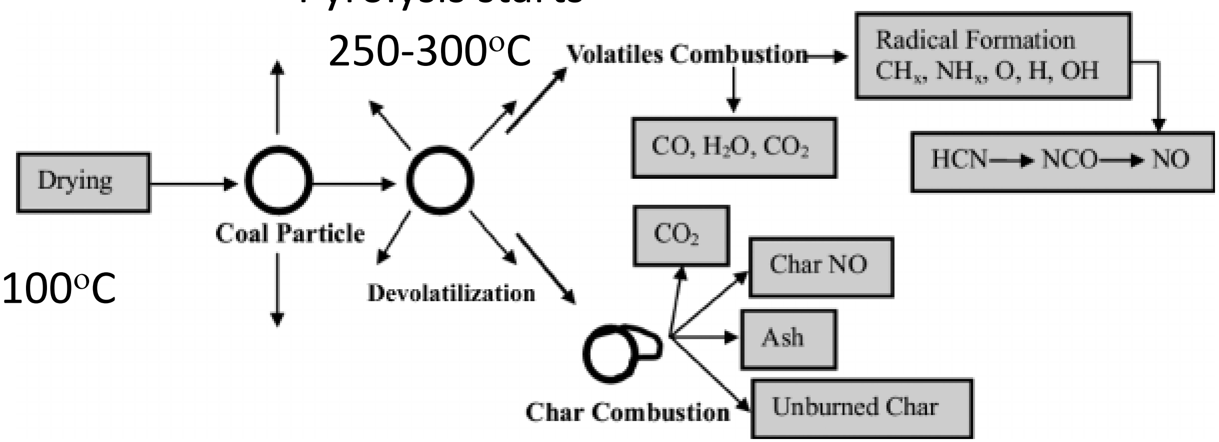
Three stages of mass loss:

- 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.

Pyrolysis starts

250-300°C

100°C

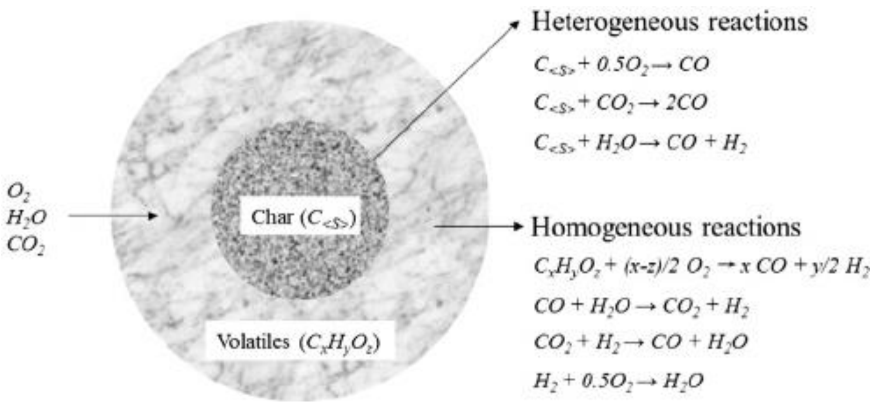


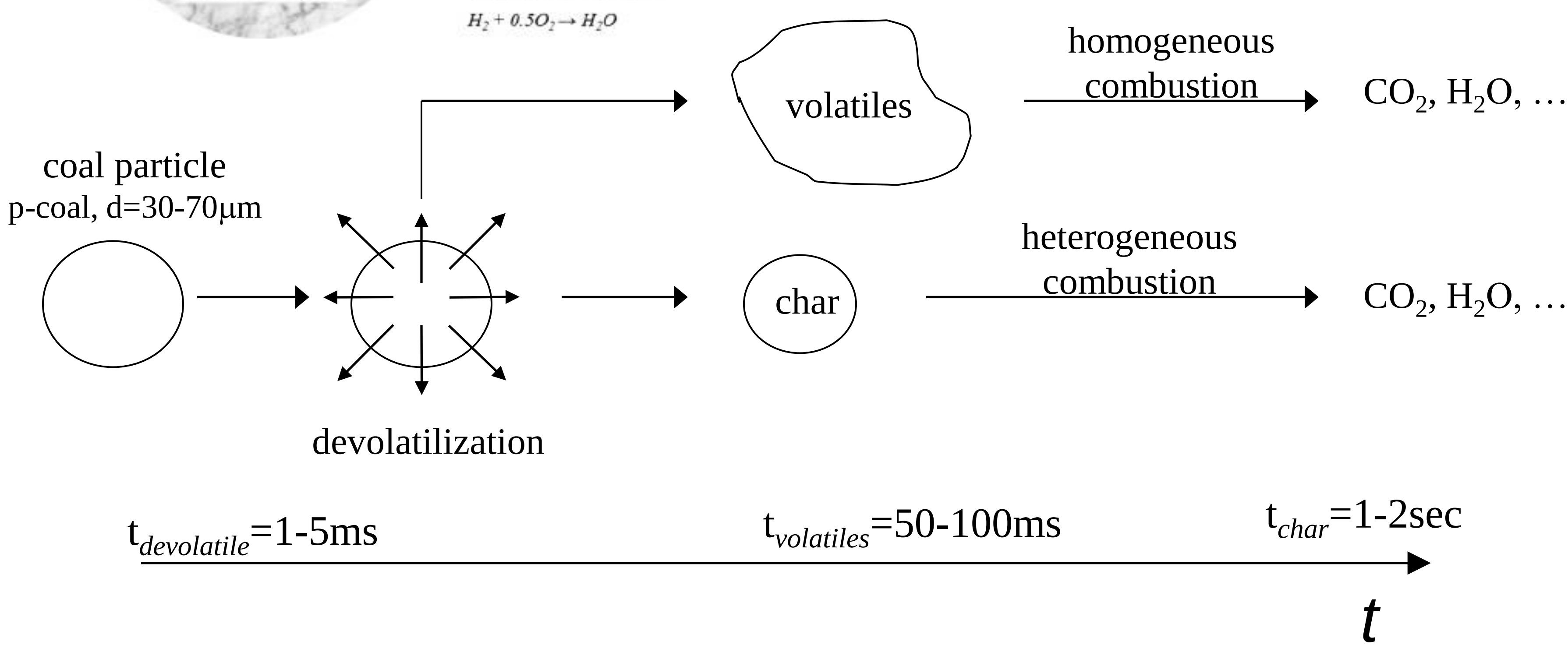
900°C

Fixed carbon combustion starts

Coal particle weight decreases

Coal combustion





Combustion in solids

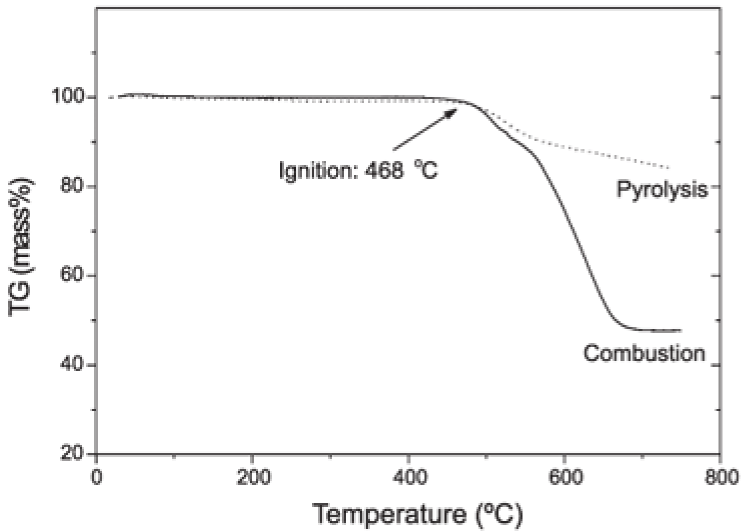
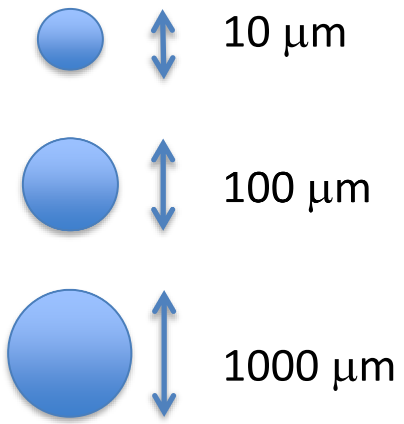


Figure 2. TG results for pyrolysis and combustion of the coal used for determining the ignition temperature

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 MODEL – 1 layer

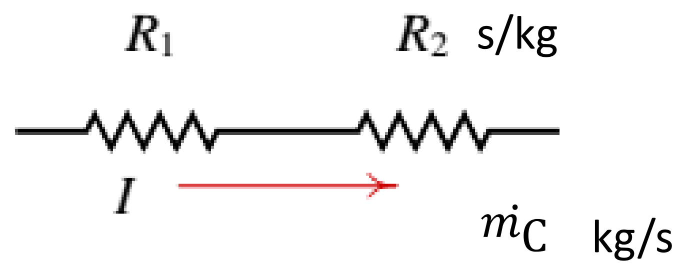


$$R_{kin} = \frac{M_{O_2} R T_s}{4\pi r^2{}_s \; k_c M_C M_{mist} P}$$

Kinetic mechanism

$$R_{diff} = \frac{s + yO2, s}{4\pi r_s \;\; \rho D^M}$$

Diffusion mechanism



$\Delta V = \Delta yO_2$

y = mass fraction

Combustion in solids

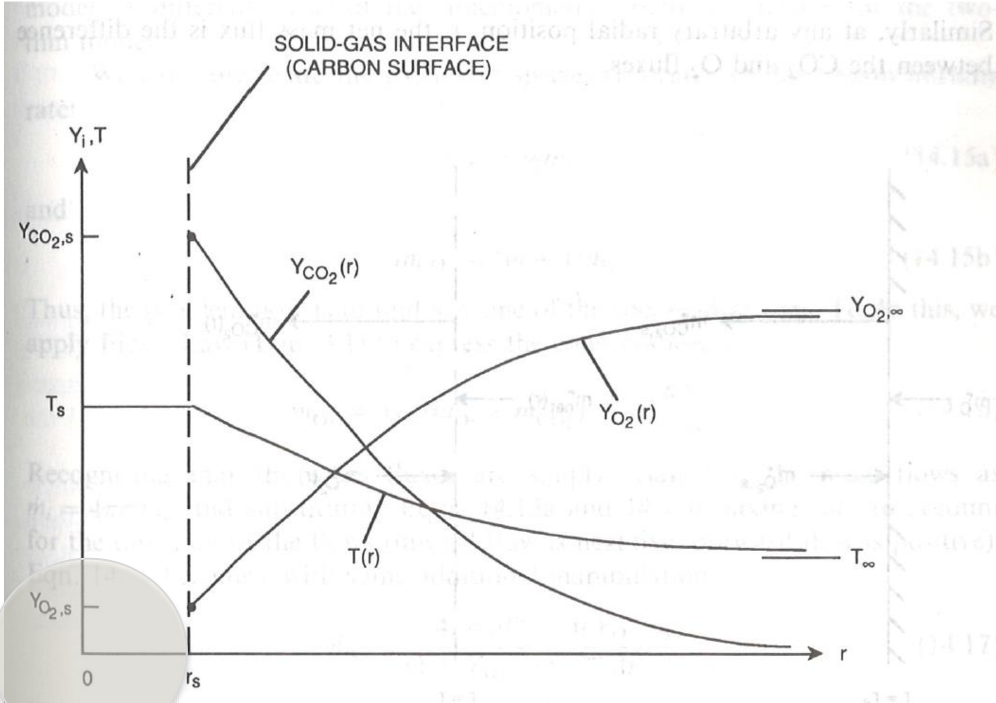
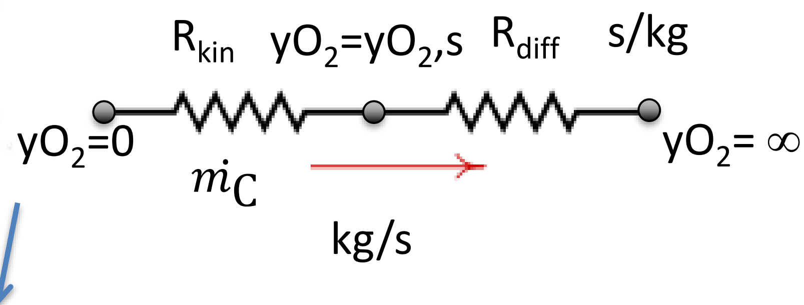


FIGURE 14.3
Species and temperature profiles for one-film model of carbon combustion assuming that CO_2 is the only product of combustion at the carbon surface.

COMBUSTION MODEL – 1 layer



y = mass fraction

Combustion in solids

A.exp (-E_A/R.Ts)

$$R_{kin} = \frac{s}{4\pi r^2{}_s\ \rho k_c}$$

Kinetic rate ~ $3*10^5$exp (-17966/Ts) m/s

Mixture density ρ = *P/(R/M*Ts)*

Mixture molar mass~ 29 kg/kmol

s= M_{O_2}/MC

$$R_{diff} = \frac{s + yO2,s}{4\pi r_s\ \rho D^M}$$

Diffusion rate ~ $1.2*10^{-4}$ m^2/s

0.5 x Particle Diameter

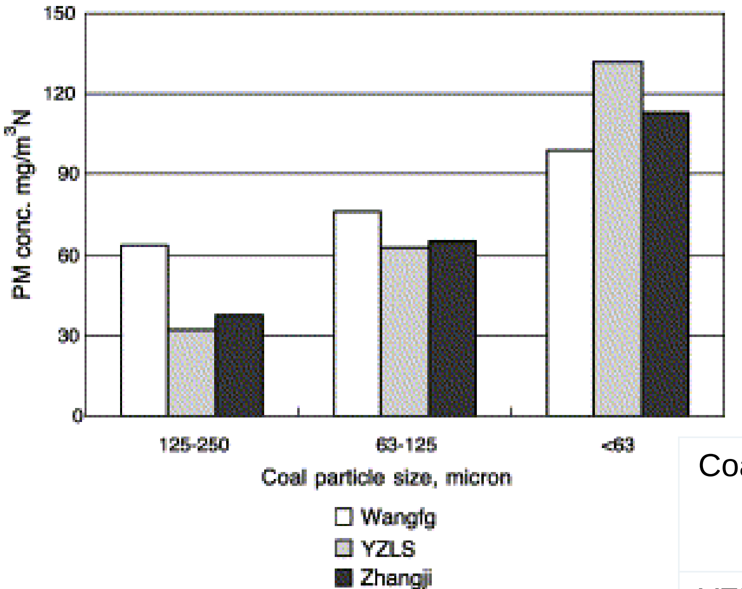
Combustion in solids

Time for burning = D^2/K_B

$$K_B = \frac{8\rho D^M}{\rho_C} \ln\left(1 + \frac{yO2,\infty}{s}\right)$$

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

Control of PM10 and PM2.5

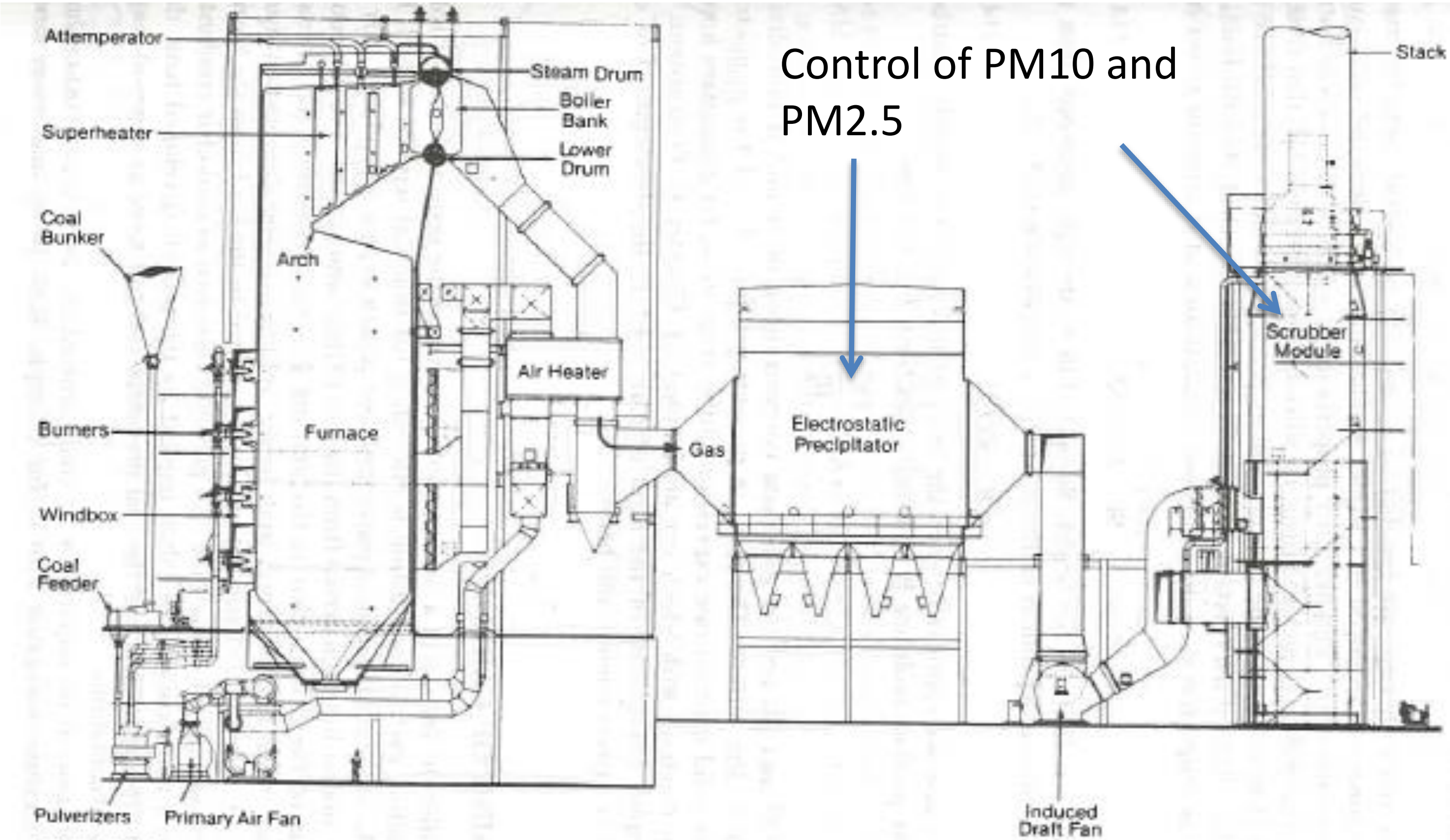


FIGURE 14.1
Pulverized-coal boiler. (Reprinted from Ref. [1] with permission of Babcock and Wilcox Co.)

Combustion in solids

Scrubber "Spray tower"

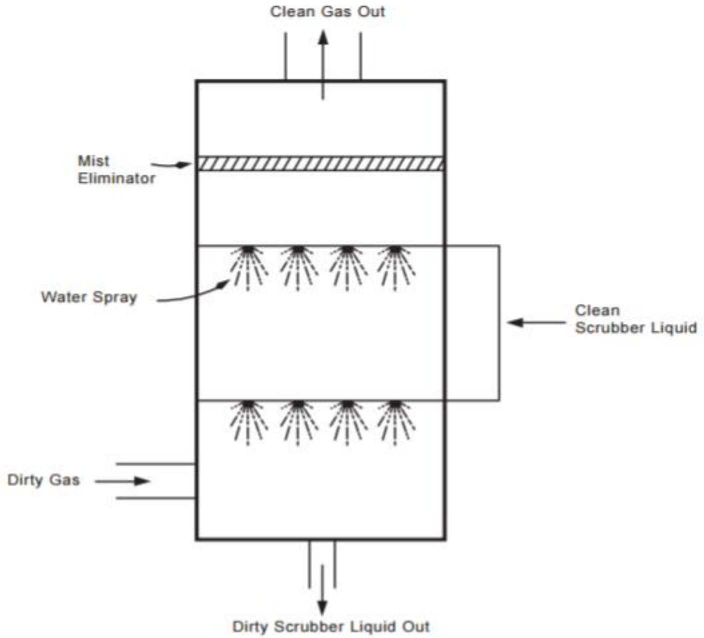


Figure 2.1: Spray Tower [4]

"Cyclonic Spray"

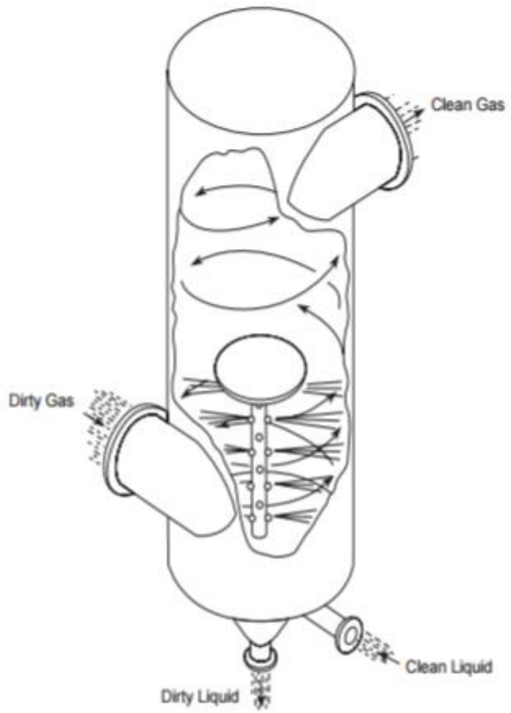


Figure 2.2: Cyclonic Spray Scrubber [3]

Combustion in solids

Combustion of coal main pollutants:
NOx, SO_2 and PM!!!

Emissions

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 SO_2 concentration in the flue gas.

iii) Compare [SO2] with the legislation limits, 3% O_2 200 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%

Emissions

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

a) Determine the **ar** and **daf** ultimate analysis.

b) What is the fuel according to the Seyler diagram?

c) What would be the (A/F)s in mass and molar basis?

d) What will be the first thing that is burned? Estimate its chemical formula.

e) What would be the colour of the flame in a forest fire situation? Justify.

Obrigado

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