COAL FIRED BOILER - PRINCIPALS

Executive Talk : Coal Fired Boiler - Principles

Funded by : Akaun Amanah Industri Bekalan Elektrik (AAIBE)

Presented by:
Bernard Anderson
Principal Process Design Engineer
HRL Technology Pty Ltd.

Presentation Outline

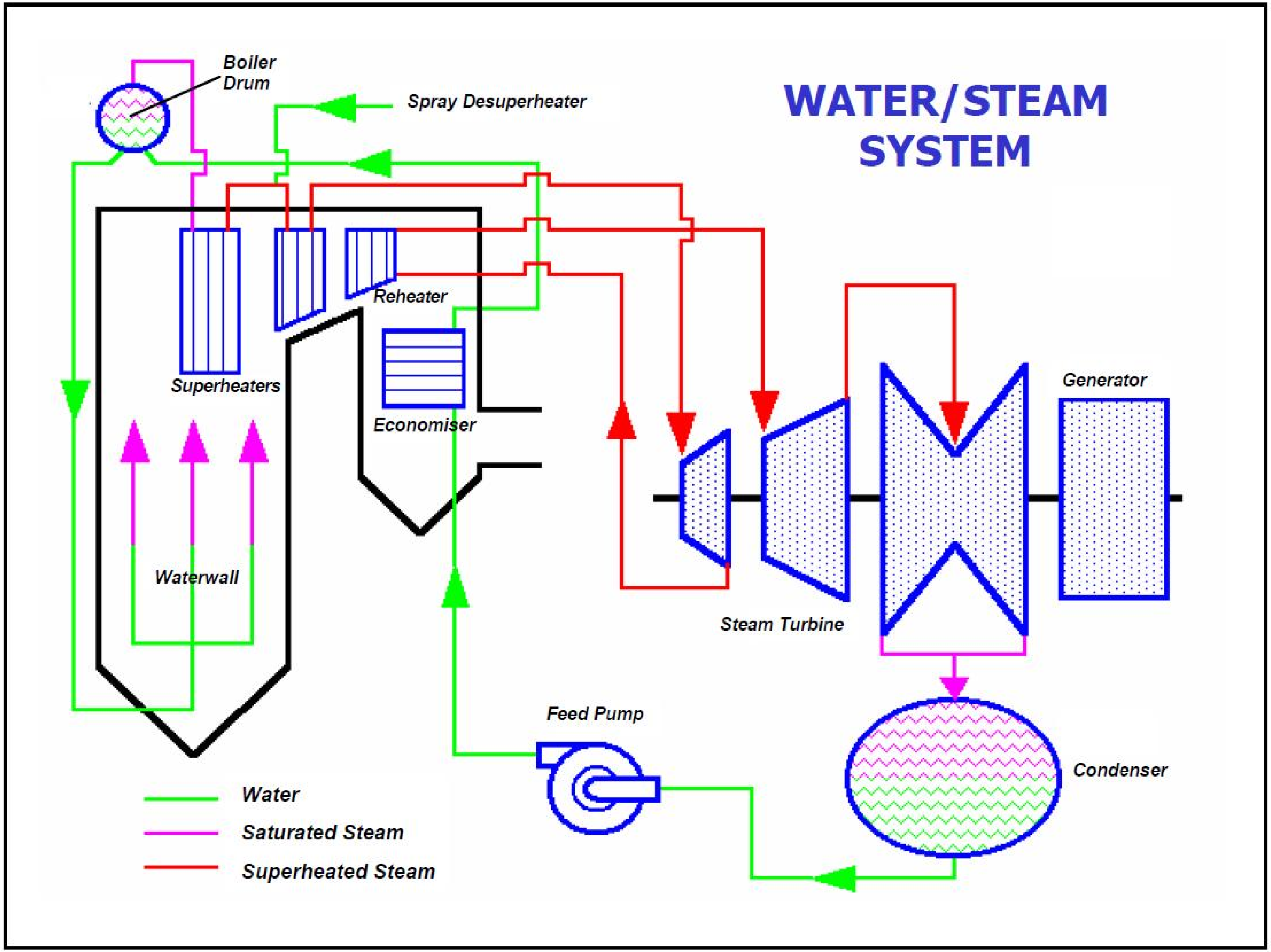
1. Coal Fired Power Plant – Basics
2. Origin and Properties of Coal
3. Influence of Coal Properties on Boiler Operation
4. Effect of Steam Cycle Conditions on Efficiency
5. Problems that can be Caused by Coal in Boilers
6. Examples of Power Plant Problems Caused by Coal

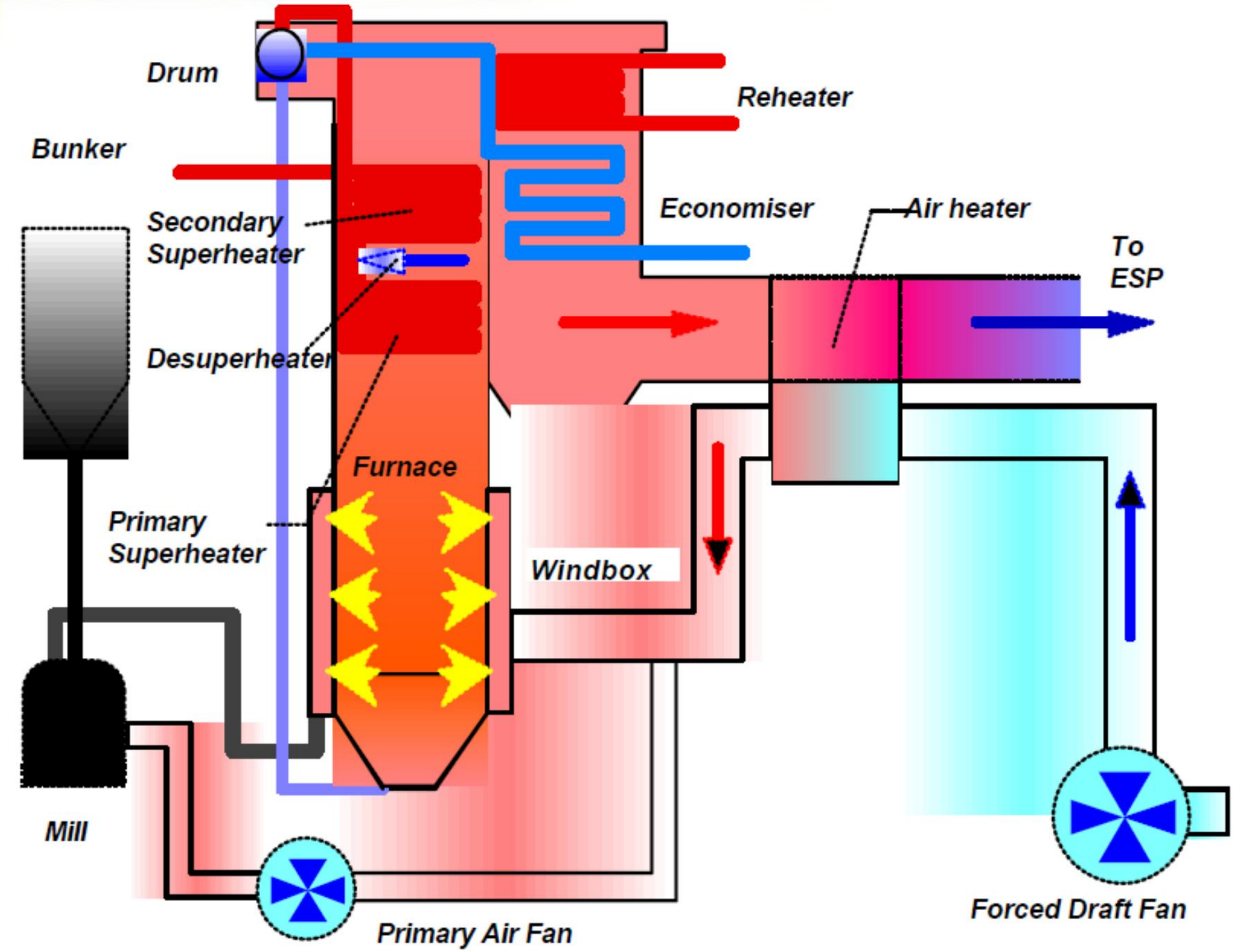
POWER PLANT BOILER

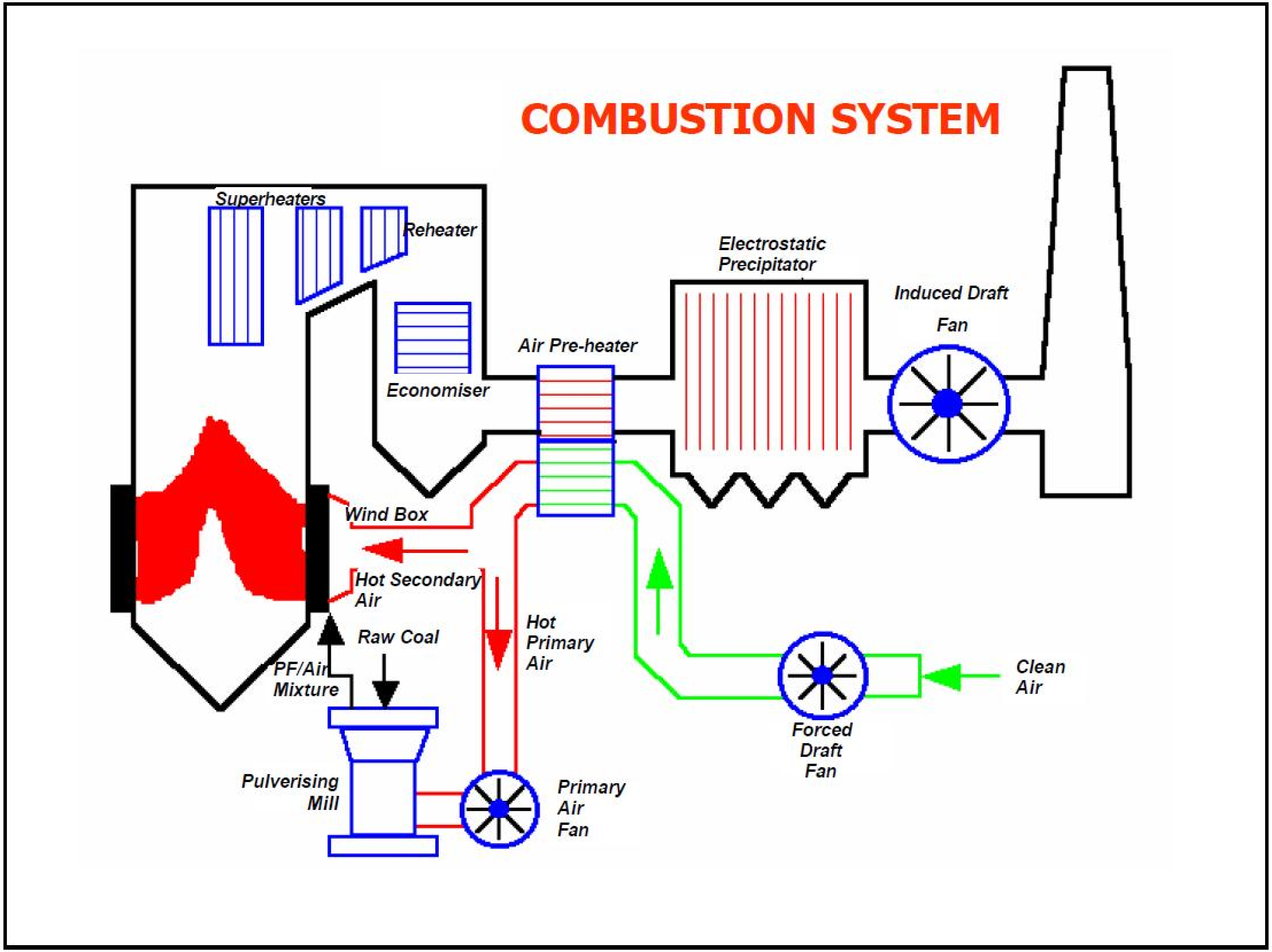
- Produce steam of the specified quality at the desired production rate.
- Contain the combustion process to facilitate heat transfer from the flames and hot gases to the water and steam tubes.
- Facilitate stable combustion conditions for the coal.

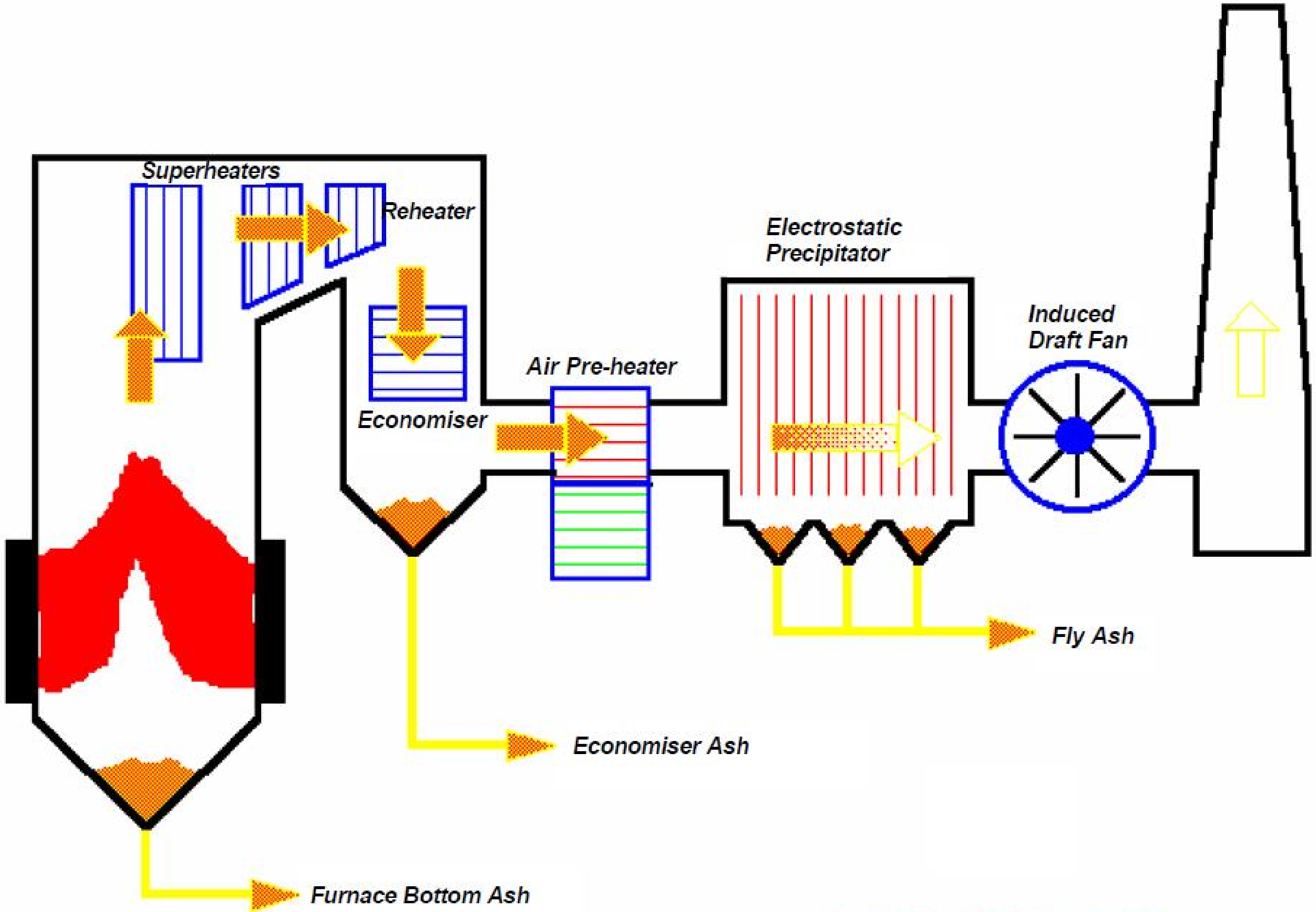
POWER PLANT OPERATING SYSTEMS

- Water/Steam
- Coal/Air/Flue Gas
- Ash


Boiler
Drum
Spray Desuperheater
WATER/STEAM
SYSTEM
Reheater
Superheaters
Economiser
Generator
Waterwall
Steam Turbine
Feed Pump
Condenser
Water
Saturated Steam
Superheated Steam


Drum
Reheater
Bunker
Economiser
Air heater
Secondary Superheater
To ESP
Desuperheater
Furnace
Primary Superheater
Windbox
Mill
Primary Air Fan
Forced Draft Fan


COMBUSTION SYSTEM
Superheaters
Reheater
Economiser
Air Pre-heater
Electrostatic
Precipitator
Induced Draft
Fan
Wind Box
Hot Secondary
Air
Raw Coal
PF/Air
Mixture
Hot
Primary
Air
Clean
Air
Forced
Draft
Fan
Pulverising
Mill
Primary
Air
Fan


Superheaters
Reheater
Electrostatic Precipitator
Induced Draft Fan
Air Pre-heater
Economiser
Fly Ash
Economiser Ash
Furnace Bottom Ash

ASH SYSTEM

Power Station Videos

- ..\Videos\Coal Fired Power Plant.mp4
- ..\Videos\How a thermal power plant works.mp4

The energy experts The energy experts

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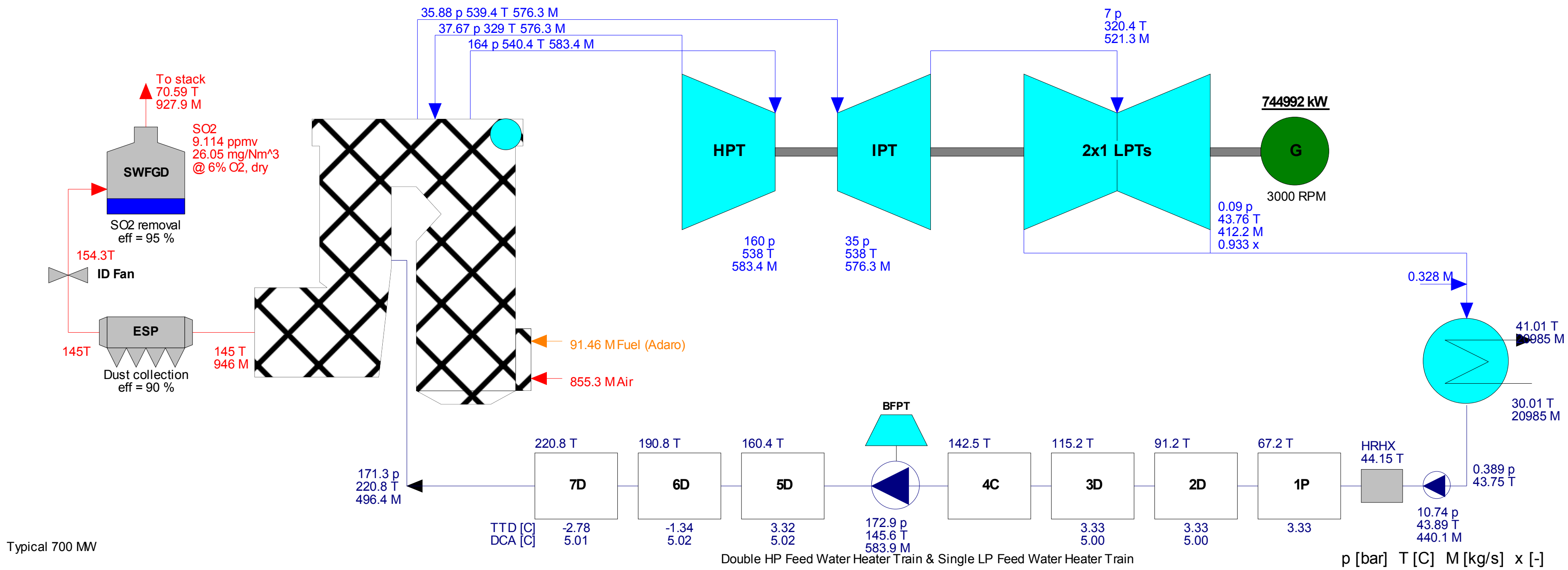
Power Plant Overview

Plant gross power	744992	kW
Plant net power	701303	kW
Number of units	1	
Plant net HR (HHV)	10235	kJ/kWh
Plant net HR (LHV)	9632	kJ/kWh
Plant net eff (HHV)	35.17	%
Plant net eff (LHV)	37.37	%
Aux. & losses	43689	kW
Fuel heat input (HHV)	1993778	kJ/s
Fuel heat input (LHV)	1876453	kJ/s
Fuel flow	7902	t/day

Ambient
1.013 p
30 T
80% RH
27.09 T wet bulb



STEAM PRO 25.0 Bernie HRL Technology Pty Ltd.
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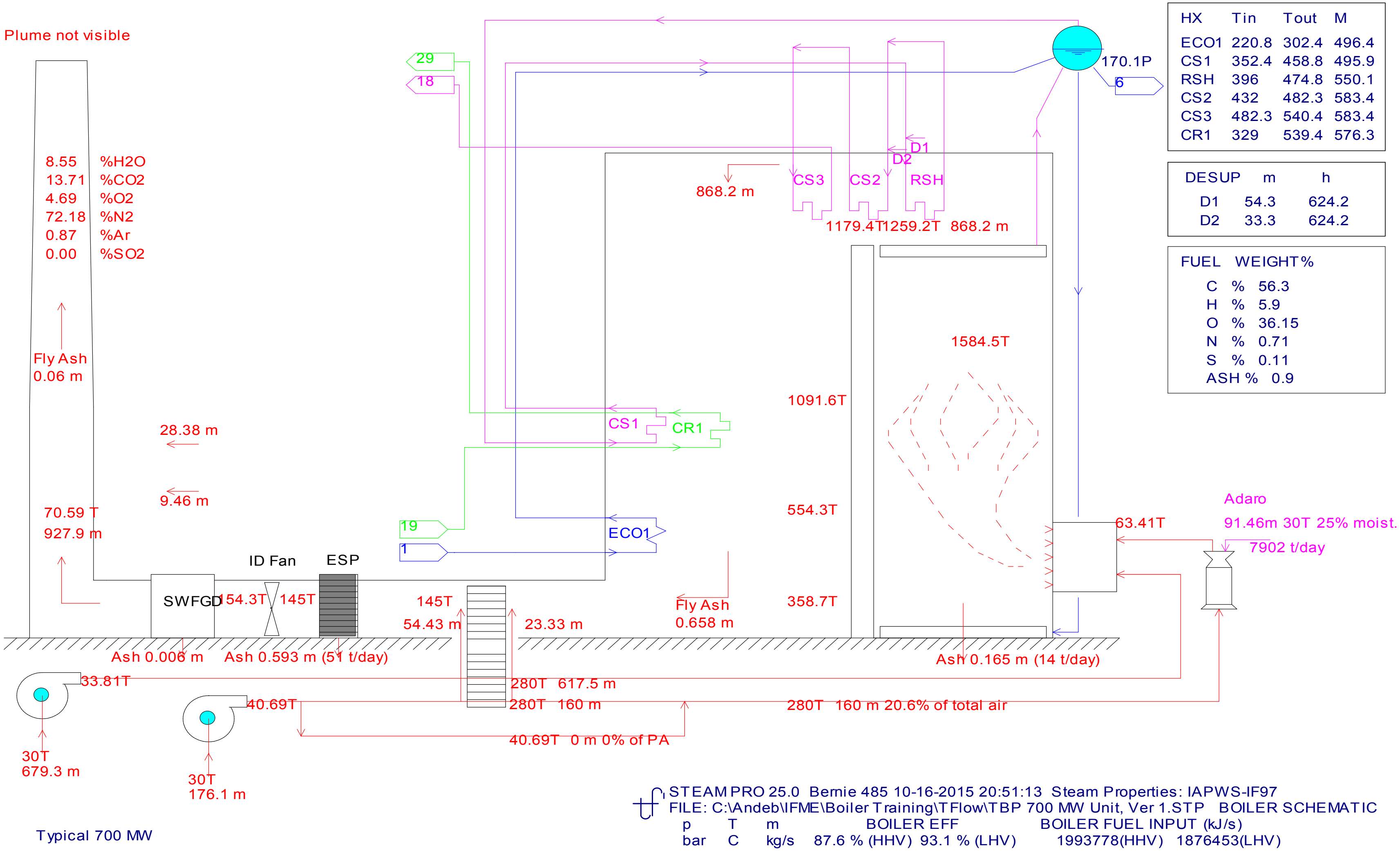
Boiler Details



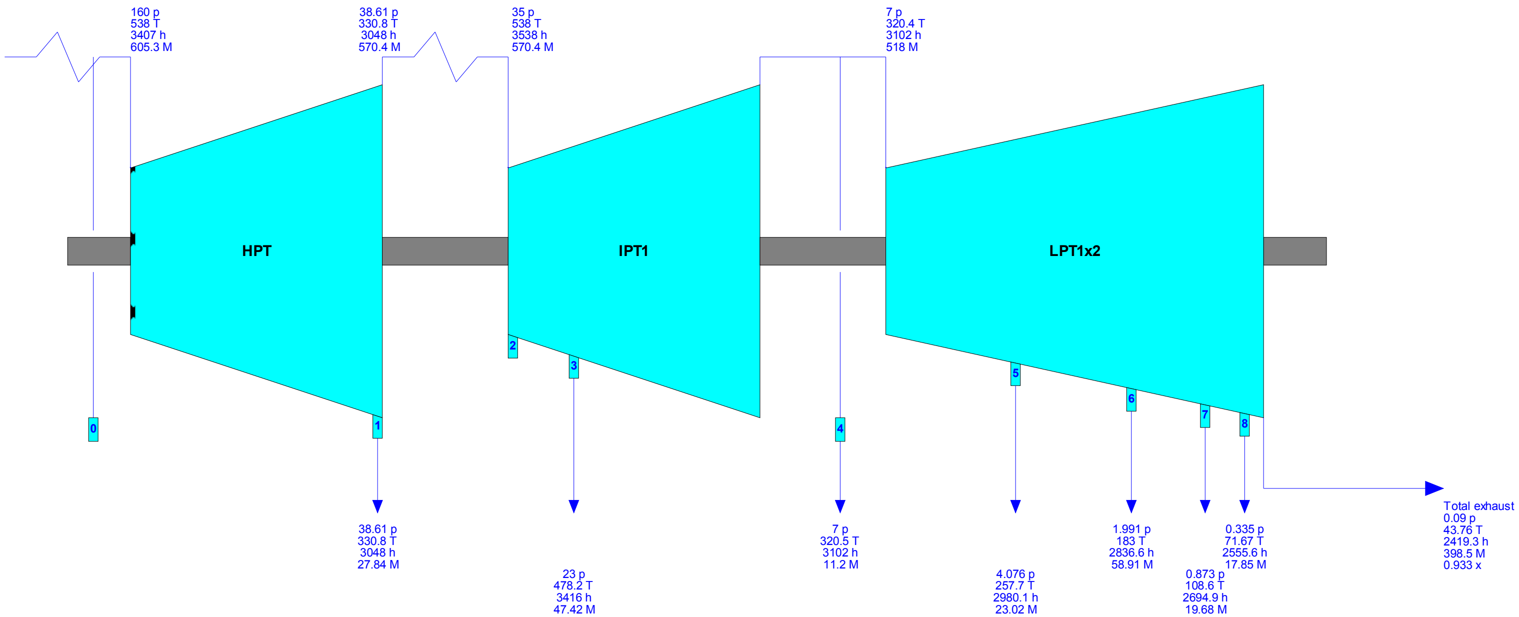
HX	Tin	Tout	M
ECO1	220.8	302.4	496.4
CS1	352.4	458.8	495.9
RSH	396	474.8	550.1
CS2	432	482.3	583.4
CS3	482.3	540.4	583.4
CR1	329	539.4	576.3

DESUP	m	h
D1	54.3	624.2
D2	33.3	624.2

FUEL	WEIGHT%	
C	%	56.3
H	%	5.9
O	%	36.15
N	%	0.71
S	%	0.11
ASH	%	0.9

Turbine Details

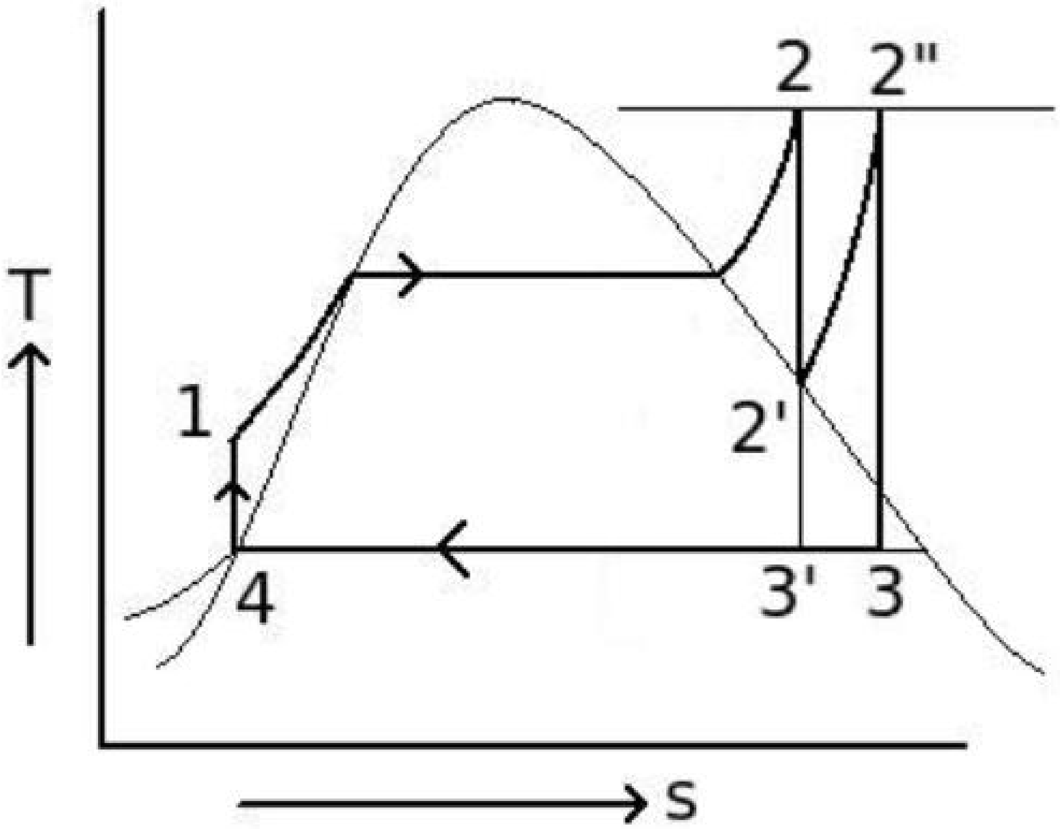
Expansion power	758300	kW
Mechanical loss	2448.6	kW
Generator loss	10959	kW
Generator power	744893	kW



Typical 700 MW

p [bar] T [C] h [kJ/kg] M [kg/s] x [-]

Rankine Cycle with Reheat



T-s Diagram of Rankine Cycle with Reheat

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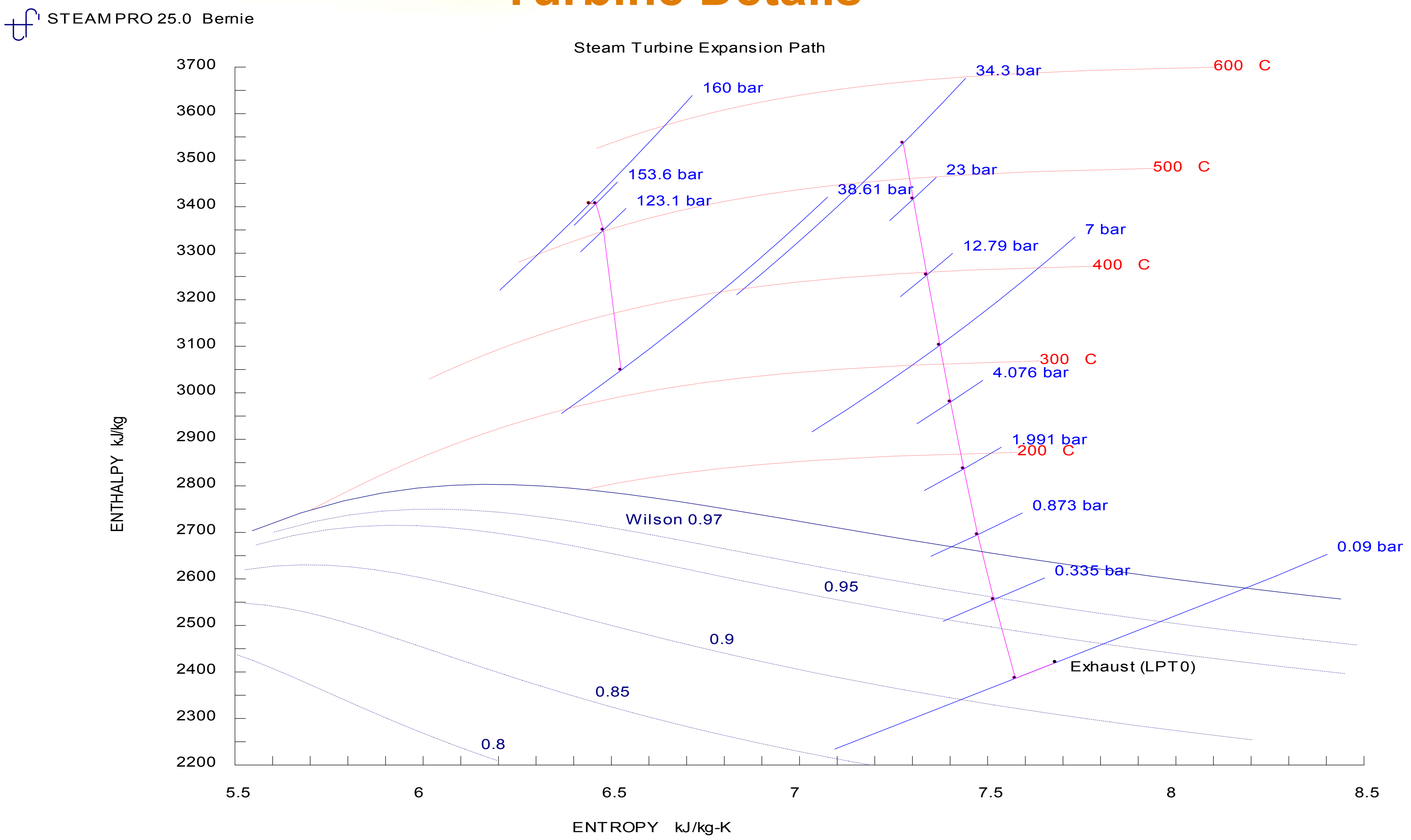
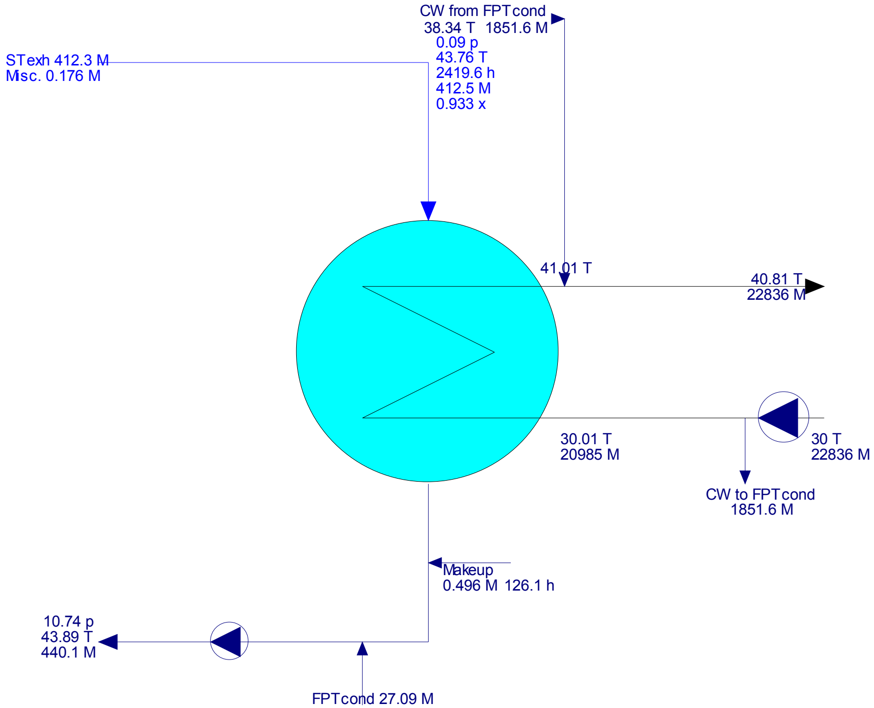
Turbine Details



Power Plant Details

Condenser heat rejection	922497	kJ/s
Condensate pump power	697.1	kW
Condenser CW pump power	4225	kW



Typical 700 MW

p [bar] T [C] h [kJ/kg] M [kg/s] x [-]

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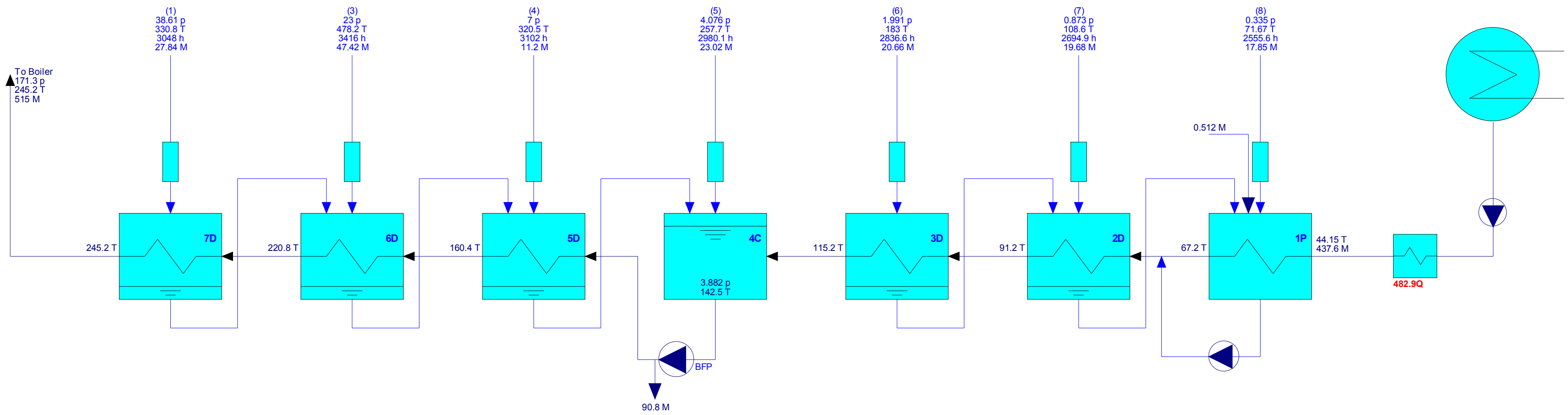
Feed Water Details

Double HP Feed Water Heater Train & Single LP Feed Water Heater Train



Typical 700 MW

p [bar] T [C] h [kJ/kg] M [kg/s] Q [kJ/s] x [-]

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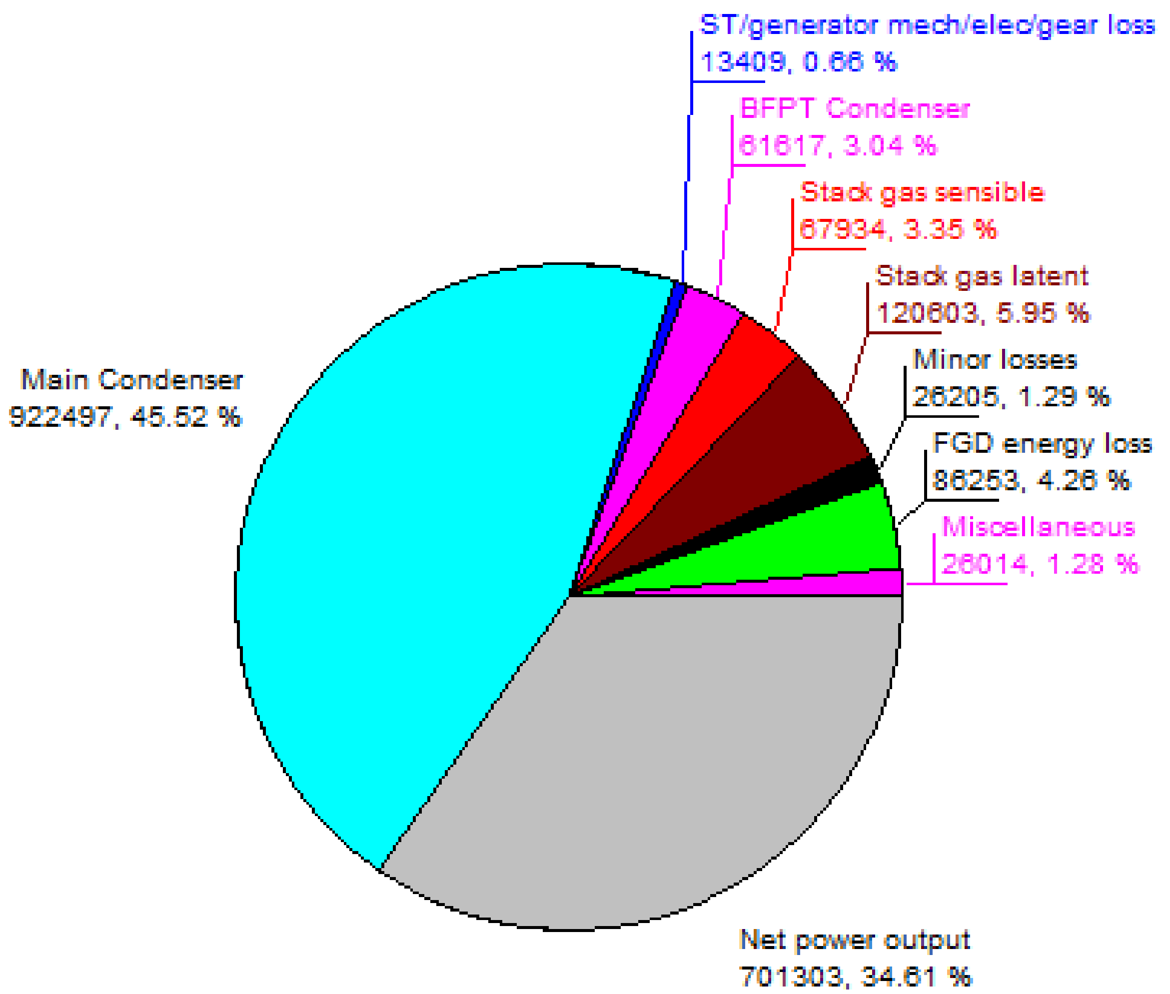
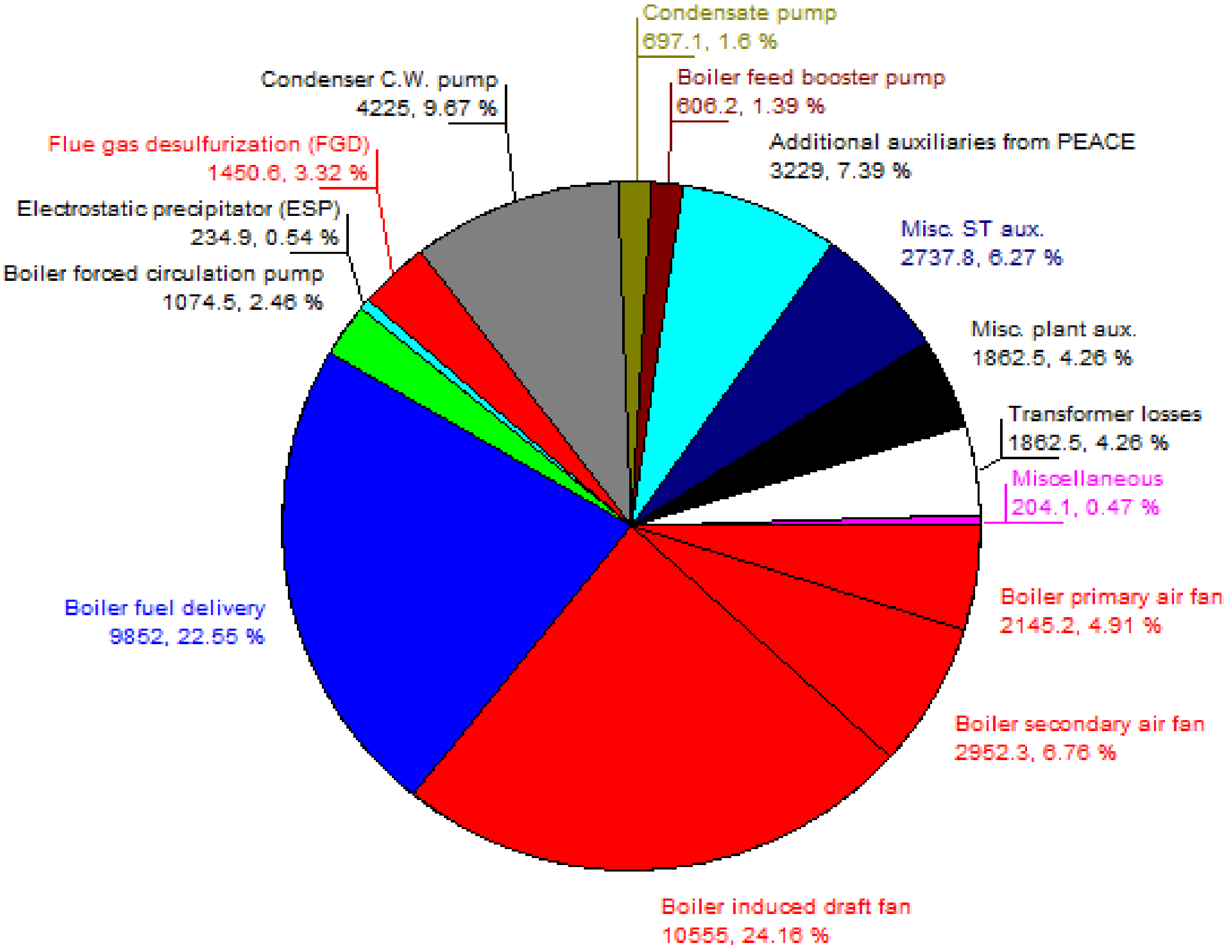
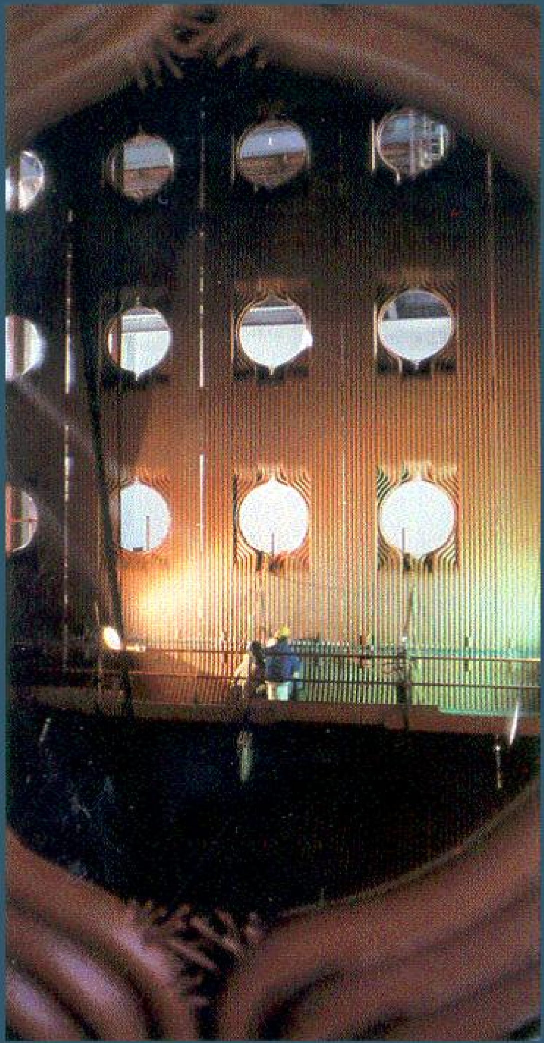
Unit Energy Outputs



Unit Auxiliaries and Losses





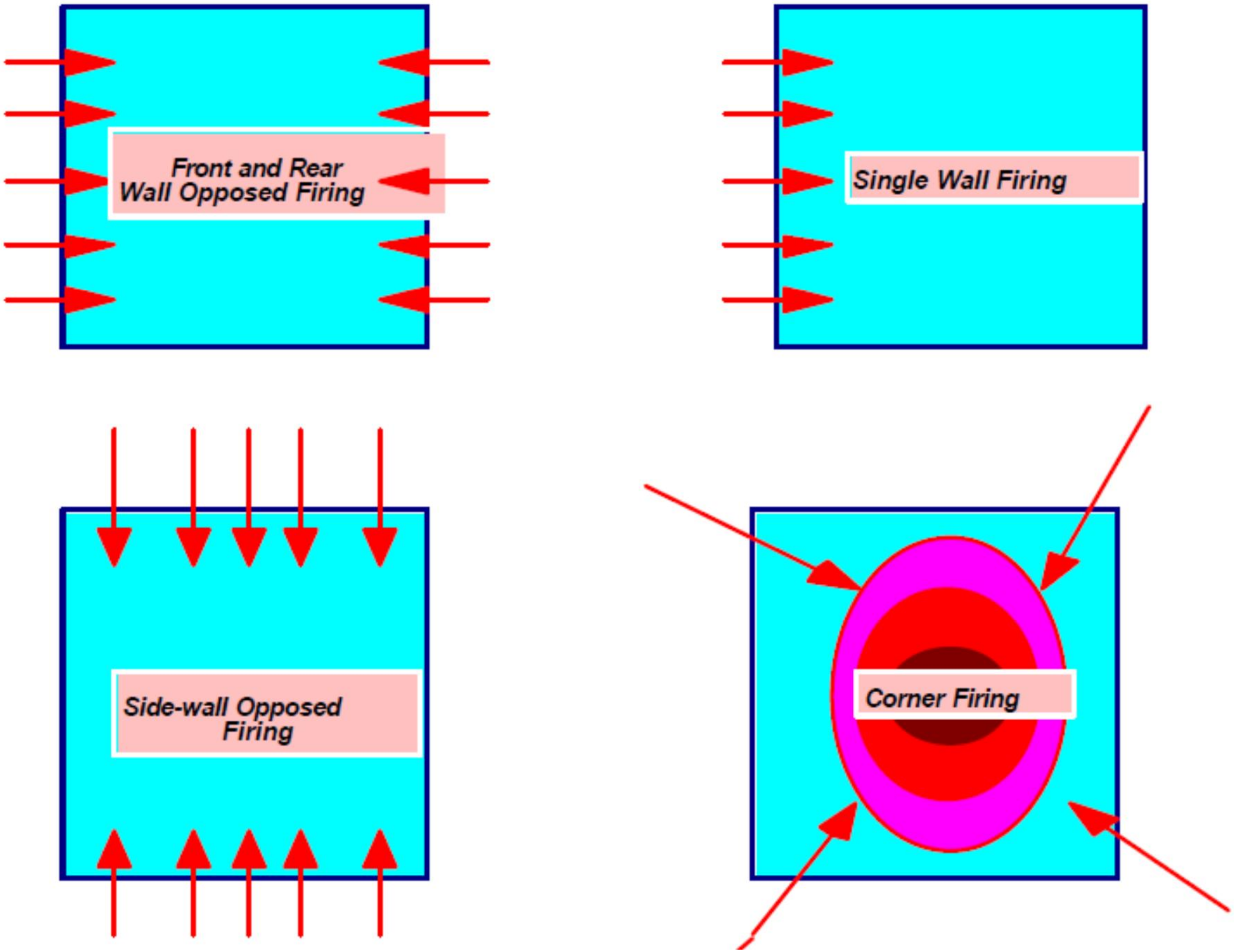
BOILER UNDER

CONSTRUCTION

POWER PLANT BOILER

Main types of firing arrangements:

- Swirl burners - opposed and single wall fired.
- Slot burners - corner fired.


Front and Rear
Wall Opposed Firing
Single Wall Firing
Side-wall Opposed
Firing
Corner Firing

Coal Formation and Mining Videos

- ..\Videos\The Formation of Coal 3D.mp4
- ..\Videos\How Its Made Coal.mp4
- ..\Videos\PT Adimitra Baratama Nusantara.mp4 (2:30)

Coal Rank

- Initially Malaysia's coal fired power stations only used Bituminous coals.
- Increasing cost has lead to increasing use of lower rank coals which are cheaper and readily available.
- Existing coal fired boilers can co-fire various grades of sub-bituminous coals.
- Manjung 4 and TBP 4 designed for 100% lower grade sub-bituminous coals.

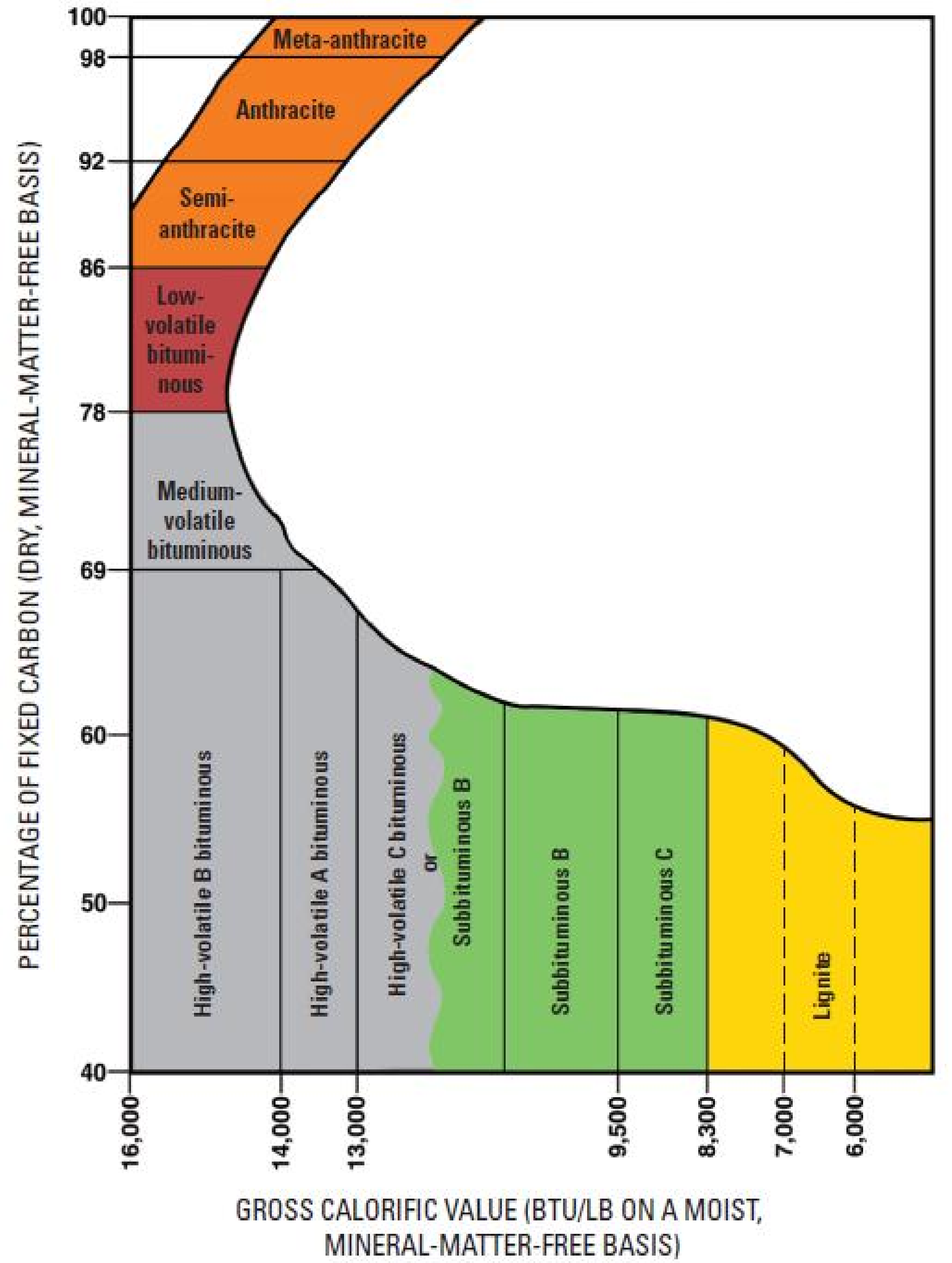
Manjung 4 Specifications

MANJUNG 4 – TECHNICAL SPECIFICATIONS

TECHNICAL DATA OF STEAM GENERATOR	GUARANTEE	MODE OF OPERATION
Main steam flow	3226 metric tons/hr | 7111 M Lb/hr	• Sliding pressure operation with daily load swings from 30% to 100%
Superheater outlet steam pressure	282 barg | 4090 psig	
Superheat/reheat steam temperature	600 °C / 605 °C | 1112 °F/1121 °F	

FUEL (AS RECEIVED)	DESIGN	RANGE	
Gross calorific value (kcal/kg) (Btu/Lb)	5200 9360	4500 – 5500 8100 – 9900	**AIR HEATER** • 2x trisector semi-modular • Regenerative air heaters
Moisture content (%wt)	22.1%	8% – 30%	**AIR AND FLUE GAS SYSTEMS**
Ash content (%wt)	1.6%	1.5% – 13.9% 1.1% – 15%	• 2x 50% primary air fans • 2x 50% induced draft fans • 2x 50% forced air draft fans
Sulphur (%wt)	0.47%	0.1% – 0.94%	**GRINDING AND FIRING PLANT**
Volatile matter (%wt)	35%	22% – 45%	• 8 gravimetric raw coal feeders • 8 HP 1023 pulverisers with dynamic classifiers
Fixed carbon (%wt)	41%	35% – 58.1%	

FLUE GAS EMISSION LEVELS AT STACK	MG/NM3 @ 6%O2	LB/MMBTU
Sulfur dioxide (SO_2)	500	0.41
Nitrogen oxides (NO_x)	500	0.41
Carbon monoxide (CO)	200	0.16



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Coal Rank Classification Chart

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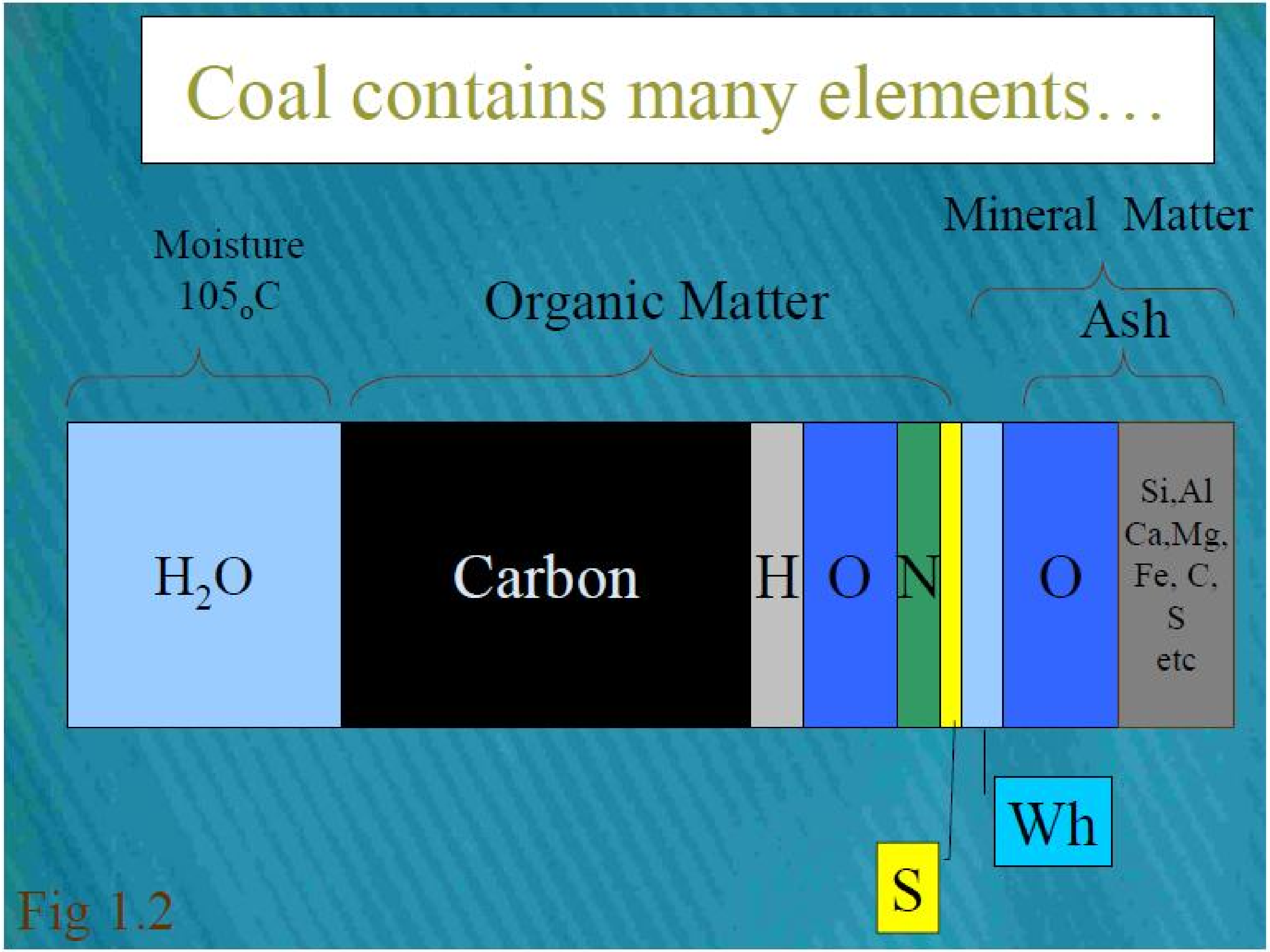
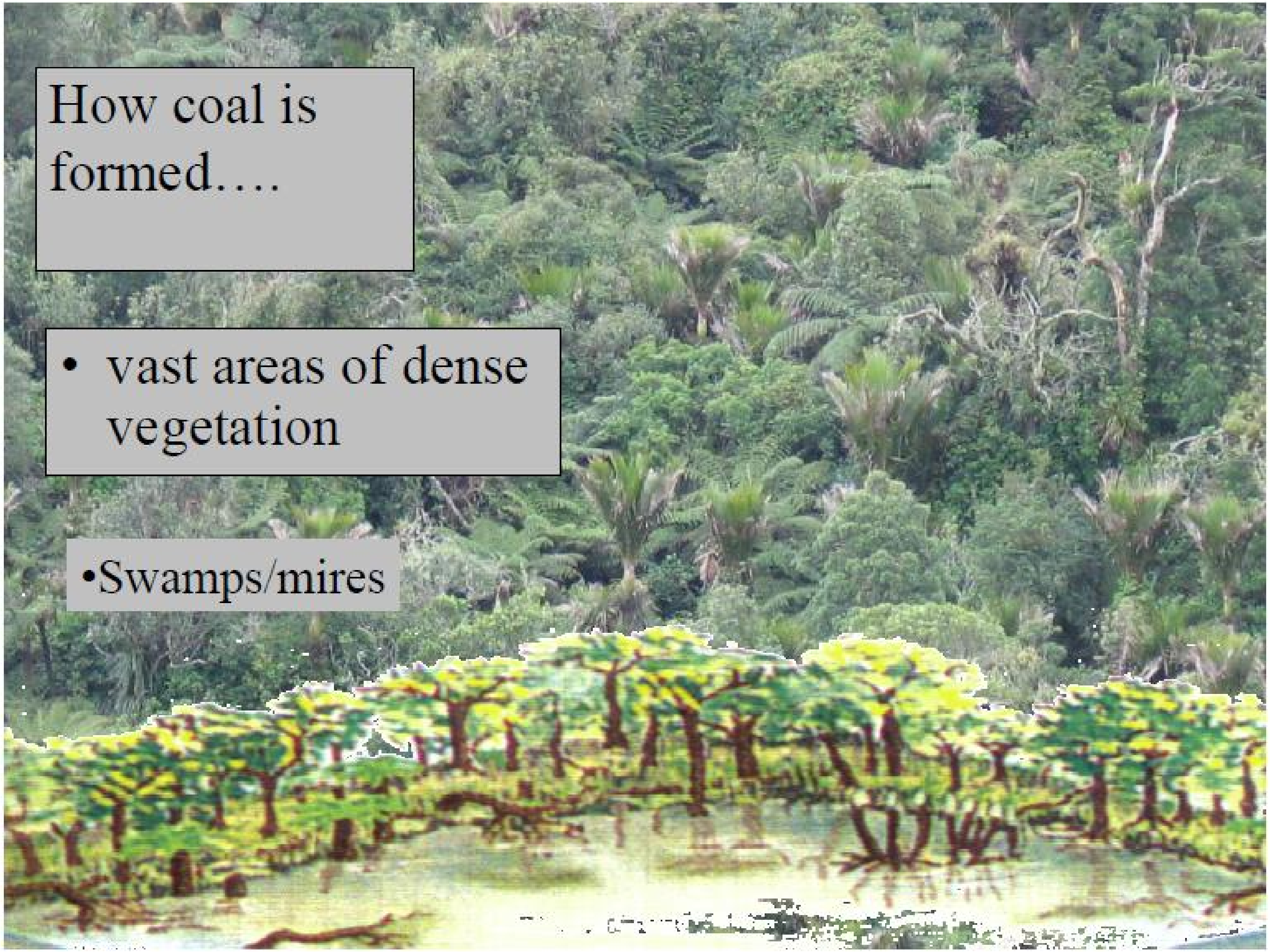
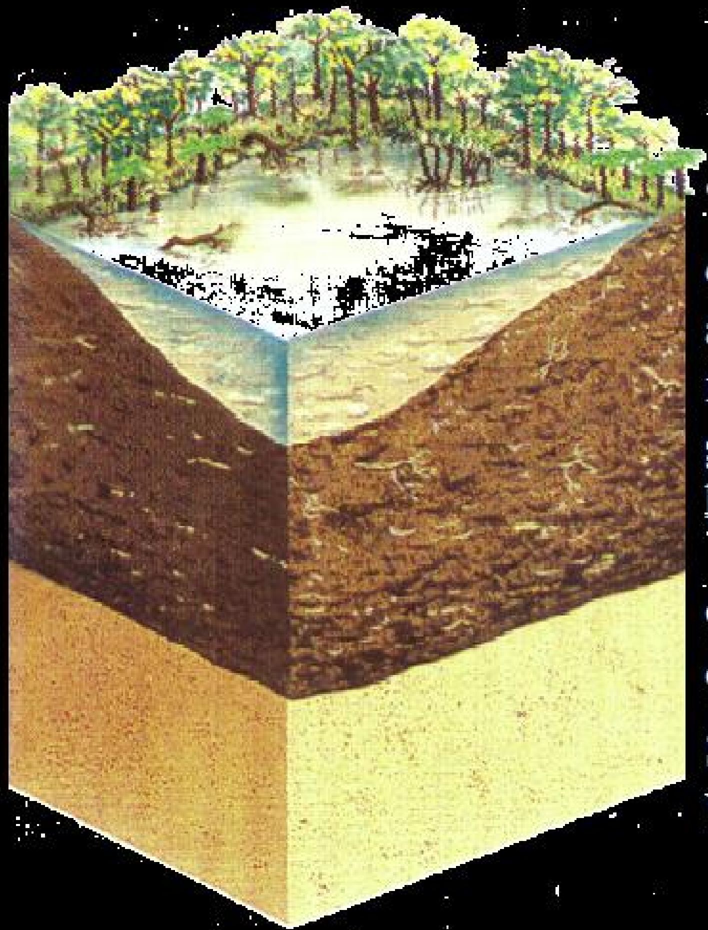
Coal Rank



Coal Formation



Coal Formation

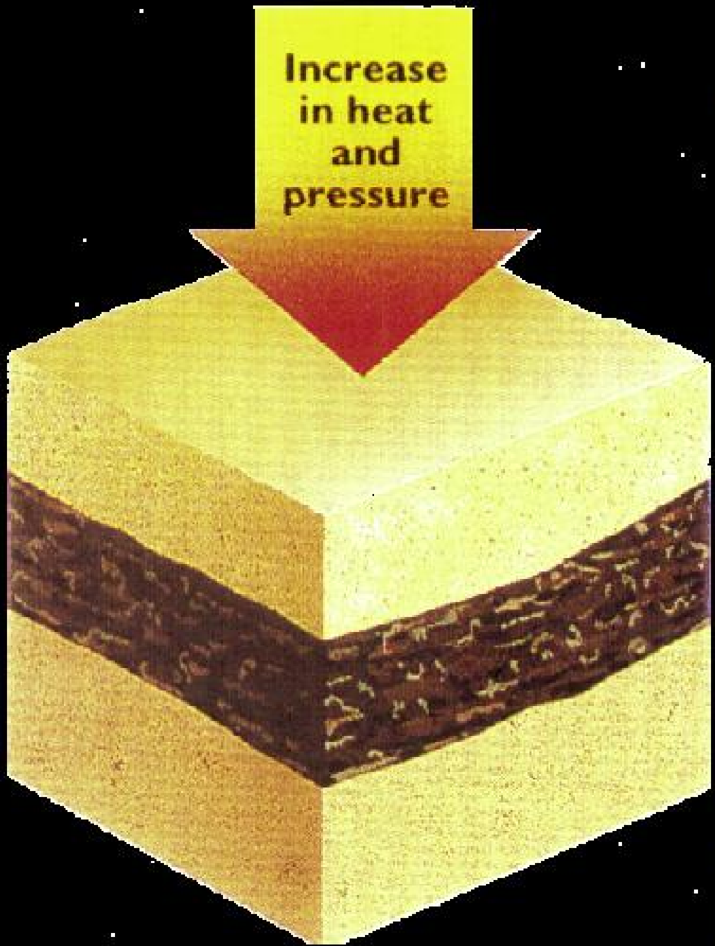


Peat

"humification"[1] – oxidation of plant matter and attack by aerobic organisms (bacteria, fungi, insects). **Hydrocarbons given off**, remaining plant tissue higher in oxygen and carbon.

% Carbon = 60% daf
% Volatile matter >60%
SE (gross) MJ/Kg = 15
Vitrinite Reflect.(max) = 0.2%

Coal Formation

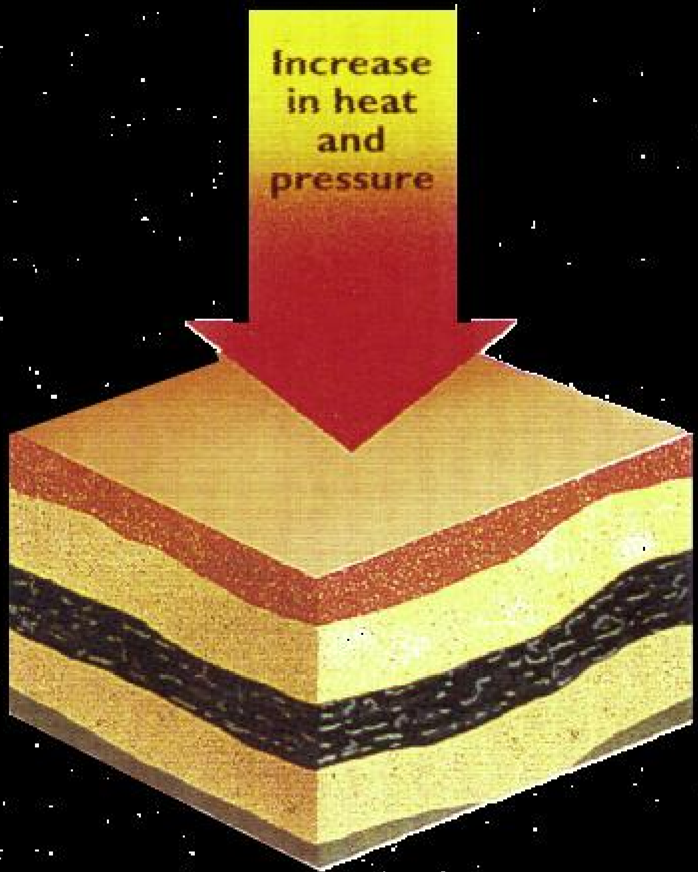


Lignite

Continued Biochemical Decomposition of plant Matter, Burial (water and/or sediment) of plant matter reduces access by oxygen.
Anaerobic organisms extract oxygen from plant tissue.
Some physico-chemical decomposition due to heat and pressure – structural and chemical changes.

Heating value increases.
% Carbon = 71% daf
% Volatile matter = 52%
SE (gross) MJ/Kg = 23
Vitrinite Reflect.(max) = 0.4%

Coal Formation



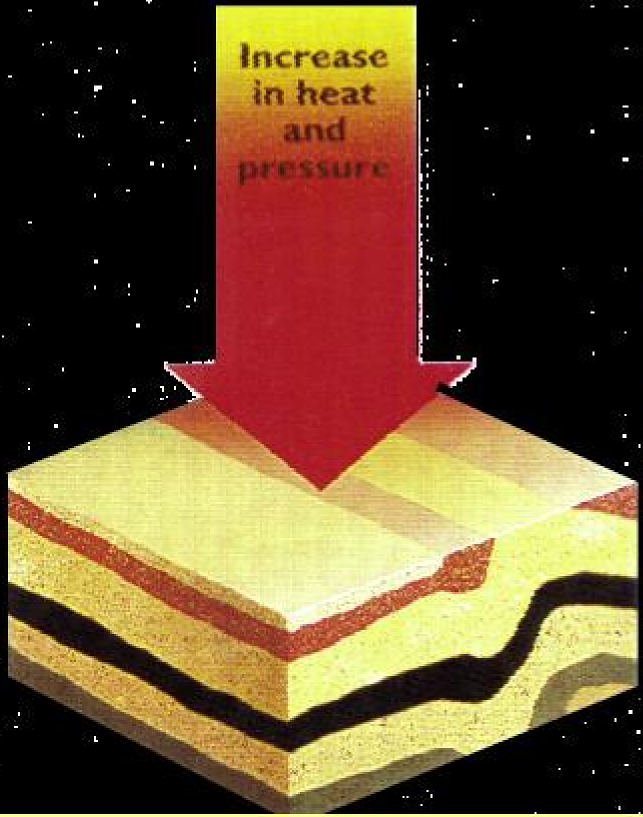
Sub-bituminous

Humic substances polymerised. Proportion of fixed carbon significantly increased. Energy value higher.
Physico-chemical changes more prominent due to depth (pressure and temperature) and time of burial.(structure and chemistry changes)

% Carbon = 80% daf
% Volatile matter =40%
SE (gross) MJ/Kg = 33.5
Vitrinite Reflect.(max) = 0.60%

Coal Formation

Bituminous



- Mostly Physico –Chemical decomposition.
- Water squeezed out, O_2 and H_2 released, then CH_4
- % Carbon = 86-90% daf
- % Volatile matter = 31-14%
- SE (gross) MJ/Kg = 35.6-36.4
- Vitrinite Reflect.(max) = 1.03-1.97%

...and so on, until anthracite is produced

Coal Rank

The Coalification Process.

With increasing pressure, temperature and time

	Composition Wt % (daf)		
	CARBON	HYDROGEN	OXYGEN
WOOD	49	7	44
PEAT	60	6	34
LIGNITE	70	5	25
SUB-BITUMINOUS	75	5	20
BITUMINOUS	85	5	10
ANTHRACITE	94	3	3

Effects of Coal Rank on a Boiler
Low Rank Coal Compared to Higher Rank Coal

- Lower Heating value – more coal, more air and more fluegas – ID Fan capacity limit.
- Higher moisture content – more fluegas.
- More mill primary air required.
- Easier to mill – better combustion
- Higher volatiles – better combustion
- Increased SH and RH steam temperatures.
- Can have higher alkali in ash – sintered ash deposits in superheater and reheater sections.
- Usually good ESP performance.

Effects of Coal Rank on a Boiler
Low Rank Coal Compared to Higher Rank Coal

- Can have alkali elements directly attached to coal molecules rather than in the ash minerals such as clay, silica, alumina.
- As a result the ash can have a high content of reactive sodium, potassium, calcium, iron and magnesium.
- These elements can cause slagging in the furnace and solidification of sintered deposits on the SH and RH tubes.
- Behaviour of the ash can be more variable and less predictable than for higher rank coal.
- Difficult to eliminate the problem with tighter coal specifications.

PLANT PERFORMANCE

Behaviour is affected by:

- Coal Properties
- Plant Design
- Method/Pattern of Operation

Power Plant Performance
Influence of Coal Properties

- Thermal Efficiency
- Availability
- Capacity
- Turn Down Capability
- Environmental

Influence of Coal Properties

Thermal Efficiency

- Carbon in Ash
- Moisture in Coal
- Heat in Flue Gas
- Excess Air / Air Heater Leakage

Influence of Coal Properties

Availability

- Slagging
- Fouling
- Erosion

Influence of Coal Properties

Capacity

- Coal Pulverising Limitation
  - Throughput
  - Mill outlet temperature
- Deposit Formation
- Emissions
  - NOx
  - Particulate

Influence of Coal Properties

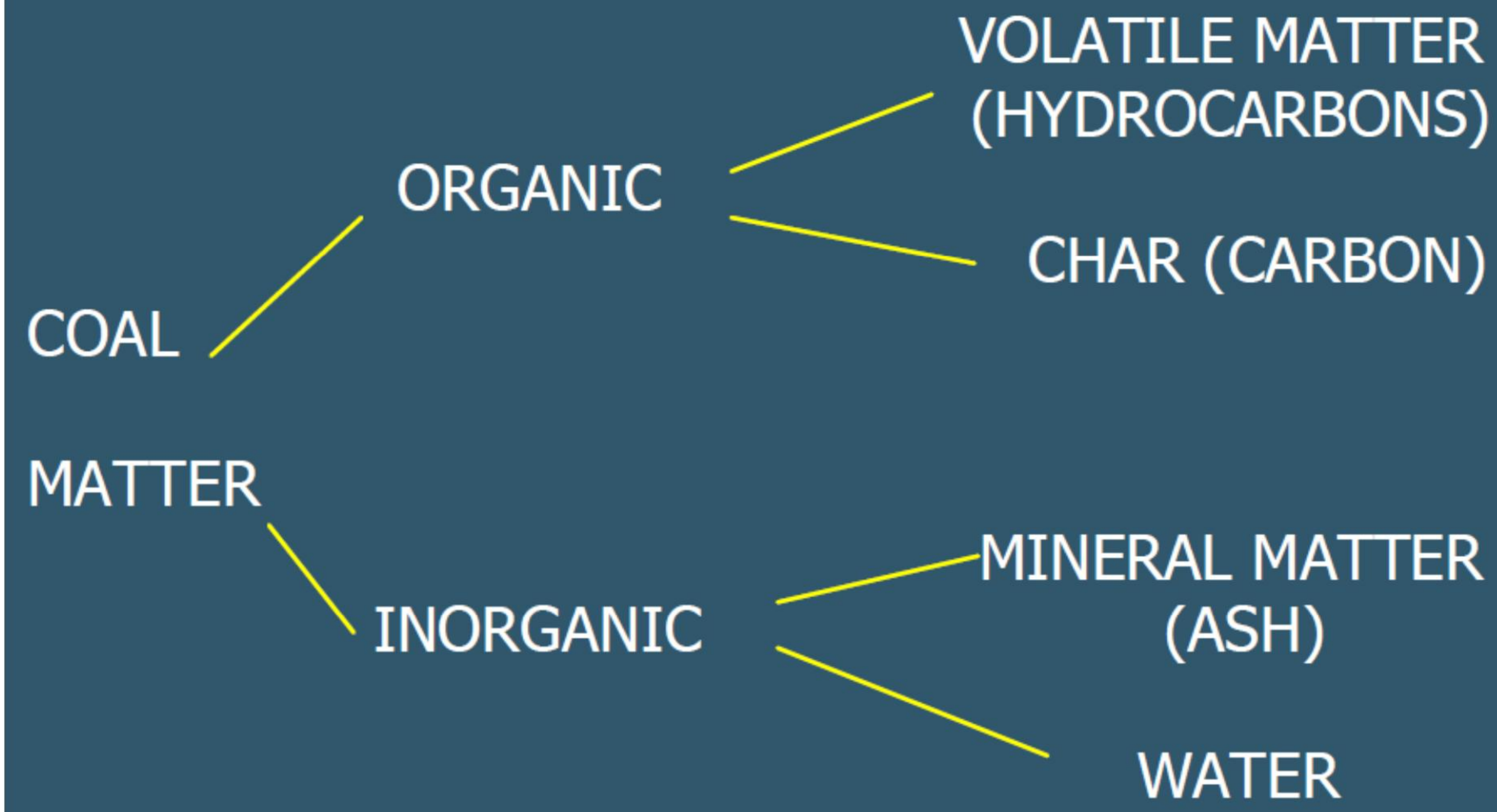
Boiler Turn Down Capability

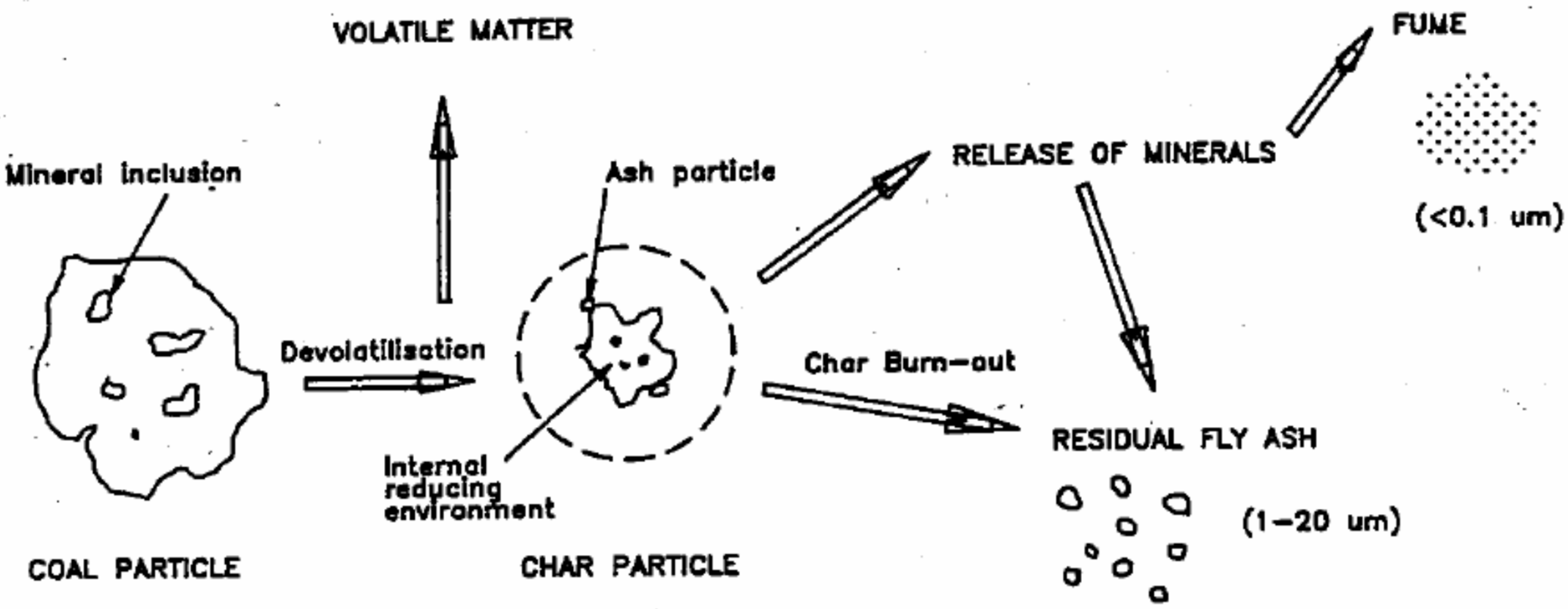
- Coal Ignitability
- Fineness of Coal Grind

Influence of Coal Properties

Environmental

- Particulates
- NOx
- SOx
- CO2
- Ash Storage


COAL
MATTER
ORGANIC
INORGANIC
VOLATILE MATTER
(HYDROCARBONS)
CHAR (CARBON)
MINERAL MATTER
(ASH)
WATER


VOLATILE MATTER
FUME
Mineral inclusion
Ash particle
RELEASE OF MINERALS
(<0.1 um)
Devolatilisation
Char Burn-out
Internal
reducing
environment
RESIDUAL FLY ASH
(1-20 um)
COAL PARTICLE
CHAR PARTICLE

	Products	Combustion
COAL ORGANICS	VOLATILE MATTER (HYDROCARBONS)	Rapid, Complete
	CHAR (CARBON)	Slow, Incomplete

Volatile Matter

- Rapid Release & Combustion (50 milliseconds)
- Quantity of VM may be much higher than the Proximate VM
- Quantity influenced by:

– temperature (1500 °C)

– heating rate (10^5 °C/s)

High VM gives High Combustion Reactivity:

- Rapid combustion helps ignition
- Less char remaining
- Char more reactive

Char remaining after devolatilisation

- Relatively slow combustion (some remaining after 3 seconds)
- Size, porosity, density, chemical reactivity all important
- Mix of particle types

PREDICTION OF A COAL'S PERFORMANCE

Testing at Different Scales

- Standard Laboratory Analysis

  Proximate, Ultimate, HGI etc

- Bench & Pilot-Scale

  Attempt to simulate power plant processes better

- Full-scale trial burns

Stages & Scales of Coal Evaluation

	Lab. Analysis	Bench Scale Tests	Pilot Scale Tests	Power Station Tests
Precision				
Accurate Simulation				
Cost				
Sample Requirements				
Initial Resource Assessment	✣			
Geological Mapping for Coal Quality	✣	✣		
Pre-Treatment & Washability Studies	✣	✣	✣	
Trial Pit	✣	✣	✣	✣
Commercial Mining & Preparation	✣	✣	✣	✣

Standard Laboratory Analysis

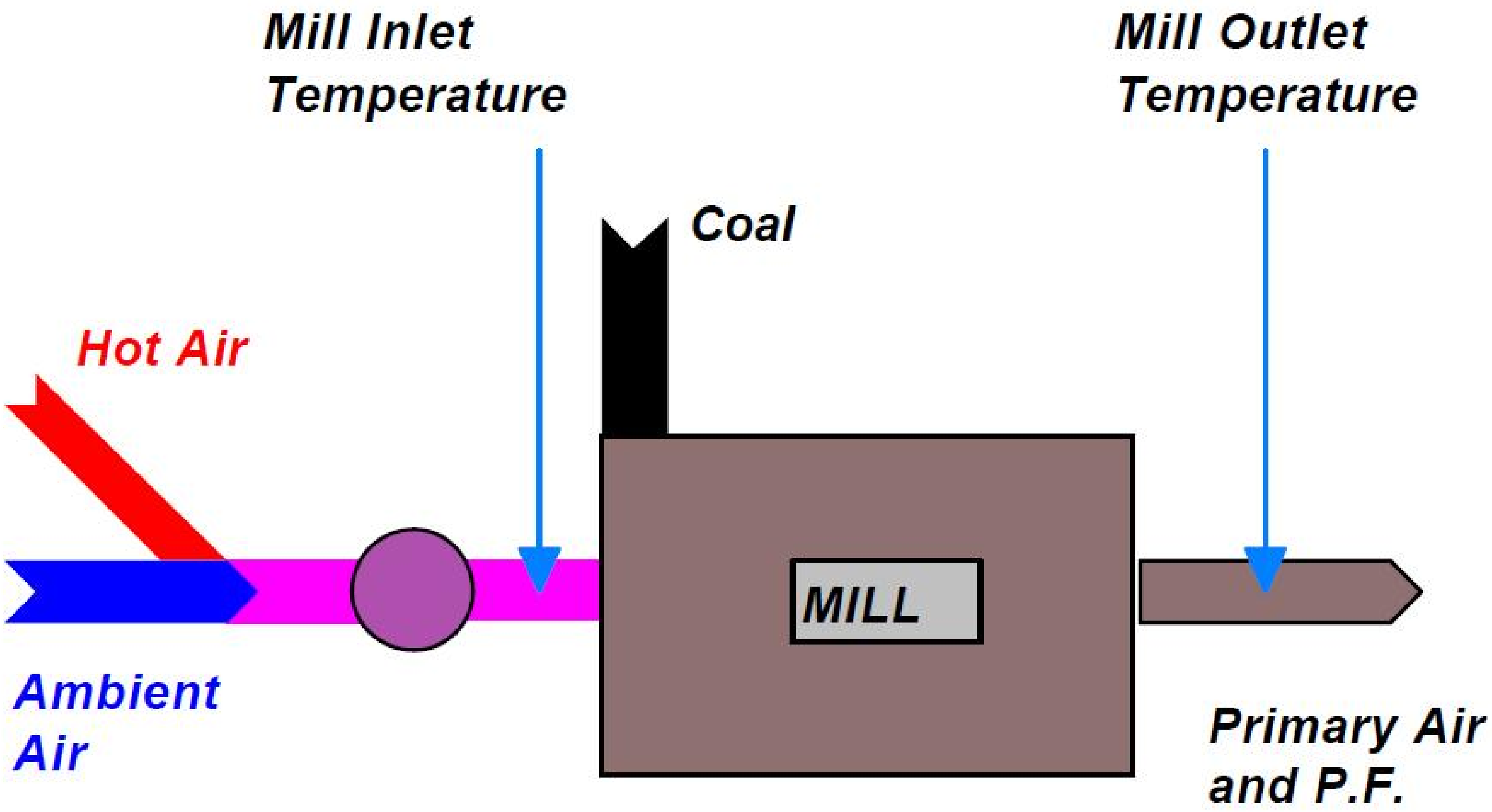
- Wide recognition
- Most suitable for contractual coal specifications
- Provides data in coal variability
- Helps to identify features of a coal that may need pilot-scale evaluation

But

- Simulation of real processes may be poor

PULVERISING MILLS

- *Pulverise coal (typically to 70% < 75 um, or finer).*
- *Dry the coal to assist with grinding, transport and combustion.*
- *Convey the pulverised coal to the boiler.*

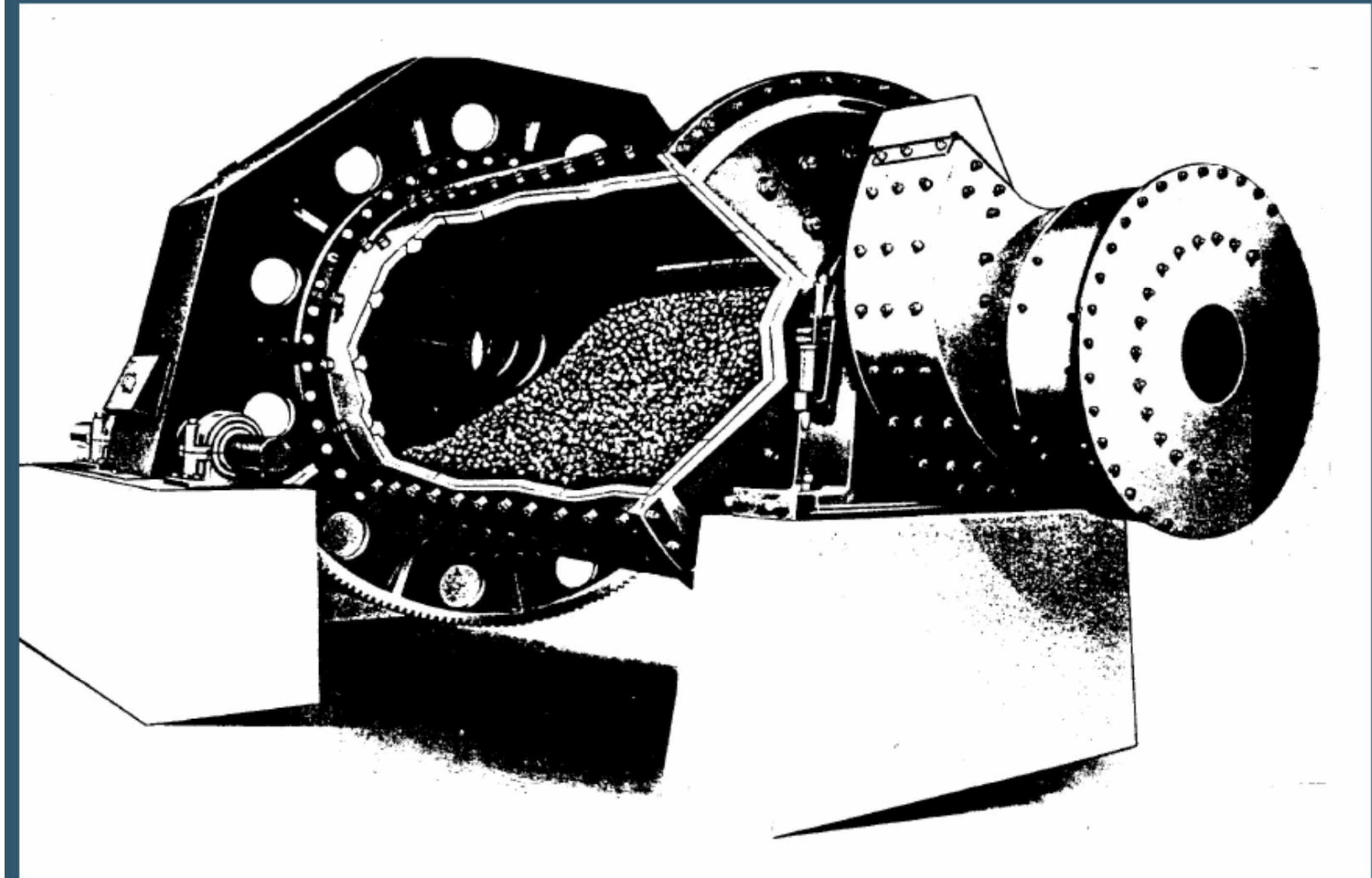

Mill Inlet Temperature
Mill Outlet Temperature
Coal
Hot Air
MILL
Ambient Air
Primary Air and P.F.

PULVERISING MILLS

Three main types:

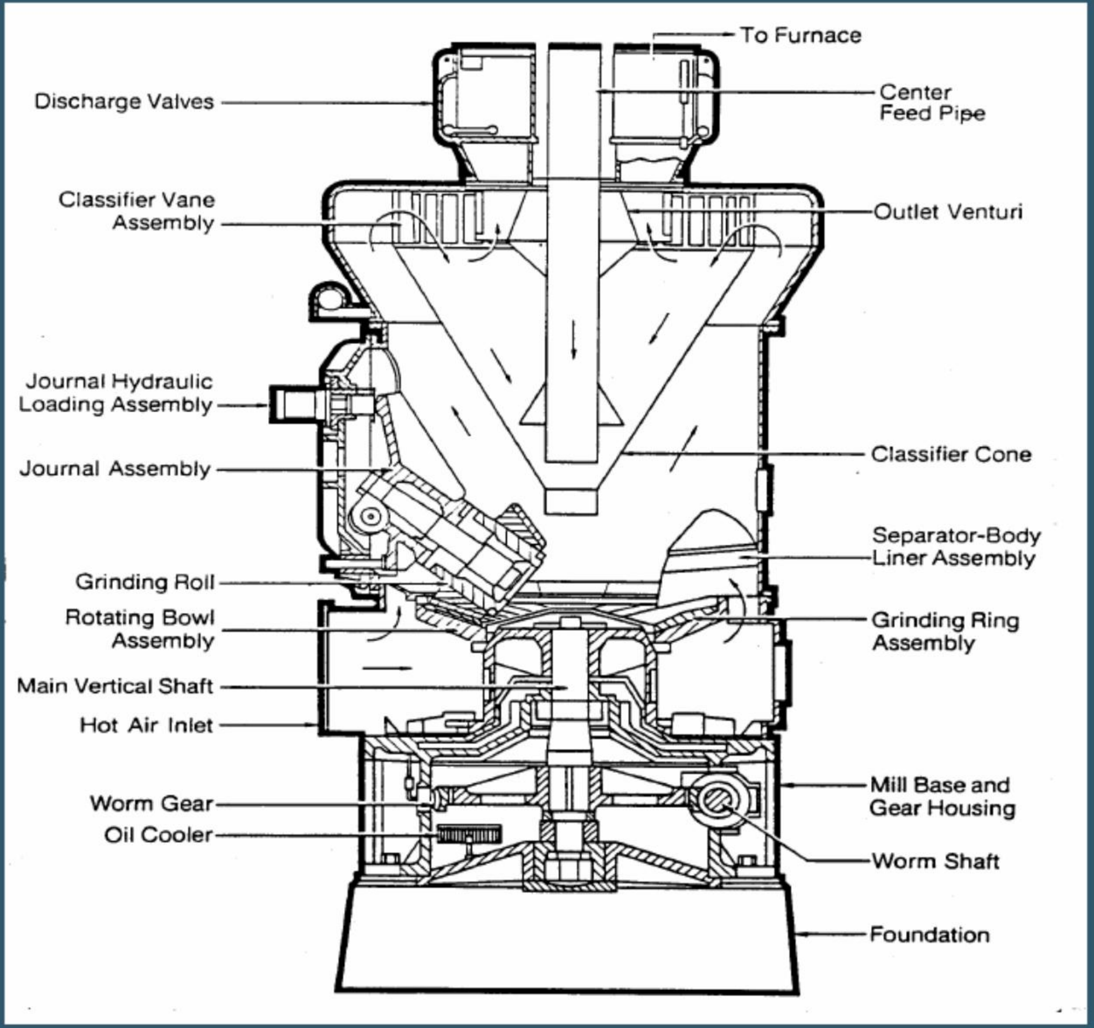
- Slow speed - ball mills
- Medium speed - vertical spindle mills
- High speed - impact/attrition mills

Ball/Tube Mill



- Tolerant of Abrasive Coal
- High Power Consumption
- Poor Dynamic Response

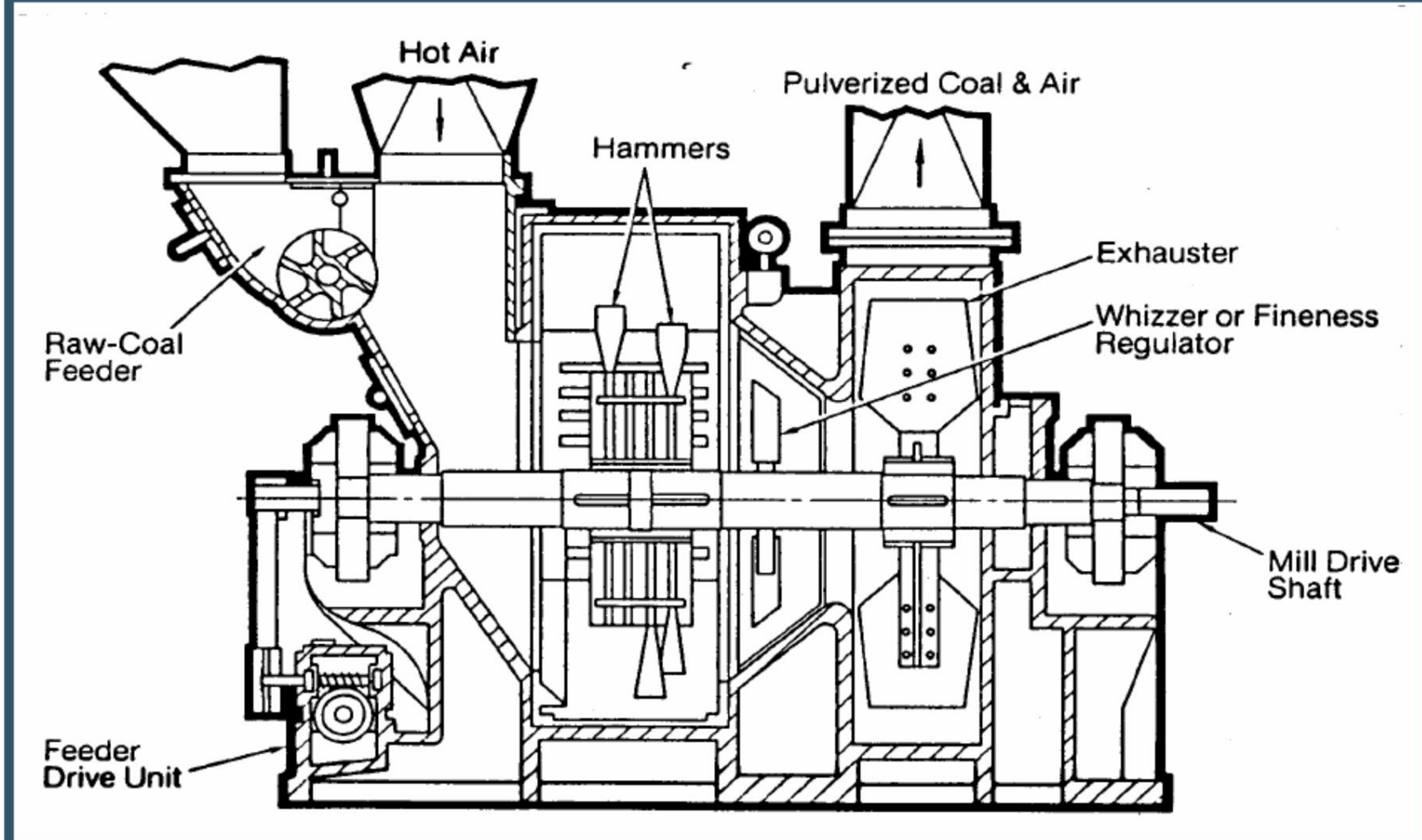
Vertical Spindle Mill (CE Raymond Bowl Mill)



Balance of:

- Abrasion Resistance
- Power Consumption
- Dynamic Response

High Speed Attritor Mill



- Very Susceptible to Abrasive Coal
- Low Power Consumption
- Good Dynamic Response

PULVERISING MILLS

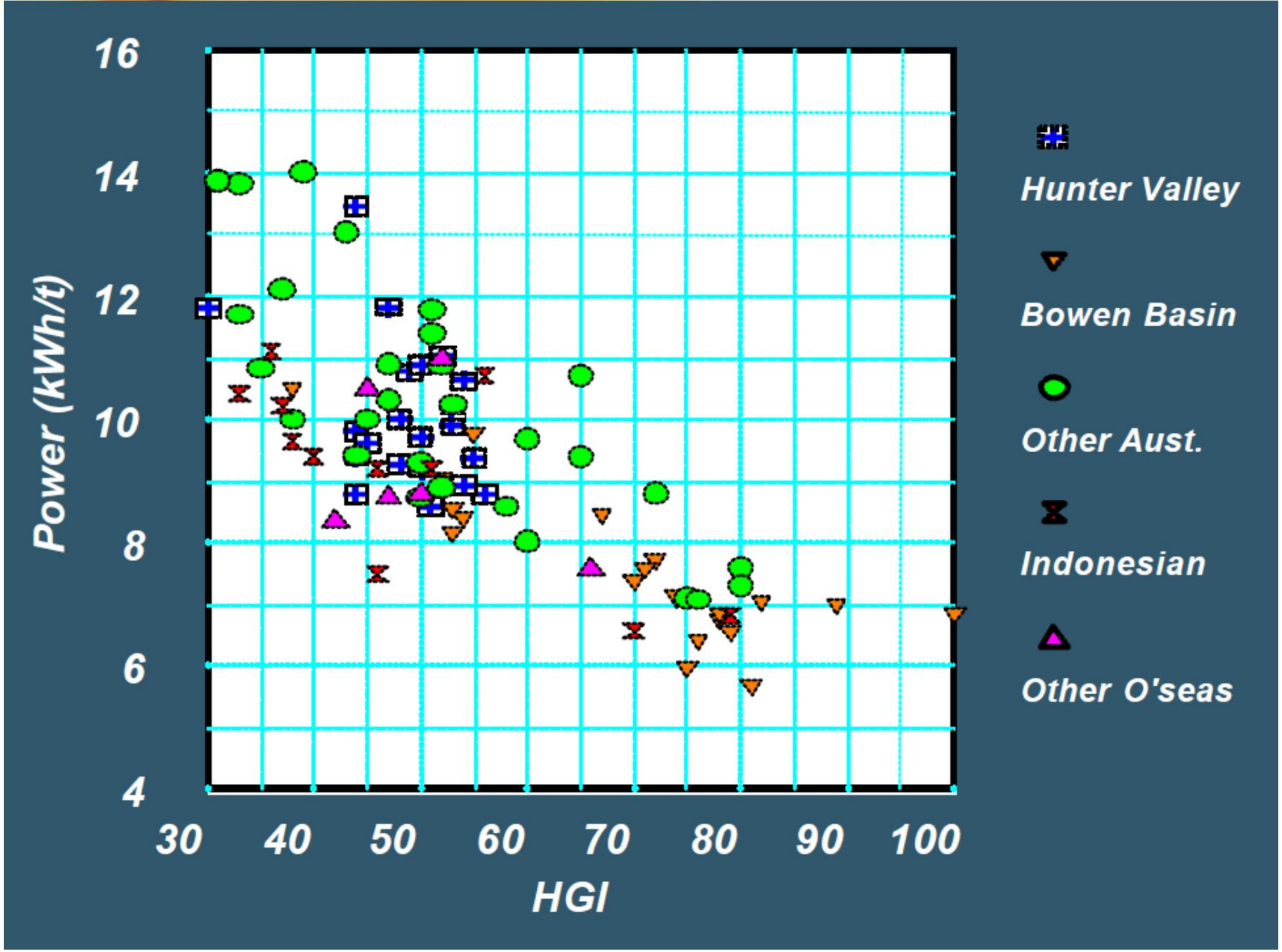
Potential performance issues:

- Capacity problems because coal is too difficult to grind.
- Capacity problems because coal has low energy content.
- PF fineness problems.
- Mill temperature problems which could lead to capacity problems or mill fires.
- High maintenance requirements because of abrasive nature of mineral matter in the coal.

 The energy experts

Milling/Pulverising

Relevant Coal Quality Parameters	Comments
Hardgrove Grindability Index (HGI)	Power consumption, fineness
Calorific Value	Required throughput
Moisture Content	Air temperature, spon. comb.
Ash Content	Abrasiveness
Abrasion Index (YGP)	Abrasiveness
Mineral composition (particularly free quartz and pyrite levels)	Abrasiveness


16
14
12
10
8
6
4
Power (kWh/t)
30
40
50
60
70
80
90
100
HGI
Hunter Valley
Bowen Basin
Other Aust.
Indonesian
Other O'seas

EFFECTIVENESS OF COMBUSTION REACTION

(Production of Heat from Coal Organic Matter)

1. **Flame Stability & Turndown Capability**
2. **Burnout Efficiency**

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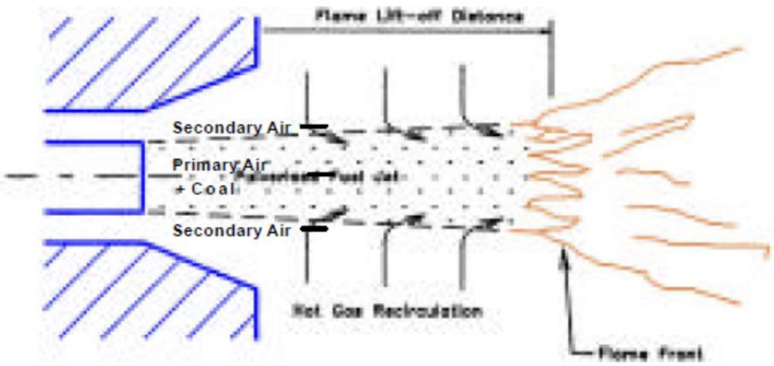
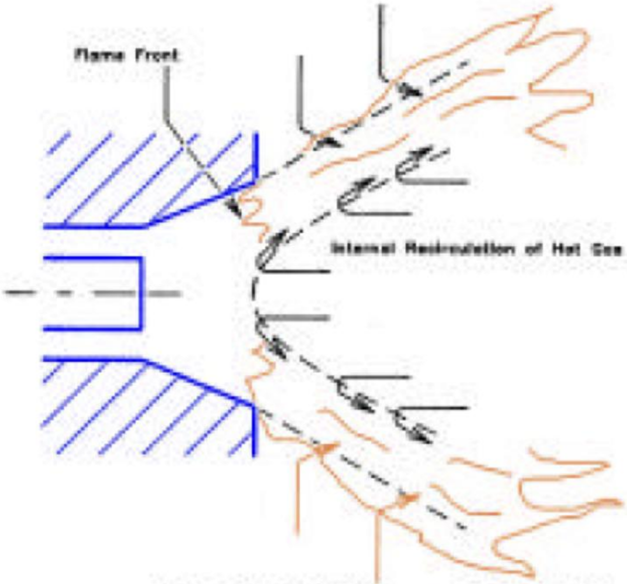
Stabilisation of Flame



(a) PF Fuel Jet with Zero Swirl



(b) Swirl Stabilised Flame at Critical Swirl

Flame Stability/Turndown

Relevant Coal Quality Parameters	Comments
VM Content (FR)*	Rapid heat generation to heat incoming coal/air
Moisture Content	
Specific Energy	
SE of VM	Not a standard test
PF Fineness (HGI)	

* Fuel Ratio (FR) = FC/VM

BURNOUT EFFICIENCY
(a component of Boiler Efficiency)

Required in order that:

- Maximum fuel value be obtained from the coal
- Minimum carbon-in-ash (Ash Utilisation)

BURNOUT EFFICIENCY (%)

$$= \frac{\text{Combustibles Burnt}}{\text{Total Combustibles}}$$

BOILER EFFICIENCY

Unburnt Carbon Loss (Burnout Efficiency)

Dry Flue Gas Loss

Increases with increasing flue gas temperature

Wet Flue Gas Loss

Increases with increasing moisture content

Hydrogen Loss

Loss of Gross Calorific Value due to Hydrogen

Other Losses (estimated 0.5 - 1.0%)

	Products	Combustion
COAL ORGANICS	VOLATILE MATTER (HYDROCARBONS)	Rapid, Complete
	CHAR (CARBON)	Slow, Incomplete

Burnout Efficiency

Relevant Coal Quality Parameters	Comments
VM Content (FR)*	Related to char quantity
Maceral Analysis	Related to char quality
Vitrinite Reflectance	Related to char quality
PF Fineness (HGI)	

* Fuel Ratio (FR) = FC/VM

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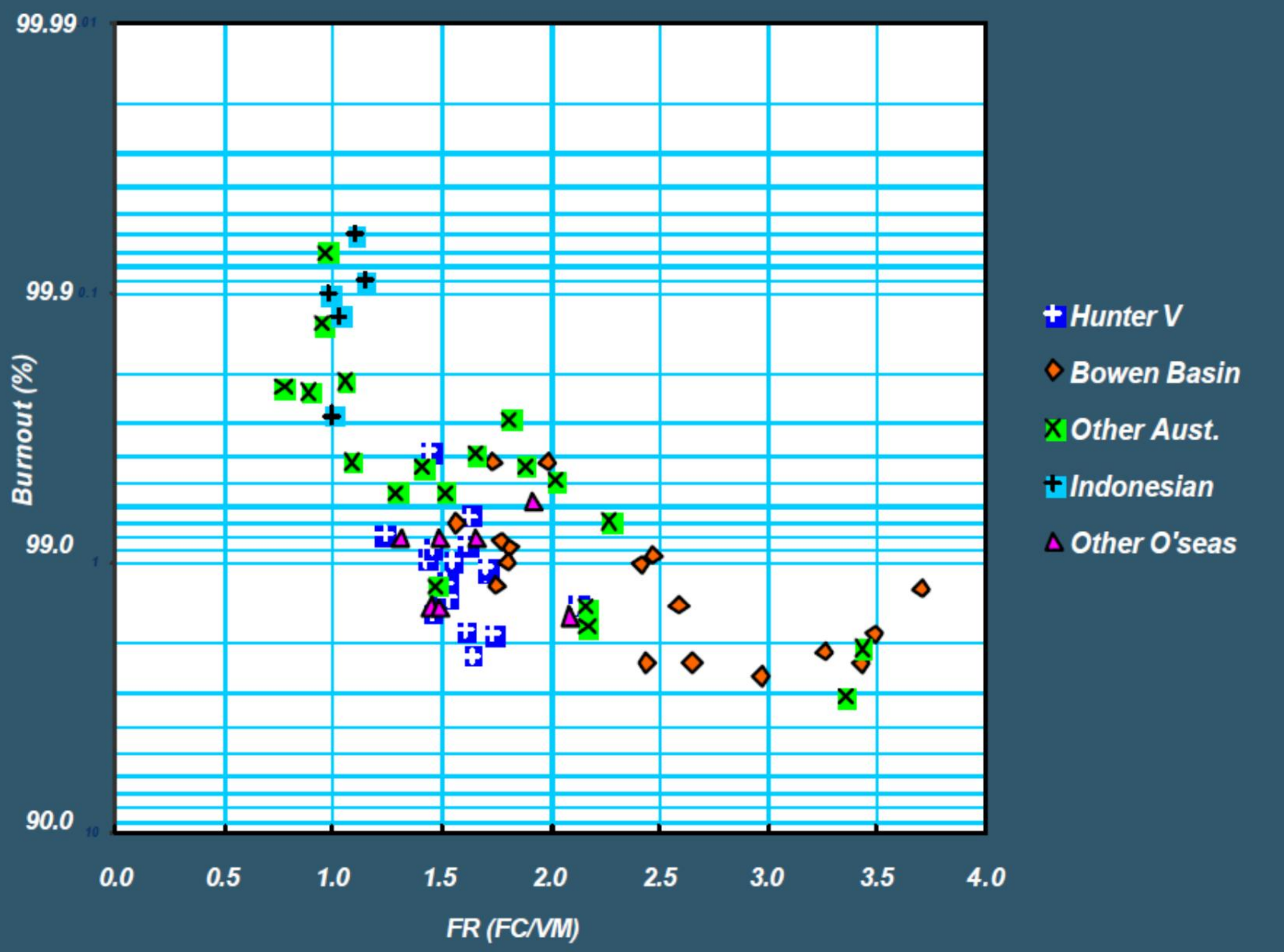
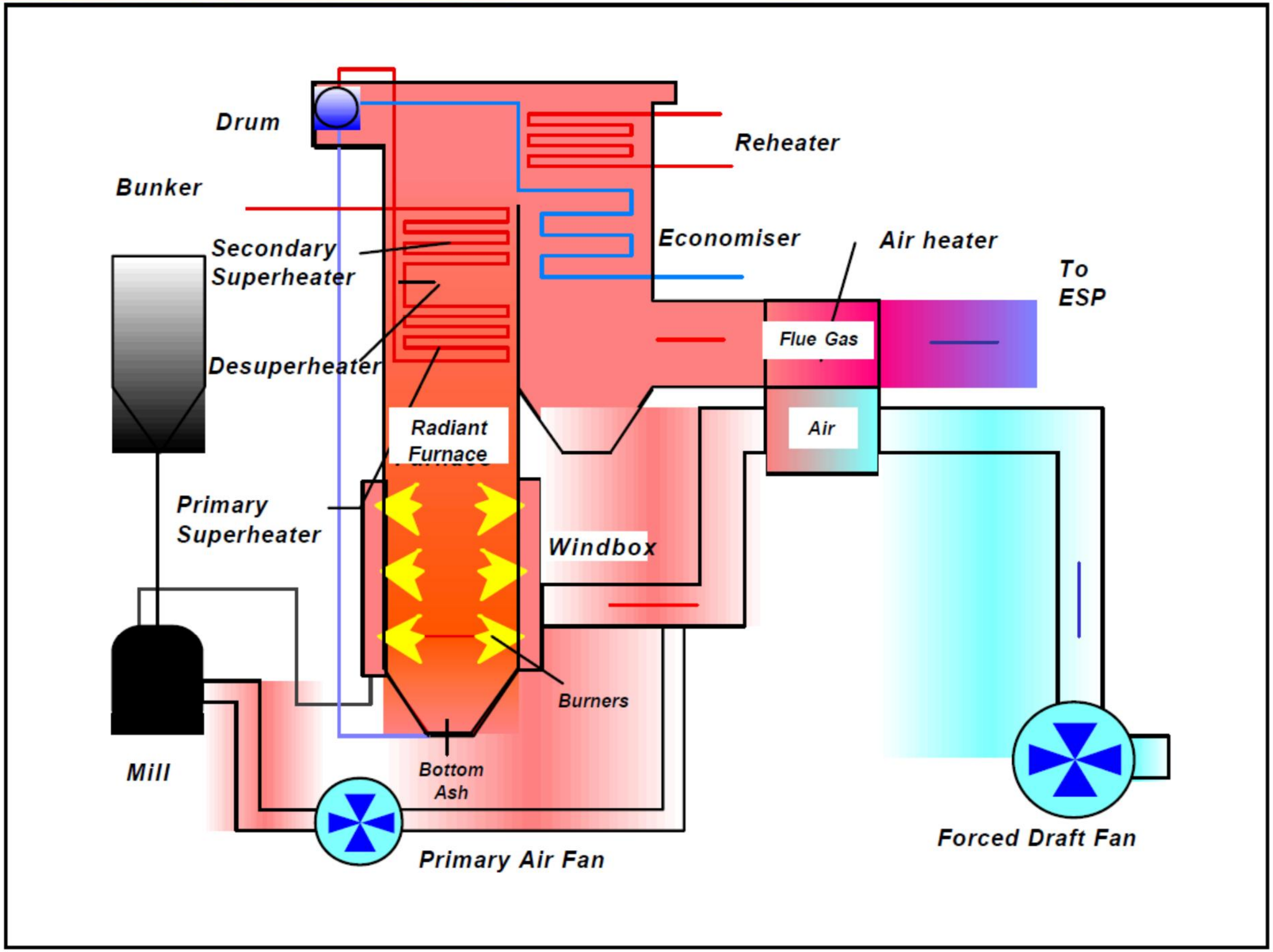
BURNOUT EFFICIENCY



ASH DEPOSITION

Covers:

- Deposition on tubes in the furnace area - SLAGGING
- Deposition in convective sections - reheaters, economisers and air heaters - FOULING.


Drum
Reheater
Bunker
Economiser
Air heater
To ESP
Secondary Superheater
Flue Gas
Desuperheater
Radiant Furnace
Air
Primary Superheater
Windbox
Burners
Mill
Bottom Ash
Forced Draft Fan
Primary Air Fan

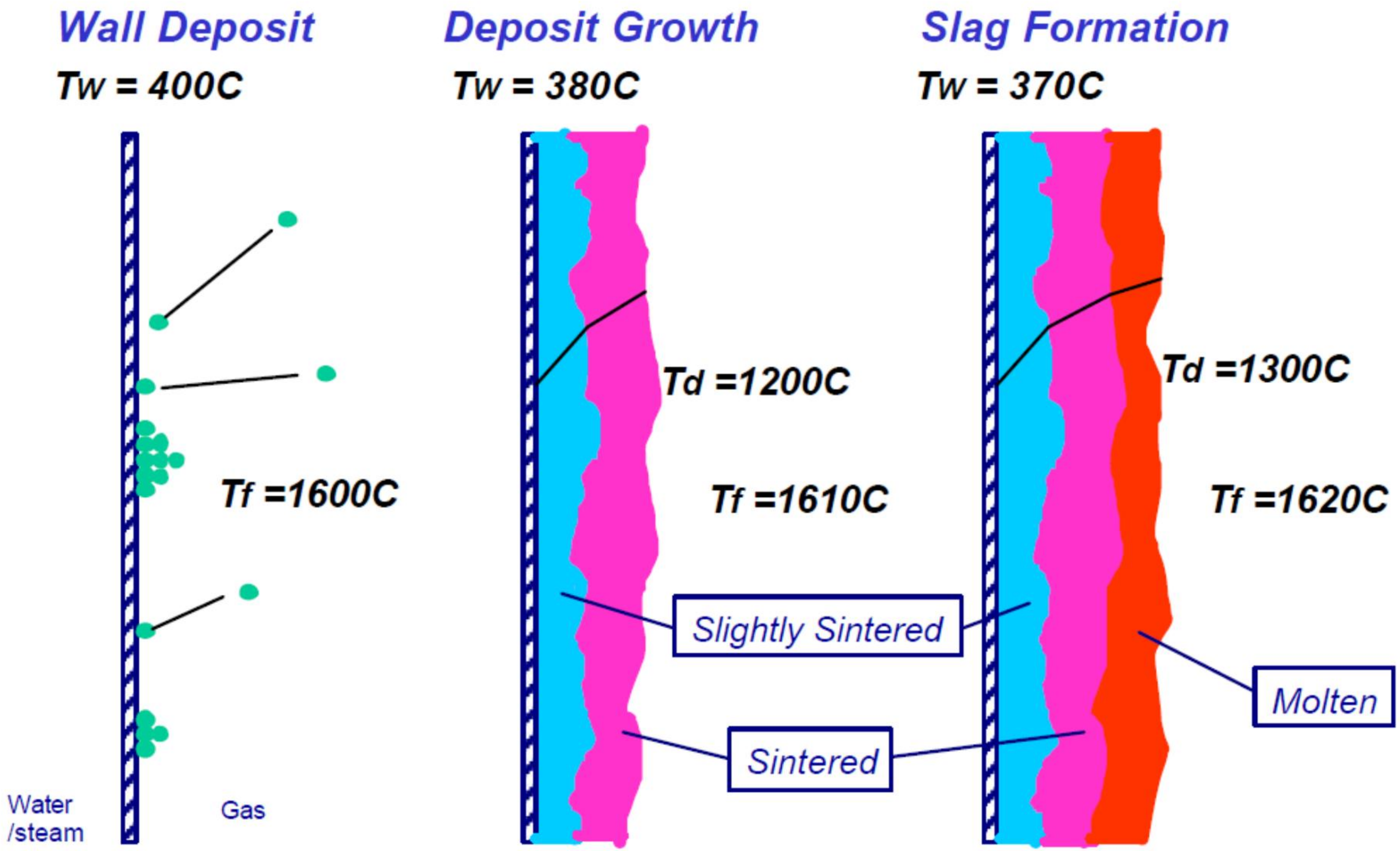
EFFECTS OF SLAGGING

- Interference with heat transfer balance - too little in radiant section, too much in convective section
- High Furnace Exit Temperature (Superheater Metal Temperature)
- High Boiler Exit Temperature (Boiler Efficiency)

EFFECTS OF SLAGGING

- Lumps in Bottom of Furnace (Damage, Blockages)
- Interference with Burner Flow Patterns
- Excessive Soot-Blowing (Steam Wastage, Erosion)

SLAG FORMATION



EFFECTS OF FOULING

- High Boiler Exit Temperature (Boiler Efficiency)
- Low Steam Temperature
- Excessive Soot-Blowing (Steam Wastage, Erosion)
- Poor Gas Flow Distribution (Erosion)
- Air-Heater Performance (Blockages, Heat Transfer)

ASH DEPOSITION

Affected by:

- Coal Properties - mineral composition, moisture.
- Firing Arrangement
- Operating pattern

Deposit Formation

Relevant Coal Quality Parameters	Comments
Ash Fusion Temperature	IDT, Spherical Temp., Hemispherical Temp., Flow Temp.
Ash Analysis	Fe, Ca, Mg, Na, K
Indices based on Ash Analysis	Many & various

ASH DEPOSITION

Limitations of Laboratory Tests:

- AFT does not take account of selective deposition
- AFT does not take account of variations in combustion conditions related to coal rank
- Indices are not applicable to all coals. Most do not apply to southern hemisphere coals

ASH DEPOSITION

Example of Problem with Common Slagging Index:

Slagging Index = (Base/Acid) * Sulphur

Guidelines: If S.I.< 0.6, then no problems

If S.I. > 2.6, there will be problems

But Australian Coals generally have S.I. values< 0.6 because they have low sulphur values.

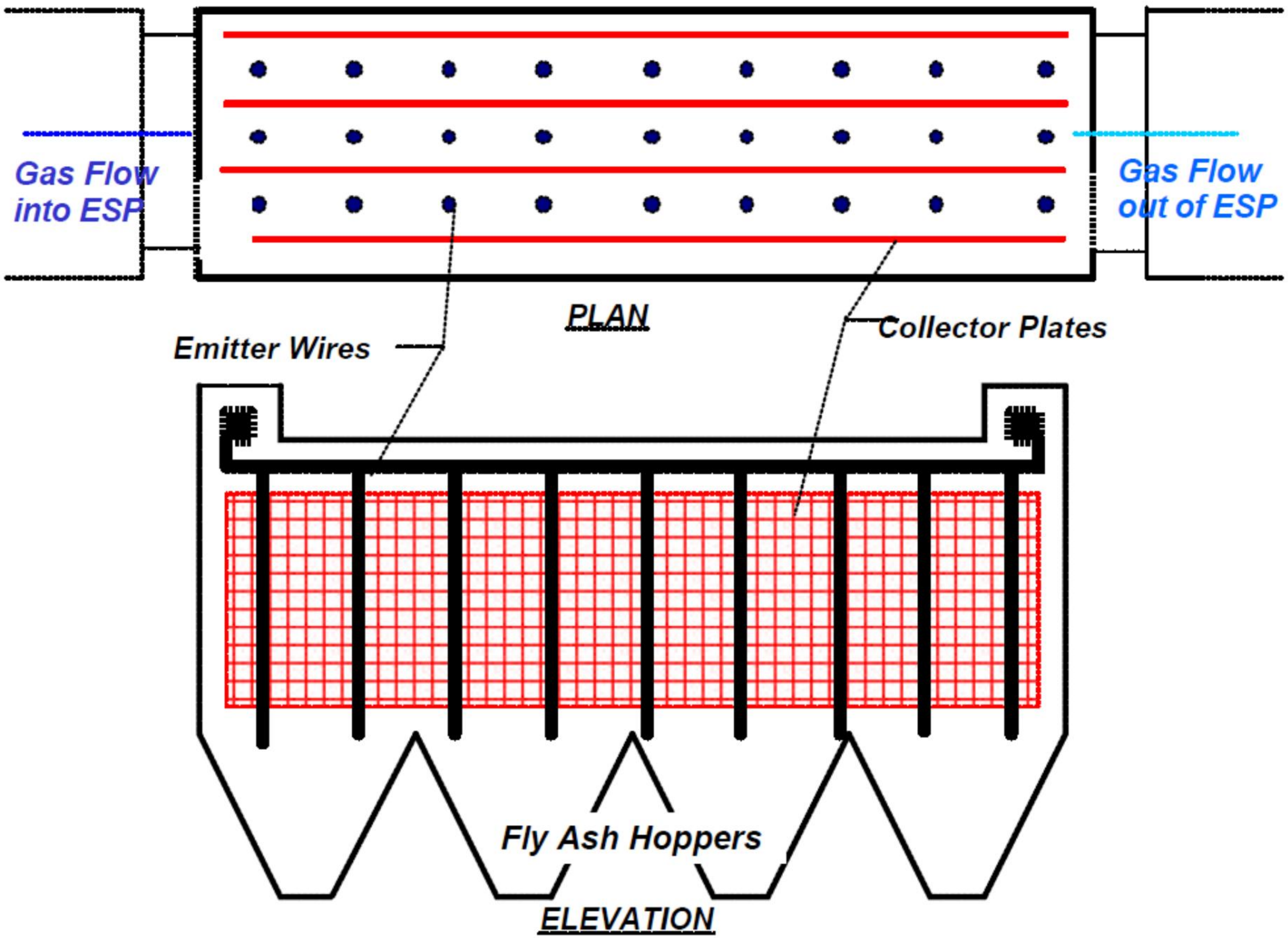
They can still cause slagging problems

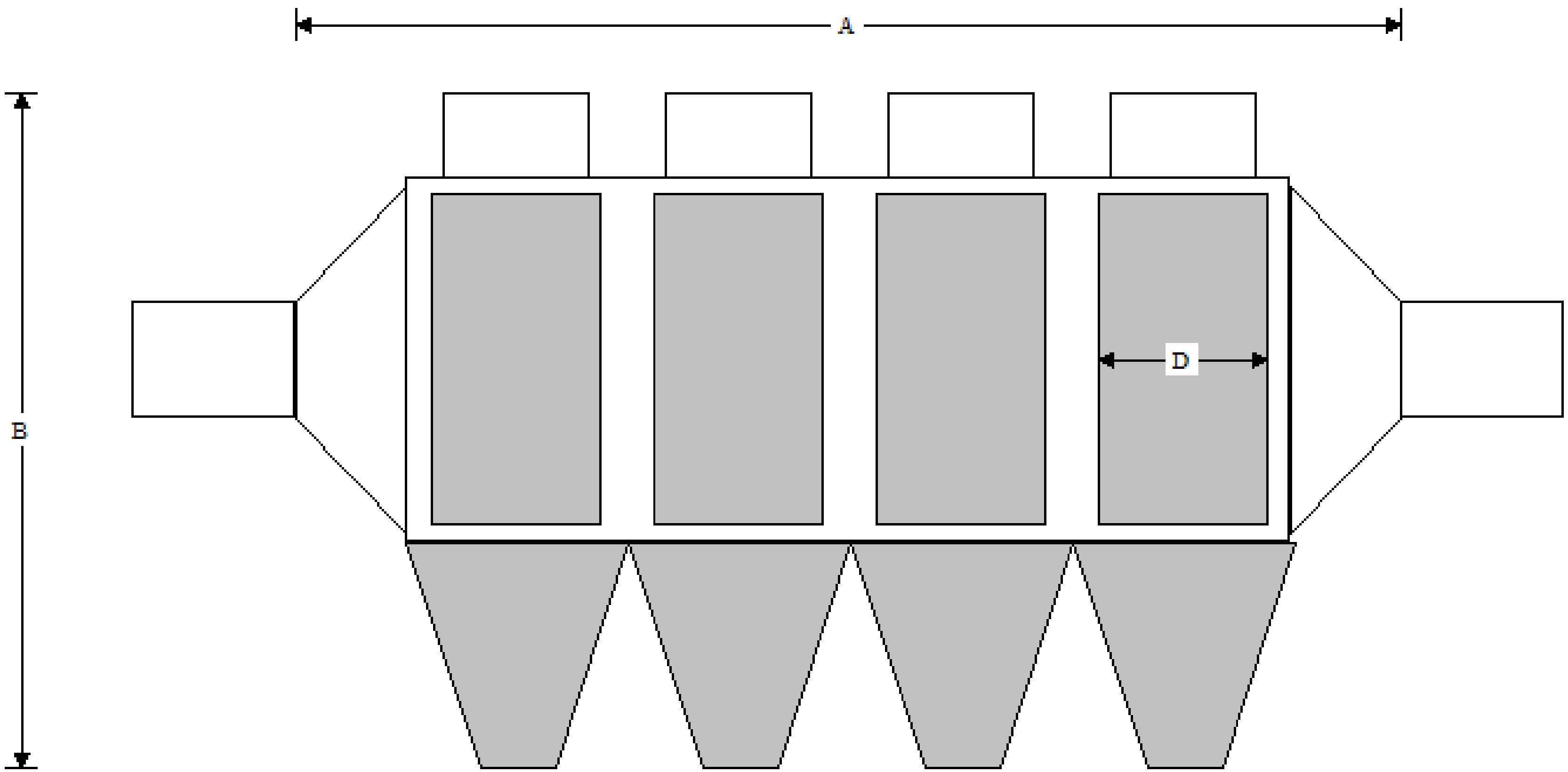
 The energy experts

ELECTROSTATIC PRECIPITATOR

Purpose is to:

- *Remove particulate matter from flue gas to satisfy local statutory environmental regulations.*
- *This would normally require a collection efficiency of >99.5%.*


Gas Flow into ESP
Gas Flow out of ESP
PLAN
Emitter Wires
Collector Plates
Fly Ash Hoppers
ELEVATION


A
B
D

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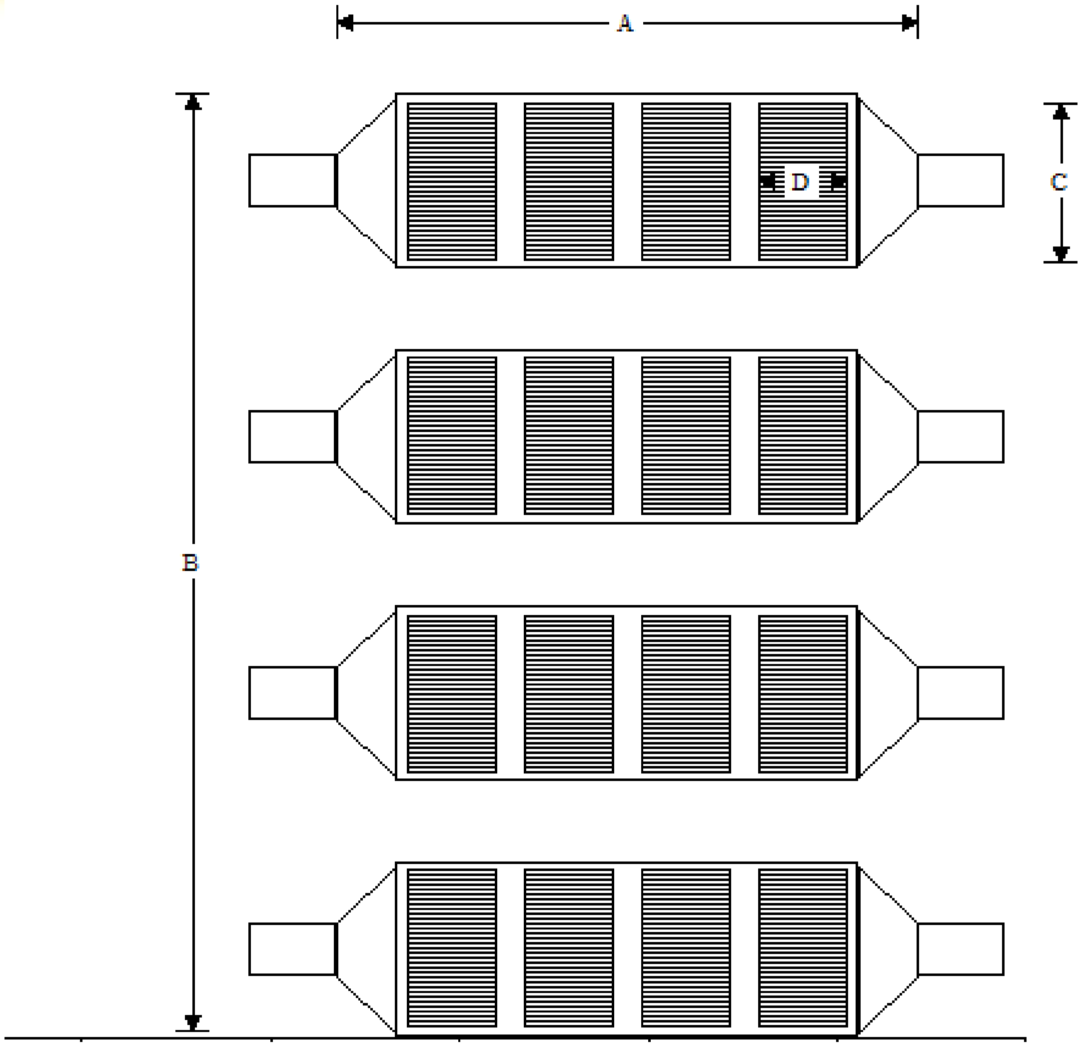
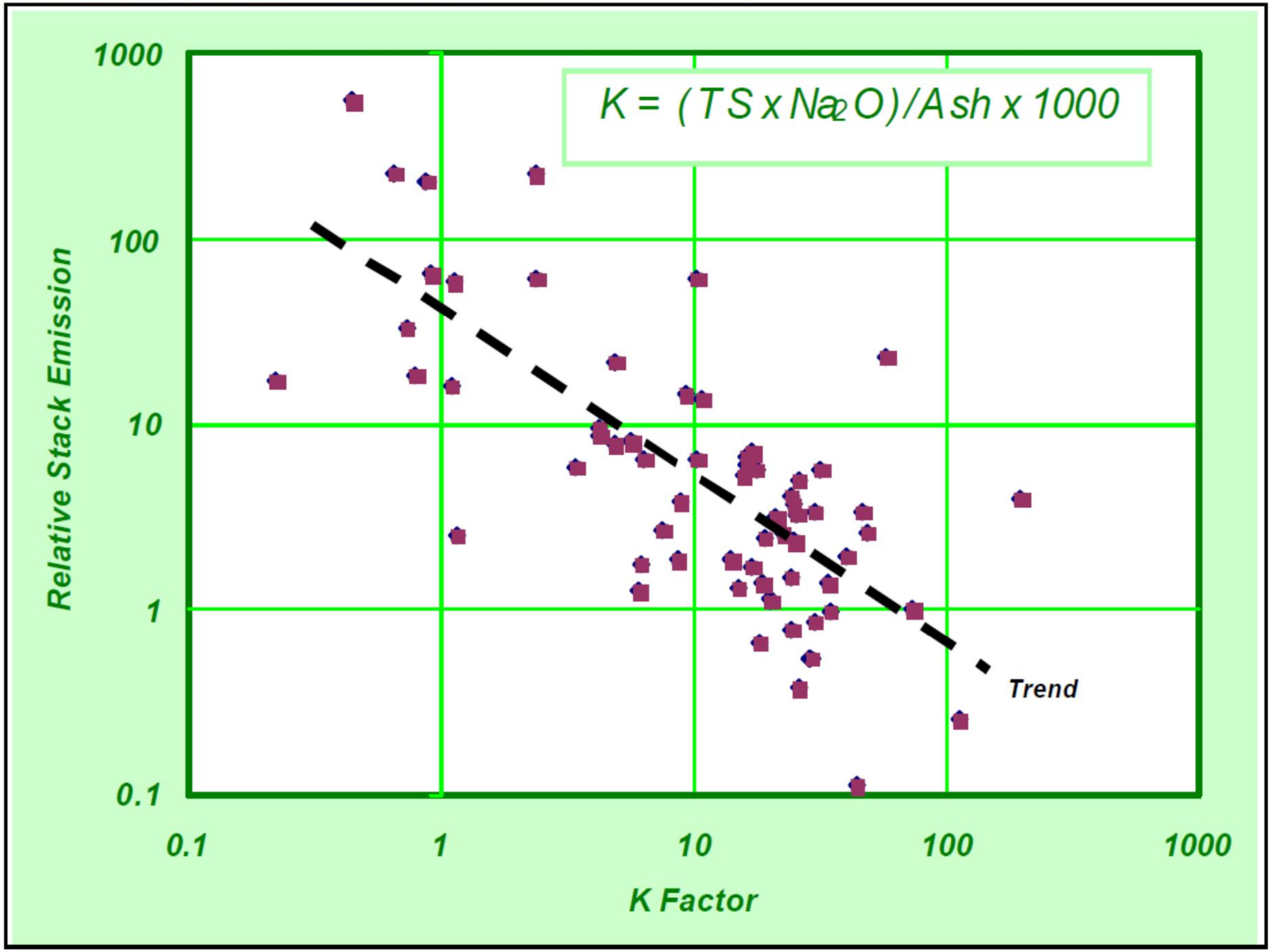
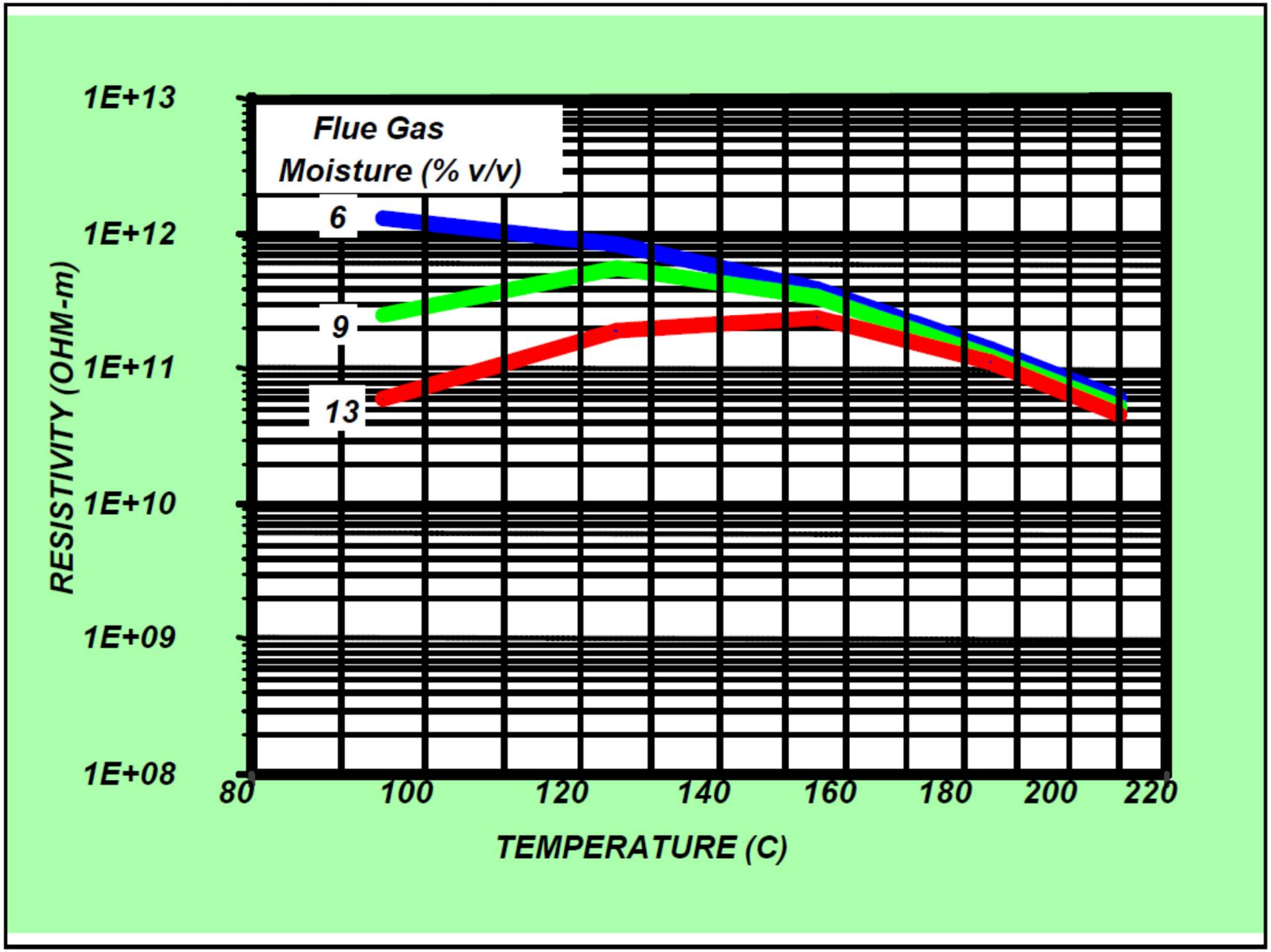


ELECTROSTATIC PRECIPITATOR Collection Efficiency

Determined by:

- Electrical resistivity
- Ash chemistry
- Coal sulphur content
- Particle size distribution
- Cohesiveness of ash layer


K = (TS x Na2O)/Ash x 1000
1000
100
10
1
0.1
Relative Stack Emission
0.1
1
10
100
1000
K Factor
Trend


Flue Gas
Moisture (% v/v)
6
9
13
1E+13
1E+12
1E+11
1E+10
1E+09
1E+08
RESISTIVITY (OHM-m)
80
100
120
140
160
180
200
220
TEMPERATURE (C)

SO_x FORMATION

Composed of:

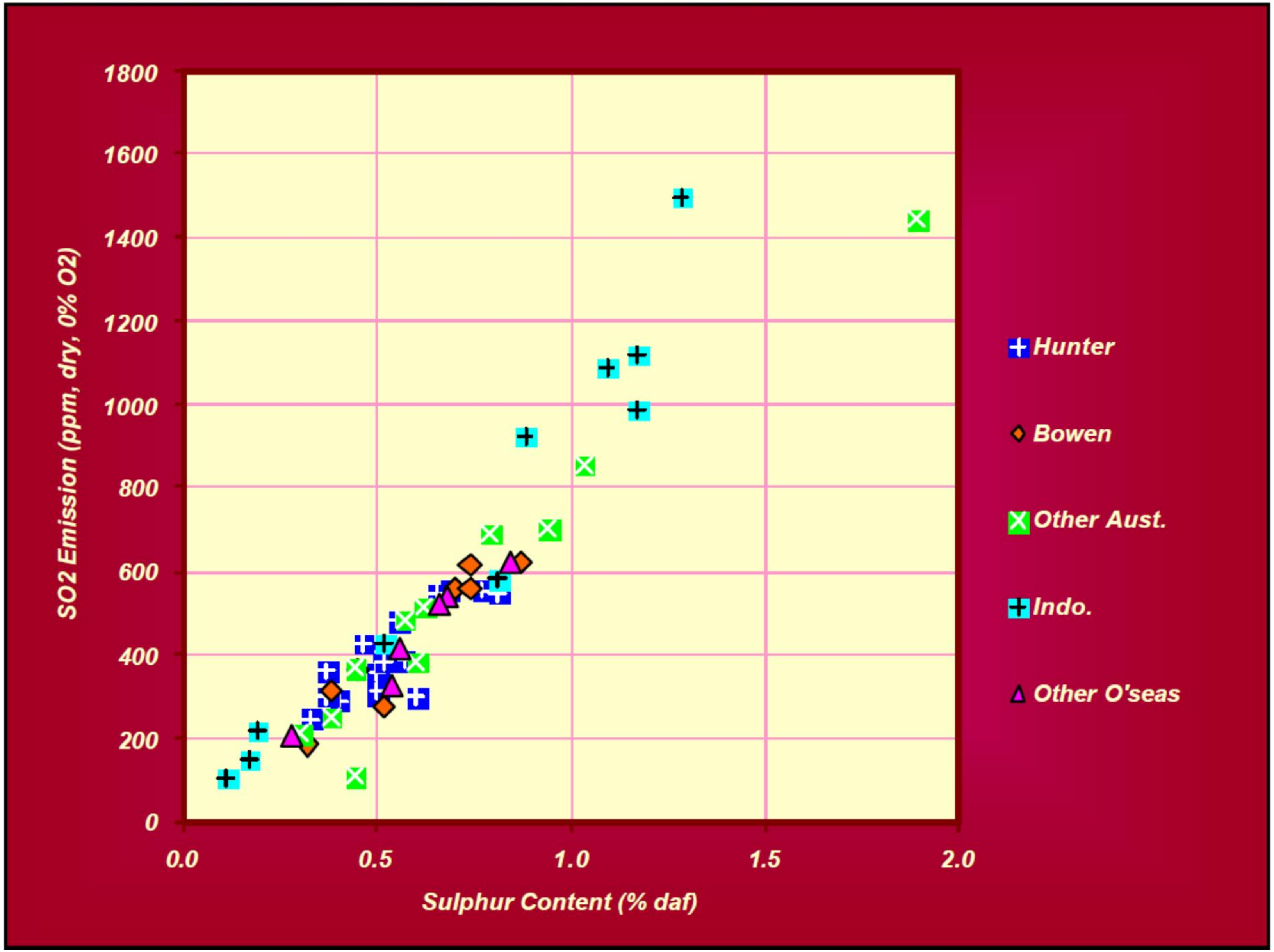
- *SO_2 (predominates in stack)*
- *SO_3 (predominates in atmosphere)*

Negative Effect:

- *Acid Rain*

Positive Effect:

- *SO_3 may improve electrostatic precipitation*


1800
1600
1400
1200
1000
800
600
400
200
0
0.0
0.5
1.0
1.5
2.0
SO2 Emission (ppm, dry, 0% O2)
Sulphur Content (% daf)
Hunter
Bowen
Other Aust.
Indo.
Other O'seas

SO_2 Formation

Relevant Coal Quality Parameters	Comments
Coal Sulphur Content	Strong predictor
Ash Chemistry	SO_2 absorbed by Ash
Ash Content	

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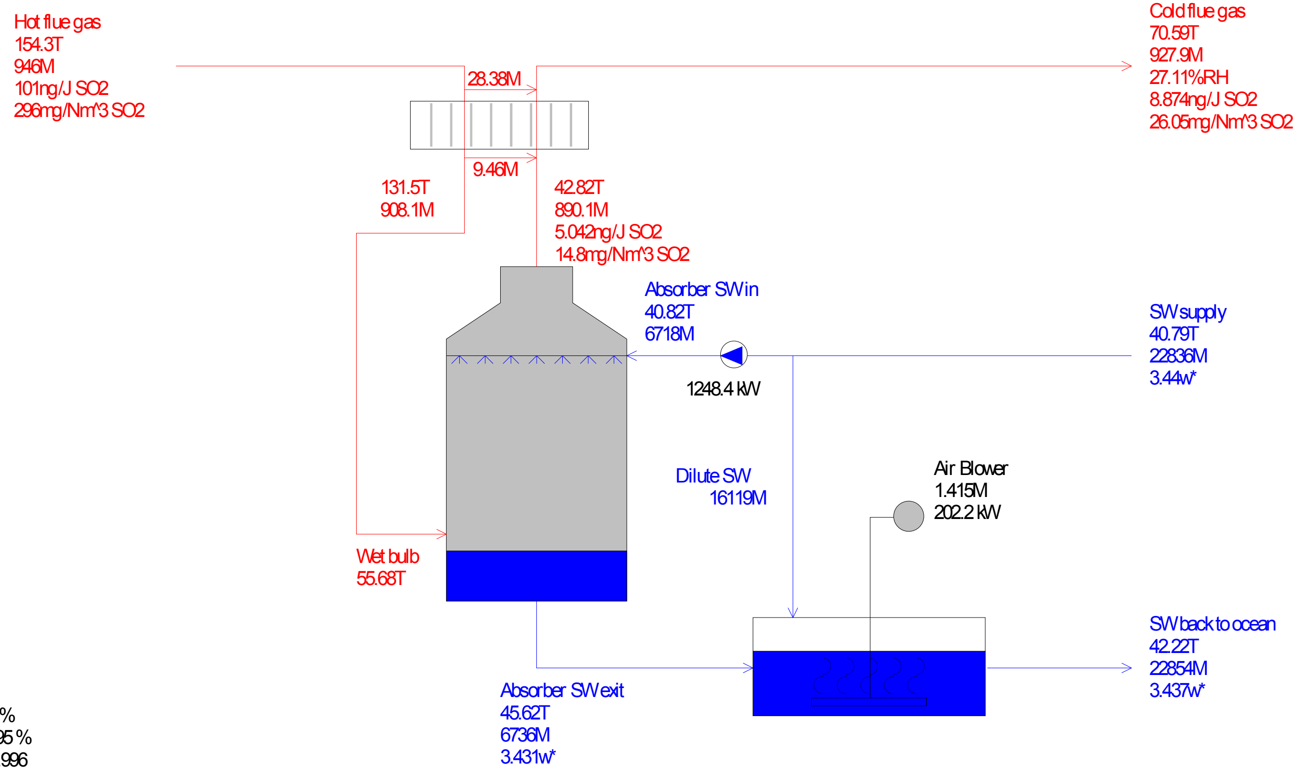
Fluegas Desulphurisation Unit

SWFGD Flow Circuit - One Unit (Engineering Design)



Typical 700 MW

FGD SO2 removal efficiency = 91.2 %
Absorber SO2 removal efficiency = 95 %
Number of transfer units (NTU) = 2.996
Absorber L/G = 10.85 L/Nm^3
Total SO2 removed = 0.1834 kg/s
Total auxiliary power = 1450.6 kW

P[bar] T[C] M[kg/s] w*[wt% salinity]

STEAM PRO 25.0 Bernie HRL Technology Pty Ltd.
485 10-16-2015 20:51:13 C:\Andeb\IFME\Boiler Training\TFlow\TBP 700 MW Unit, Ver 1.STP

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NO_x FORMATION

Composed of:

- N_2O
- NO
- NO_2

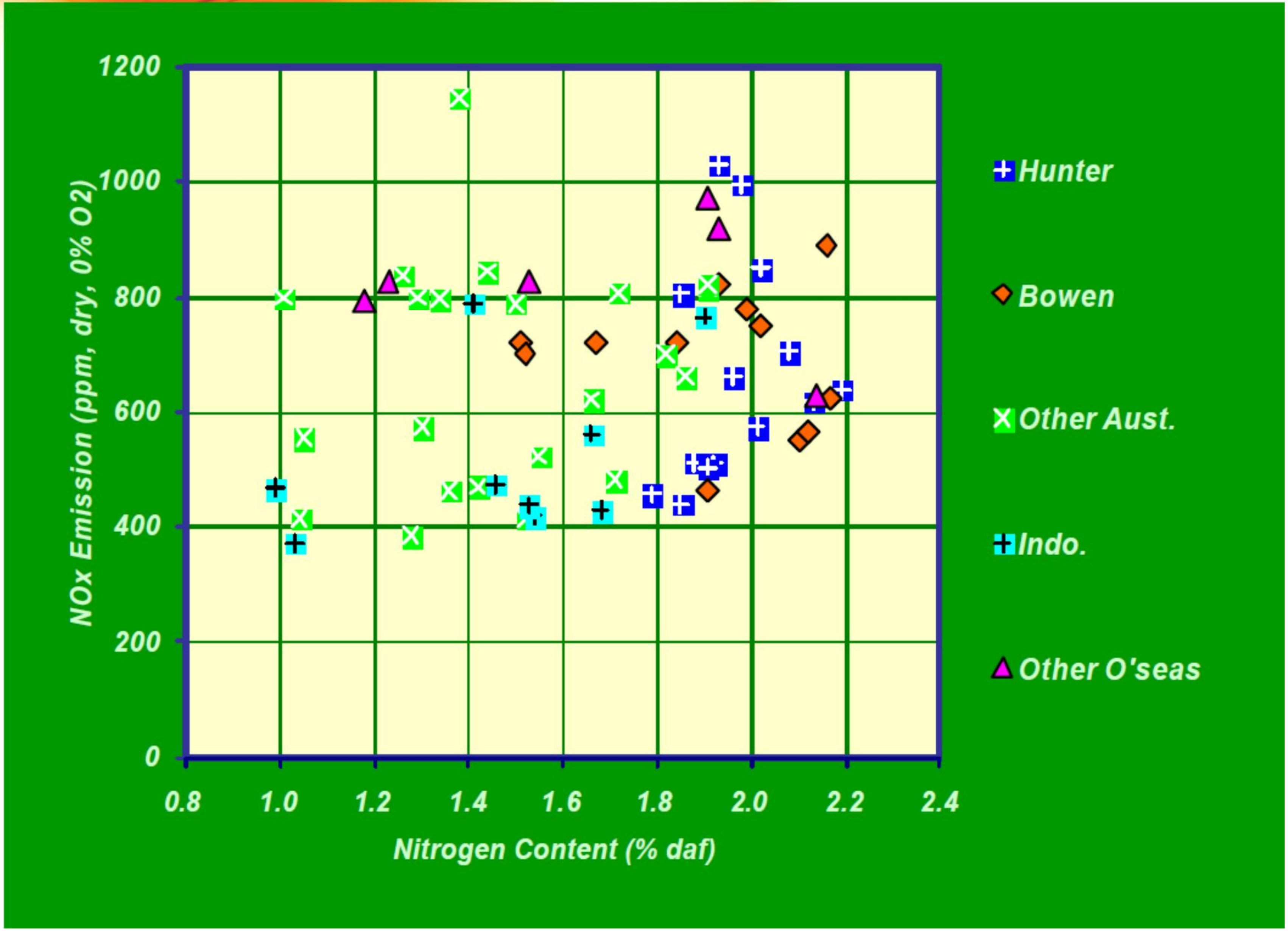
Effects:

- Photochemical Smog
- Acid Rain

NO_x FORMATION

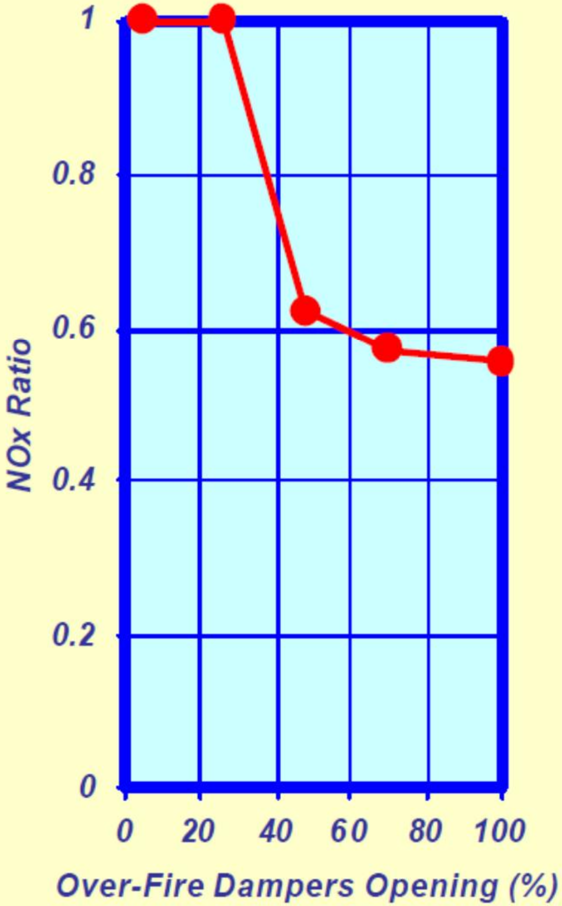
Formed From:

- Nitrogen in Coal (Main Source)
- Nitrogen in Combustion Air (Lesser Source)

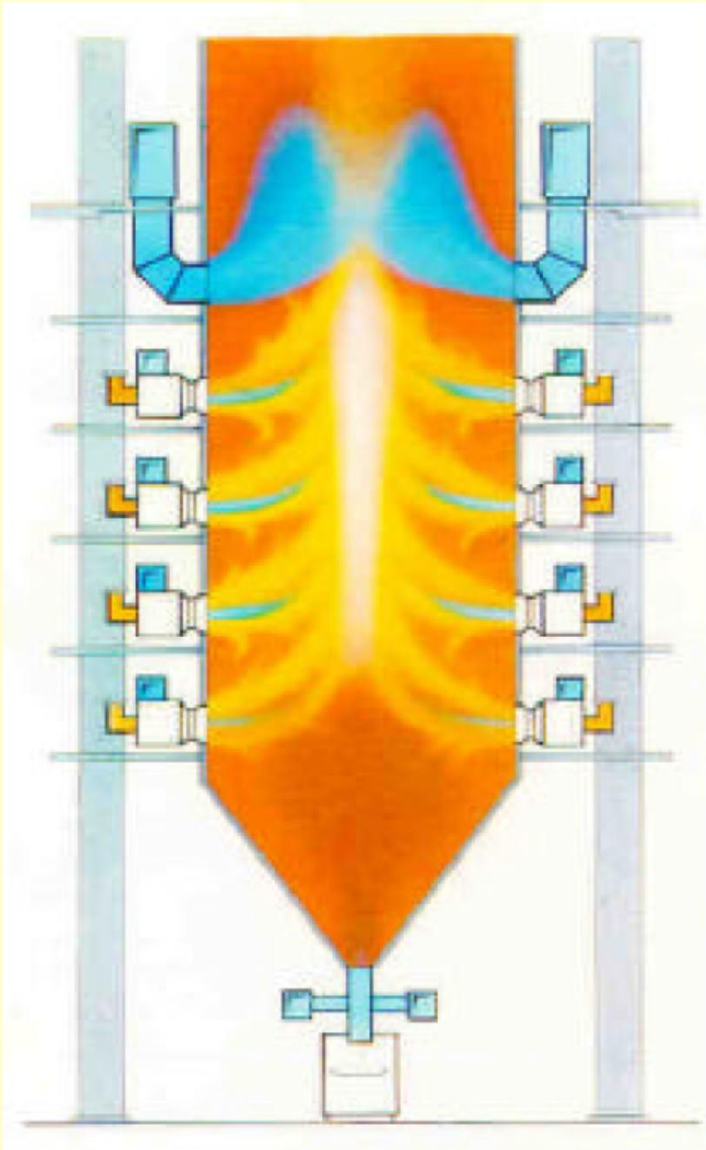

1200
1000
800
600
400
200
0
NOx Emission (ppm, dry, 0% O2)
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
Nitrogen Content (% daf)
Hunter
Bowen
Other Aust.
Indo.
Other O'seas

NO_x Formation

Relevant Coal Quality Parameters	Comments
Coal Nitrogen Content	Major Source, but poor predictor
VM Content	Low NOx Combustion Systems
Moisture Content	Flame Temperature
Coal Rank, Organic Chemistry	Complex Reactions



Low - NOx
Air staging in the Furnace



Fly Ash Disposal & Utilisation

Choices:

- Disposal
  - Occupies Valuable Land
  - Impacts on Water Quality
- Utilisation
  - How to find enough Uses?

Fly Ash in Concrete

Typical Requirements

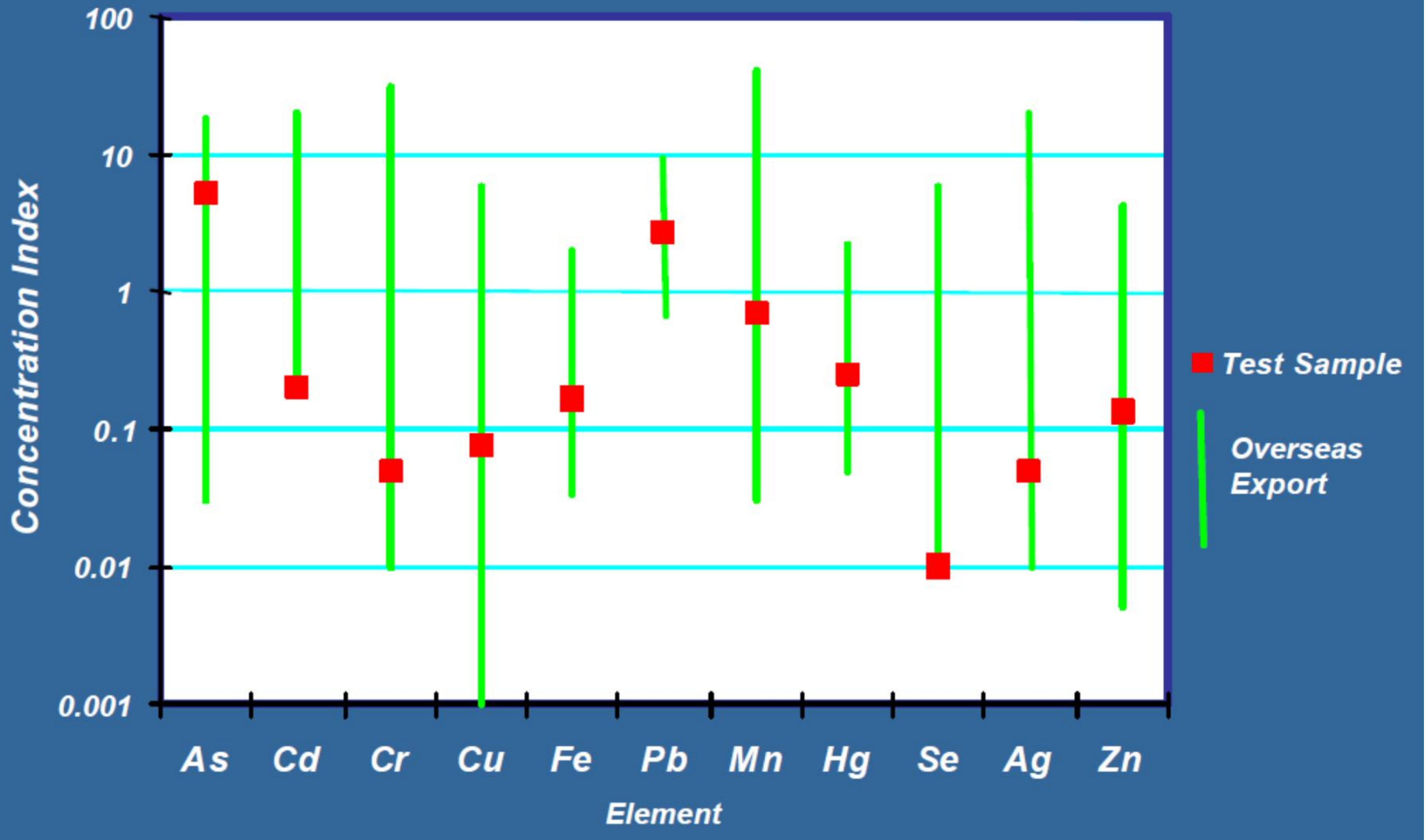
- *Carbon in Ash (maximum specified)*
- $SiO_2 + Al_2O_3 + Fe_2O_3$ *(mininimum specified)*
- SO_3 *(max)*
- *Available alkalis (max)*
- *Fineness (min)*
- *Strength of Concrete Test Piece (min)*
- *Water requirement (max)*

Ash Disposal

- *Principal issue is release of leachable trace elements into ground water and surface water*
- *Toxicity judged by comparison of leachate analysis with drinking water standards; if Concentration Index > 100, deemed to be Hazardous Waste*

Shake Extraction (Leaching) Test

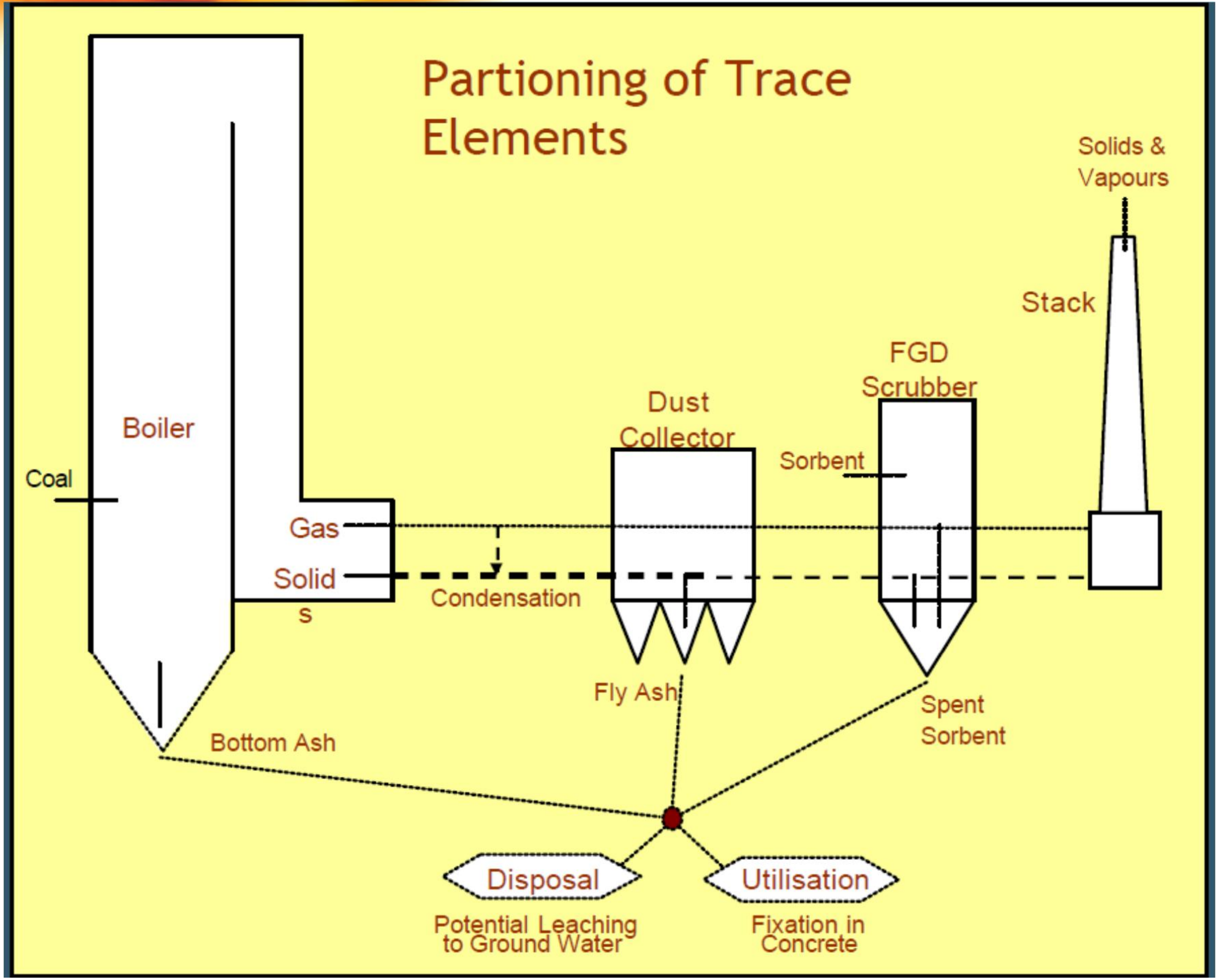
$$CI = \frac{\text{Measured Concentration}}{\text{Drinking Water Standard}}$$



Levels of Trace Element Leaching

Depends on:

- Trace elements in coal, then in ash
- Nature of ash (size, degree of melting)
- Major elements & radicals in ash (Ca, Mg, Na, K, Cl, SO_4, $CO_{3)}$ which may determine ph of the leaching water
- pH of water entering the disposal site


Partioning of Trace Elements
Solids & Vapours
Stack
FGD Scrubber
Dust Collector
Sorbent
Boiler
Coal
Gas
Solid
s
Condensation
Fly Ash
Spent Sorbent
Bottom Ash
Disposal
Potential Leaching to Ground Water
Utilisation
Fixation in Concrete

Review of Effect of Coal Properties

- Please provide answers to the following Questions for discussion.
- What will be the effect if the coal is to be used in one of the existing 700 MW units in Malaysia:

1. What will be the effect if the coal CV is 5000 kcal/kg as fired.
2. The coal moisture is 25% (as fired).
3. The coal ash is 18% (as fired).
4. The HGI is 38.
5. The oxygen is 16% (as fired)
6. The sulphur is 1.2% (as fired)
7. The sodium + potassium (oxides) in ash is 5%
8. The iron oxide in ash is 11%

Effect of Steam Cycle Conditions on Unit Performance

Type of Power Plant	MW Gross	MS Pressure, Mpa	MS Temperature °C	RH Temperature °C
700 MW Subcritical	745	16.4	538	538
700 MW Ultra Supercritical	737	28.0	600	605
1000 MW Ultra Supercritical	1053	28.0	600	605
1000 MW Advanced USC	1050	30.0	700	730
700 MW GT Combined Cycle	724	16.6	600	600

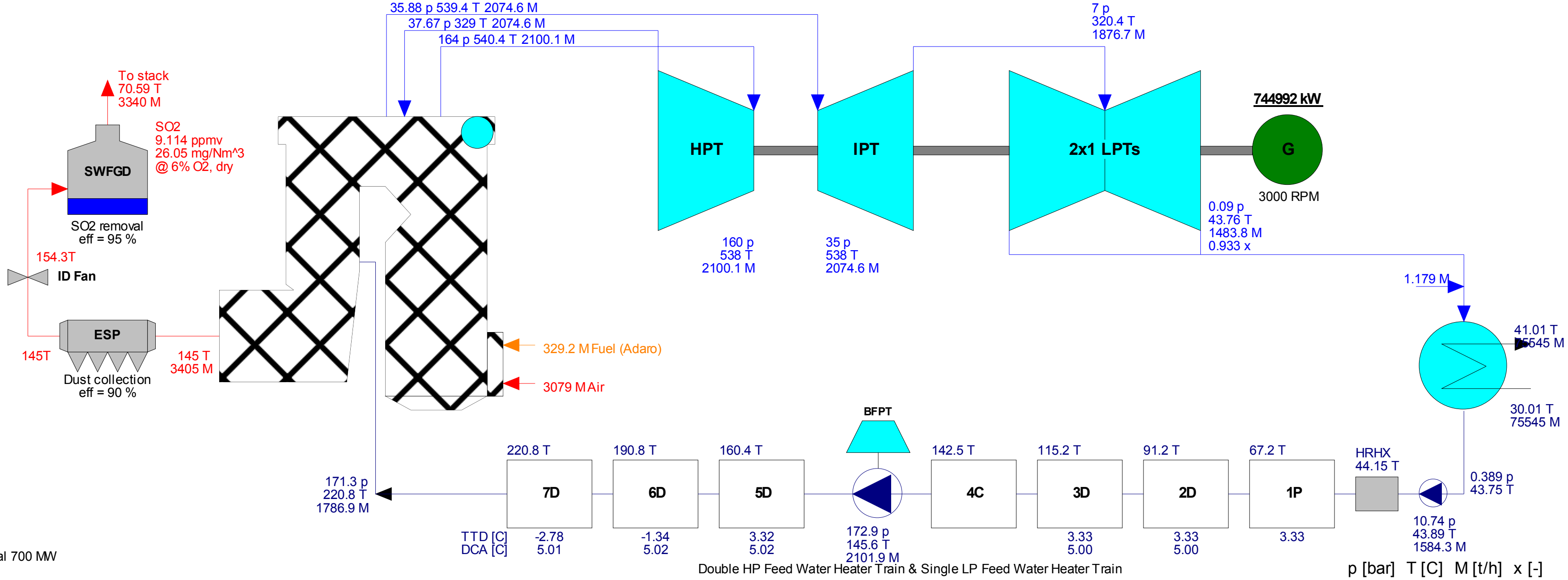
Effect of Steam Cycle Conditions on Unit Performance

Comparison of Power Plants				
Coal - Adaro 5200 kcal/kg at 1.8 $US/GJ HHV				
Natural Gas at 5.4 $US/GJ HHV				
Type of Power Plant	Unit Efficiency % Net HHV	Approx Cost $M USD	Relative Cost of Electrcity	CO2 kg/MWh gross
700 MW Subcritical	35.2	1220	100	911
700 MW Ultra Supercritical	39.9	1460	87.6	808
1000 MW Ultra Supercritical	40.1	1970	84.7	803
1000 MW Advanced USC	42.8	2230	86.6	756
700 MW GT Combined Cycle	54.4	487	95.4	330

Effect of Steam Cycle Conditions on Unit Performance
700 MW Subcritical Plant

Plant gross power	744992	kW
Plant net power	701303	kW
Number of units	1	
Plant net HR (HHV)	10235	kJ/kWh
Plant net HR (LHV)	9632	kJ/kWh
Plant net eff (HHV)	35.17	%
Plant net eff (LHV)	37.37	%
Aux. & losses	43689	kW
Fuel heat input (HHV)	7178	GJ/h
Fuel heat input (LHV)	6755	GJ/h
Fuel flow	7902	t/day

Ambient
1.013 p
30 T
80% RH
27.09 T wet bulb



Typical 700 MW

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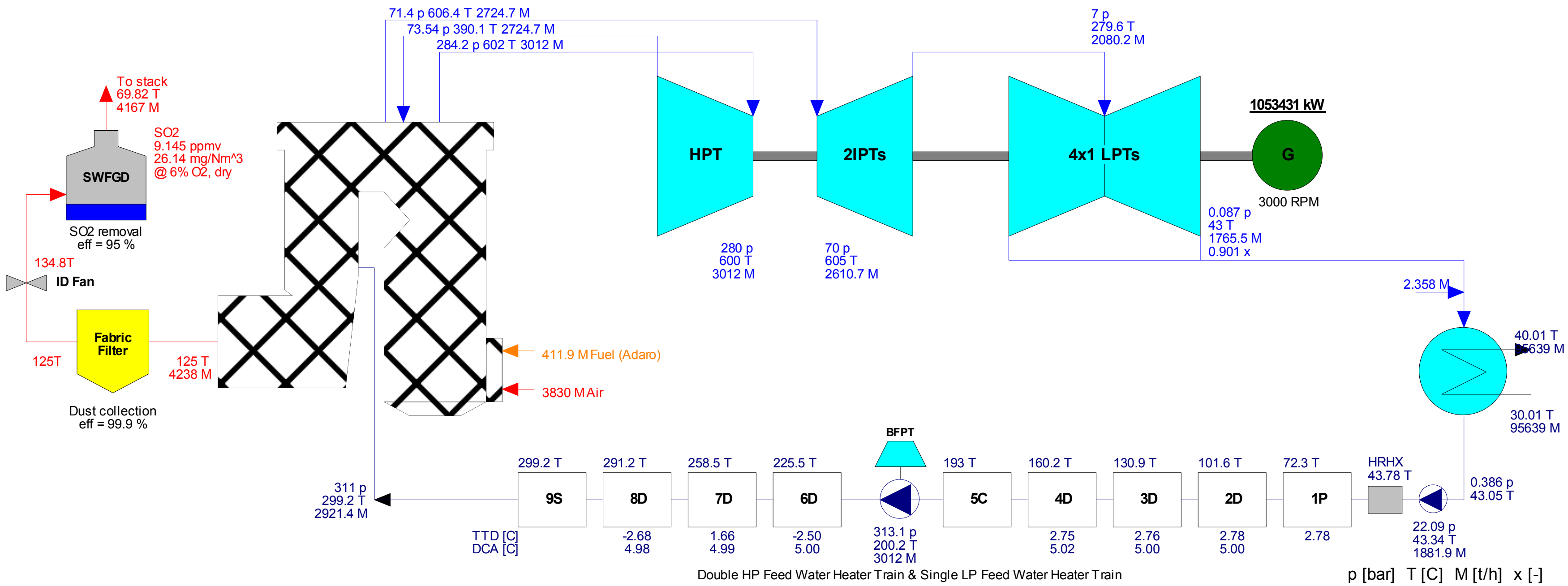
485 10-16-2015 20:48:19 C:\Andeb\IFME\Boiler Training\TFlow\TBP 700 MW Unit, Ver 1.STP

Effect of Steam Cycle Conditions on Unit Performance
1000 MW Ultra Supercritical

Plant gross power	1053431	kW
Plant net power	999841	kW
Number of units	1	
Plant net HR (HHV)	8981	kJ/kWh
Plant net HR (LHV)	8453	kJ/kWh
Plant net eff (HHV)	40.08	%
Plant net eff (LHV)	42.59	%
Aux. & losses	53590	kW
Fuel heat input (HHV)	8980	GJ/h
Fuel heat input (LHV)	8452	GJ/h
Fuel flow	9886	t/day

Ambient
1.013 p
30 T
60% RH
23.82 T wet bulb



STEAMPRO 25.0 Bernie HRL Technology Pty Ltd.
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Effect of Steam Cycle Conditions on Unit Performance
700 MW Gas Turbine Combined Cycle

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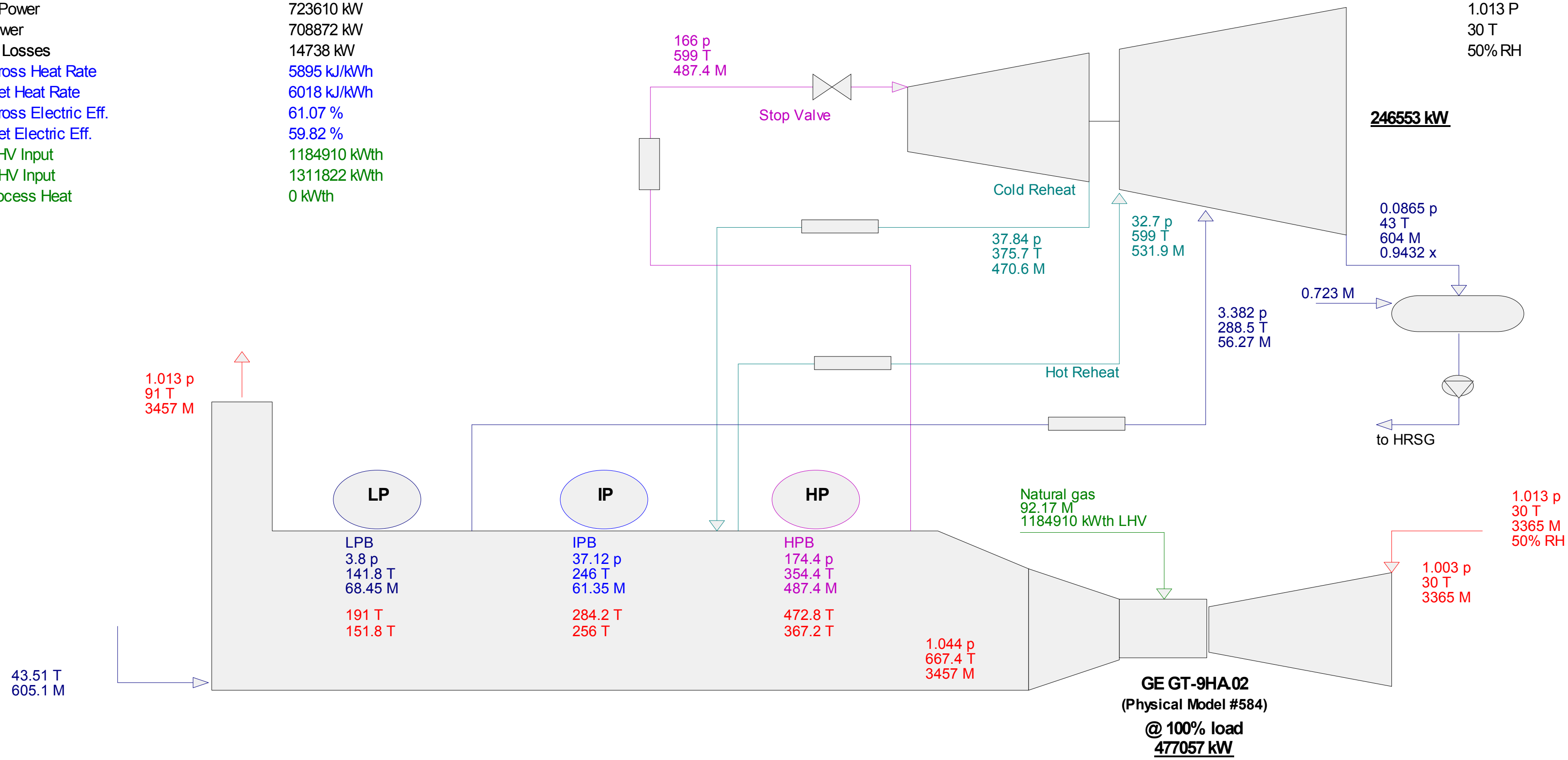
Gross Power	723610 kW
Net Power	708872 kW
Aux. & Losses	14738 kW
LHV Gross Heat Rate	5895 kJ/kWh
LHV Net Heat Rate	6018 kJ/kWh
LHV Gross Electric Eff.	61.07 %
LHV Net Electric Eff.	59.82 %
Fuel LHV Input	1184910 kWth
Fuel HHV Input	1311822 kWth
Net Process Heat	0 kWth



p [bar] T [C] M[t/h], Steam Properties: IAPWS-IF97

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WHAT CAN GO WRONG WITH A COAL FIRED BOILER?

Review of Problems that can be Caused by Coal Combustion in a Boiler.

Problems that can Occur with Any Coal

- Sticky coal – from surface water and/or clay - can block conveyors and chutes.
- Fine coal – can cause stockpile slumping following heavy rain.
- Wet Coal:
  - Low mill exit temperature.
  - Burner fuel duct blockages.
  - Reduced boiler efficiency.

Problems that can Occur with Any Coal

- Contaminated coal – large rocks or pieces of steel can damage conveyors and mills.
- High ash content:
  - Low CV
  - Excessive furnace ash.
  - High Fluegas dust emissions.
  - Reduced boiler efficiency.

Problems that can Occur with Any Coal

- Low ash fusion temperature – furnace wall slagging:
  - Reduced furnace heat transfer.
  - High furnace exit gas temperature.
  - Slag falls damage submerged chain conveyor and ash hopper walls.
  - Costly furnace cleaning.
  - Boiler tube damage.

Problems that can Occur with Any Coal

- High Sulphur content:
  - High SO_2 emissions
  - Increased FGD operating costs.
  - Increased boiler back-end corrosion.
- Low sulphur content:
  - Possible poor ESP performance.
- High load operation – increased furnace exit temperatures:
  - Increased furnace wall slagging.
  - Increased SH and RH tube fouling.

Problems with High Rank Coal

- Hard Coal (low HGI):
  - Difficult to mill.
  - Mill vibration and wear.
  - Coarse fuel to burners.
  - Excessive holdup of coal in mills – boiler instability.
- Low volatile content:
  - Can cause slow ignition.
  - Flame instability
  - Loss of flame detection – boiler trip.

Problems with High Rank Coal

- Slow burning – low furnace heat transfer:
  - Excessive superheat temperatures.
  - High tube metal temperatures.
  - Reduced boiler efficiency or output.
- Slow burning – high carbon in ash:
  - Flyash not acceptable for cement making.
  - Reduced boiler efficiency.

Problems with High Rank Coal

- High flame temperature:
  - Increased furnace heat transfer.
  - Furnace wall slagging.
  - Reduced steam temperatures.

Problems with Low Rank Coal

- Self-heating and spontaneous combustion in stockpiles.
- Dust emissions from coal plant.
- Higher moisture content – reduced boiler efficiency.
- Possible mill fires.

Problems with Low Rank Coal

- Increased Fluegas flowrate:
  - ID fan capacity can limit boiler output.
  - ESP performance reduced – higher dust emissions (worse with co-firing).
  - Higher SH and RH steam temperatures.
  - High SH and RH tube metal temperatures.

Problems with Low Rank Coal

- High alkali in ash content:
  - Sintered deposits on superheater and reheater tubes.
  - Reduced heat transfer to SH and RH steam
  - Reduced SH and RH steam temperatures.
    - Reduced unit efficiency.
    - Turbine trip.
  - Excessive sootblowing required to remove deposits online.
  - Deposits can fall onto the economiser tubes and block the gas flow.
  - Costly boiler cleaning offline.

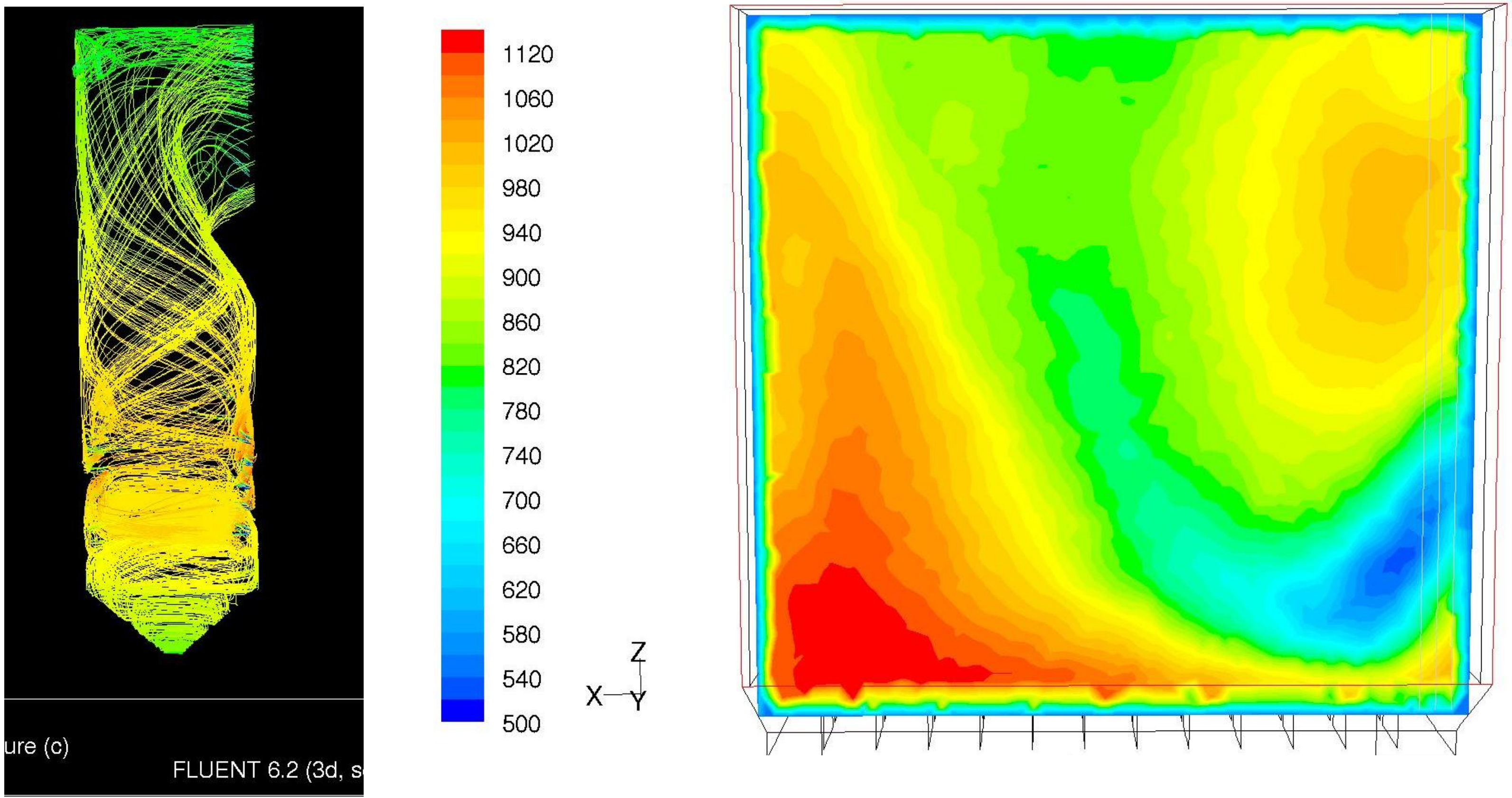
Problems with Low Rank Coal

- Co-firing high rank coal with low rank coal can aggravate ash fouling from the low rank coal because of increased furnace exit temperature.

Examples of problems encountered in boilers related to coal firing.

- **Plant: Paiton, Units 1 & 2, 2 x 400 MW, Indonesia**
  - Excessive RH tube metal temperatures on one side of boiler.
  - Coincided with increased use of low CV sub-bituminous coal.
  - Boiler design coal CV 6000 kcal/kg, operating coal 4900 – 5200 kcal/kg.
  - Higher boiler firing rates due to turbine wear
  - Higher furnace exit gas temperatures.
  - Boiler design (CE) with tangent firing causes higher gas velocity and higher gas temperatures on one side.
  - Solution: shorten RH tubes on the hot side.

Examples of problems encountered in boilers related to coal firing.



Examples of problems encountered in boilers related to coal firing.

- **Boiler Slagging and Fouling.**
  - Plant: Suralaya, Units 5 & 6, Indonesia.
  - Suralaya Power Station Units 5 and 6 (2 x 600 MW) were affected by slagging and fouling whilst burning coal supplied by PT Berau. A number of outages were caused by slag falls which damaged the submerged chain conveyors and blocked the furnace ash hopper outlet.
  - Samples of slag from the boilers and samples of leftover Berau coal were taken and analysed.

Examples of problems encountered in boilers related to coal firing.

- The chemical composition of the slag closely matched that of the coal sampled thus linking the coal sampled to the slagging problem. The sampled coal analysis was quite different to the Berau coal analyses done by both the power station and by Berau.

- The sampled coal ash contains very high levels of sodium (16.5 % Na2O in ash) which would be expected to cause severe slagging and fouling in boilers that run as hot as the Suralaya 600 MW units.

- It is believed that Berau were mining a coal seam which contained more sodium than previous seams.

Examples of problems encountered in boilers related to coal firing.

- **Furnace Slag Falls Damage Submerged Chain Conveyors.**
  - Plant: Pagbilao, 2 x 380 MW, Philippines
  - Excessive furnace slagging resulting in slag falls which have damaged the submerged chain conveyors. Boilers shutdown for repairs.
  - The coal (Tanito) has a low ash fusion temperature (1200 – 1240°C IDT) although this is within the specification range for the coal supply contract.
  - The boilers are undersized for the design load resulting in high flame temperatures.

Examples of problems encountered in boilers related to coal firing.

- There is evidence of high gas temperatures (1250 - 1300°C) close to the furnace walls which encourages slagging.
- The coal has a high iron and clay content in the ash which causes the low ash fusion temperatures.
- The boiler efficiency is reduced because of increased flue gas temperatures.
- Power station trying to avoid using the coal.

Examples of problems encountered in boilers related to coal firing.

- **Stockpile Fires**
  - Low CV sub-bituminous coal is more reactive than higher rank black coal.
  - Self-heating and spontaneous combustion of the coal in stockpiles is a common occurrence with low rank coals.
  - Can take several weeks for spontaneous combustion to occur so need to use the coal quickly.
  - Strong winds aggravate the problem by forcing more air through the stockpile.
  - Burning coal can cause damage to conveyors and mill fires.
  - The smoke can be bad for nearby villages leading to complaints.
  - Careful stockpile management and compacting required to reduce the problem.

Examples of problems encountered in boilers related to coal firing.

- **Mill Fires**
  - Plant: Hong Kong Electric, Lamma Island, 250 & 350 MW units.
  - Two mill fires occurred when burning Jembayan coal.
  - No damage was caused to the plant by the mill fires. However the incidents resulted in a temporary load reduction on the unit and expense for inspecting the mill for damage and investigation of the cause of the fires.
  - The Jembayan coal has a low rank makes it more reactive than higher ranked coals.
  - Relative Ignition Temperature tests performed on the coal showed that the samples tested had significantly lower ignition temperatures than most other coals that had been tested.
  - Solution: reduce the mill outlet temperature setting which reduces the drying and heating of the coal.

Examples of problems encountered in boilers related to coal firing.

- **Ash Hopper Explosions**
  - Plant: Millmerran, Queensland, Australia,
  - Ash falling into the furnace ash hopper water tank has caused steam explosions in the tank which has damaged the tank and tripped the furnace off-line due furnace pressure excursions.
  - This problem is typically caused by large lumps or quantities of hot ash falling into the water tank and causing rapid steam production in the tank. This creates pressure waves in the water which can damage the tank and also pressure surges in the furnace which can trip the boiler offline.
  - The explosions appear to be caused by weak friable deposits of ash falling from the furnace walls or superheater tubes that breakup rapidly when they hit the water.
  - The solution requires the deposition to be reduced so that large deposits are not formed.

Examples of problems encountered in boilers related to coal firing.

- **Furnace Ash Hopper Filled with Solidified Slag**
  - Plant: Stanwell PS, Queensland, Australia, 4 x 365 MW.
  - Unit 1 experienced a significant slagging episode during mid-March 2004. The episode led to the formation of clinker / slag on the furnace water walls of the boiler that extended halfway along the boiler hearth. This caused large lumps of clinker to bridge across the boiler hopper and then block the draglink conveyor. The Unit had to be shut-down for 8 days so that the major clinker / slagging formation could be removed and then the Unit returned to service.
  - On the occasion of the furnace blockage the ash content of the coal was 17% instead of the usual 12% and also had higher iron content than normal. The ash was found to sinter at temperatures between 1150 and 1200°C

Examples of problems encountered in boilers related to coal firing.

- **Fly-Ash Hopper Collapse**
  - Liddell PS, NSW Australia.
  - Fabric Filter section collapsed. Unit offline for months for repairs.
  - A high ash level alarm in a flyash hopper of a fabric filter was ignored. The ash was not being removed from the filter hopper and eventually the weight of the ash caused the entire filter to collapse.
  - Better operator training required to avoid a repeat.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- **Manjung PS, 3 x 700 MW plus 1 x 1000 MW**
  - Boiler (700 MW unit) tripped offline following a slag fall when burning DEJ coal.
  - DEJ coal blamed for causing slagging boiler instability.
  - Investigation revealed that the slag was caused by the coal used before DEJ.
  - The Manjung 700 MW boilers had a design problem with poor stability of the water level in the steam drum. If level gets too high or too low the boiler and turbine will be tripped offline and can take some hours to get it back online.

Examples of problems encountered in boilers related to coal firing.

- The DEJ coal was harder than other coals and difficult to mill. This caused an increased holdup of coal in the grinding mills which caused a slower response of the coal flow to the burners to changes in the coal feed rate into the mills.

- The slow response of the coal flow to the burners lead to increased instability in the boiler pressure and drum level controls. This lead to the boiler trip when it was disturbed by the slag fall.

- The boiler control system needed some retuning for the harder coal which had to be done by the OEM.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- **Kapar Stage 3, 2 x 500 MW.**
  - Problem occurred during a trial burn with Ensham Coal (Australian). When burning 100% Ensham coal at boiler loads above about 60% the main steam and reheat steam temperatures to the turbine would drop excessively. The normal steam temperature is around 538°C but it was dropping down as low as 410°C which was too low for the turbine and also caused a loss of efficiency.
  - The drop in steam temperature was being caused by too much heat transfer occurring in the furnace and not enough in the superheaters.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- The reason for the change in heat transfer was not clear and may have been caused by the ash properties or higher flame temperatures

- The Stage 3 boiler design was not suitable for the Ensham coal however the coal performed satisfactorily in the Kapar Stage 2 boilers.

- The Ensham coal only be used in Stage 3 boilers when co-fired with another coal

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- **Kapar Stage 2, 3 x 300 MW**
  - Combustion trial with Bontang coal (Indonesian).
  - Bontang coal is a low rank coal with a good CV and low ash content but high sodium and potassium in the ash.
  - Boiler operation initially OK but after 4 days there were large ash deposits in the furnace and on the superheater tubes. Operation was able to continue with increased use of sootblowers to control the ash deposits.
  - After about 8 days on Bontang coal the furnace gas pressure started to increase despite the ID fan running at full capacity. The problem was caused by a thick layer of ash deposits on top of the economiser tubes.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- After 10 days the boiler was shut down with a tube leak adjacent to the economiser. This was probably caused by erosion of the wall tubes due to high gas velocities in the remaining gas flow path.

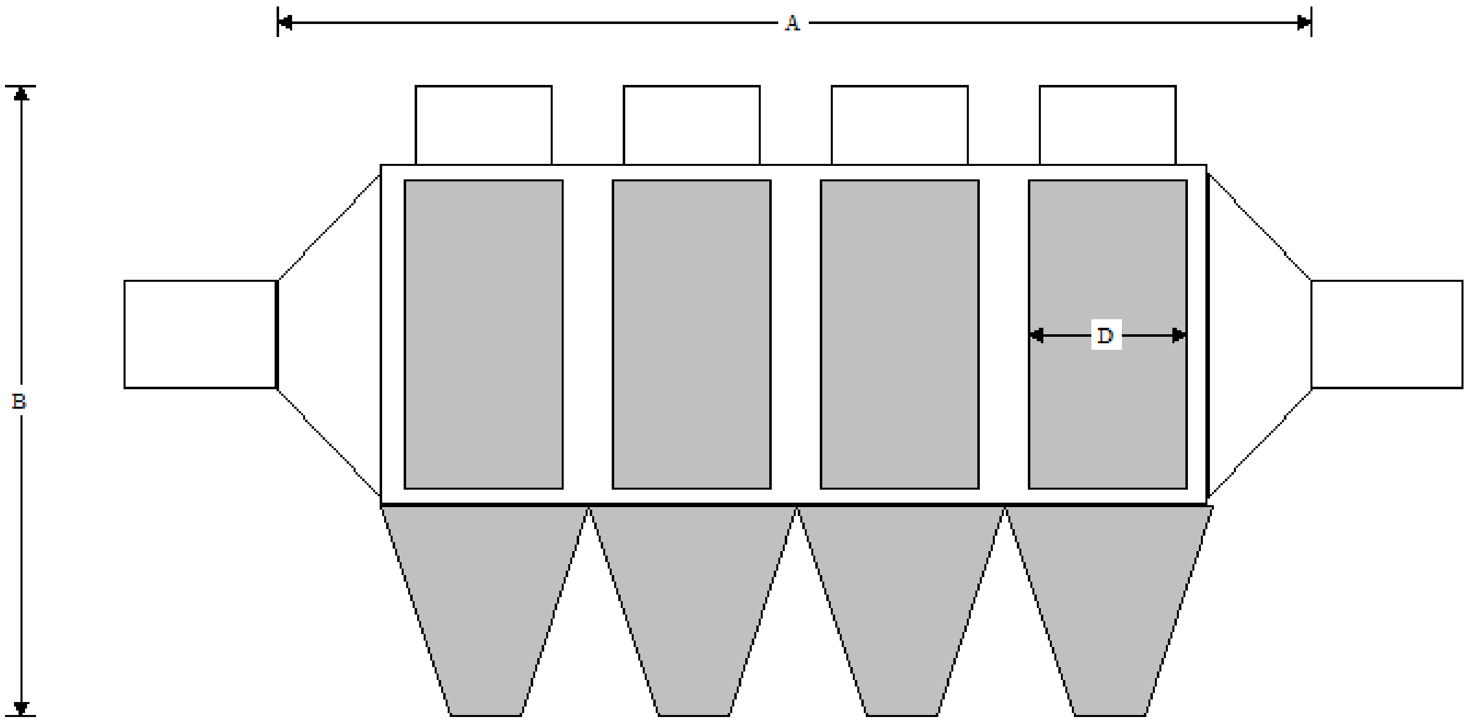
- The tube repairs were expensive and the boiler was offline for a few days.

- The ash deposition was due to the relatively high sodium and potassium content of the ash. This causes sintering of the ash deposits in superheater and reheater tube banks. When the deposits are blown off the tubes with sootblowers they fall down and can accumulate on the top of the economiser because of the closer tube spacing there.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- **Tanjung Bin PS, 3 x 700 MW Units.**
  - Problem: High fluegas dust emissions being attributed to the use of Forzando (South African) coal.
  - Several shipments of this coal have been successfully burnt at this power station except for a problem with elevated dust emissions from the electrostatic precipitators (ESP). Forzando coal does not cause this problem at other power stations.
  - The ESPs on each unit TBP consist of four parallel flow paths each with four zones in series. It was apparent from the ESP high voltage (HV) power supply data that only the first zone of each flow path was operating with a normal voltage. The other three zones in each path were operating with voltages too low for good ESP operation. The low voltages were causing the high dust emissions.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations



Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- At the same time, examination of the HV data for the other two units at TBP which were operating on different coals showed the same pattern of low voltages on 3 out 4 zones for each flow path. Hence the problem was due to the ESP design, not the Forzando coal.
- A review of the historical data for the TBP ESP indicated that this problem was present most of the time except for a few days after a boiler and ESP clean. This suggested the problem was caused by a build-up of ash on the ESP plates which can take a few days to accumulate. This problem is caused by inadequate rapping of the plates. If the ash layer builds up too much a phenomenon called “back corona” occurs which reduces the HV voltage and the efficiency of the ESP.
- TBP have improved the ESP rapping and reduced the dust emissions enough to meet the emission limits.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- **Tanjung Bin PS, 3 x 700 MW**
  - Problem: TBP have suffered from ash fouling, economiser tube bank blockages and reheater and superheater tube failures.
  - There is some correlation between blockage of the economiser tube banks and use of Twistdraai (South African) coal in all three units at TBP but several other coals were also burnt at the same time.
  - TBP had been operating at high load continuously for long periods which leads to high gas temperatures and increase ash deposit formation.
  - The blockage of the economiser tube banks appears to cause problems with reheater and superheater tube failures.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- There is clear evidence that at least one of the TBP boilers is suffering from an imbalance in the fuel and air splits. This could cause or contribute to ash fouling and overheating of reheater tubes.
- Twistdraai coal does not appear to have an ash composition that would cause ash fouling but the Kayan sub-bituminous coal that was co-fired with it does have relatively high alkali in ash.
- The Twistdraai coal was burnt without problems at Manjung, Kapar and Jimah power stations. It has also been used extensively in other countries without fouling problems.

Examples of problems encountered in boilers related to coal firing in Malaysian Power Stations

- The two-pass boiler design with finned tube economiser is not a good design for use with low rank coals which cause sintered deposits in the superheater and reheater tube banks. Deposits falling from these tube banks will fall onto the top of the economiser tubes and can't get though because of the tight fin spacing.
- It is important to avoid the use of low rank coals such as the Kayan coal, which has elevated levels of sodium and potassium, in a two-pass boiler with a finned tube economiser.

- End of Presentation
- Questions
- Discussion