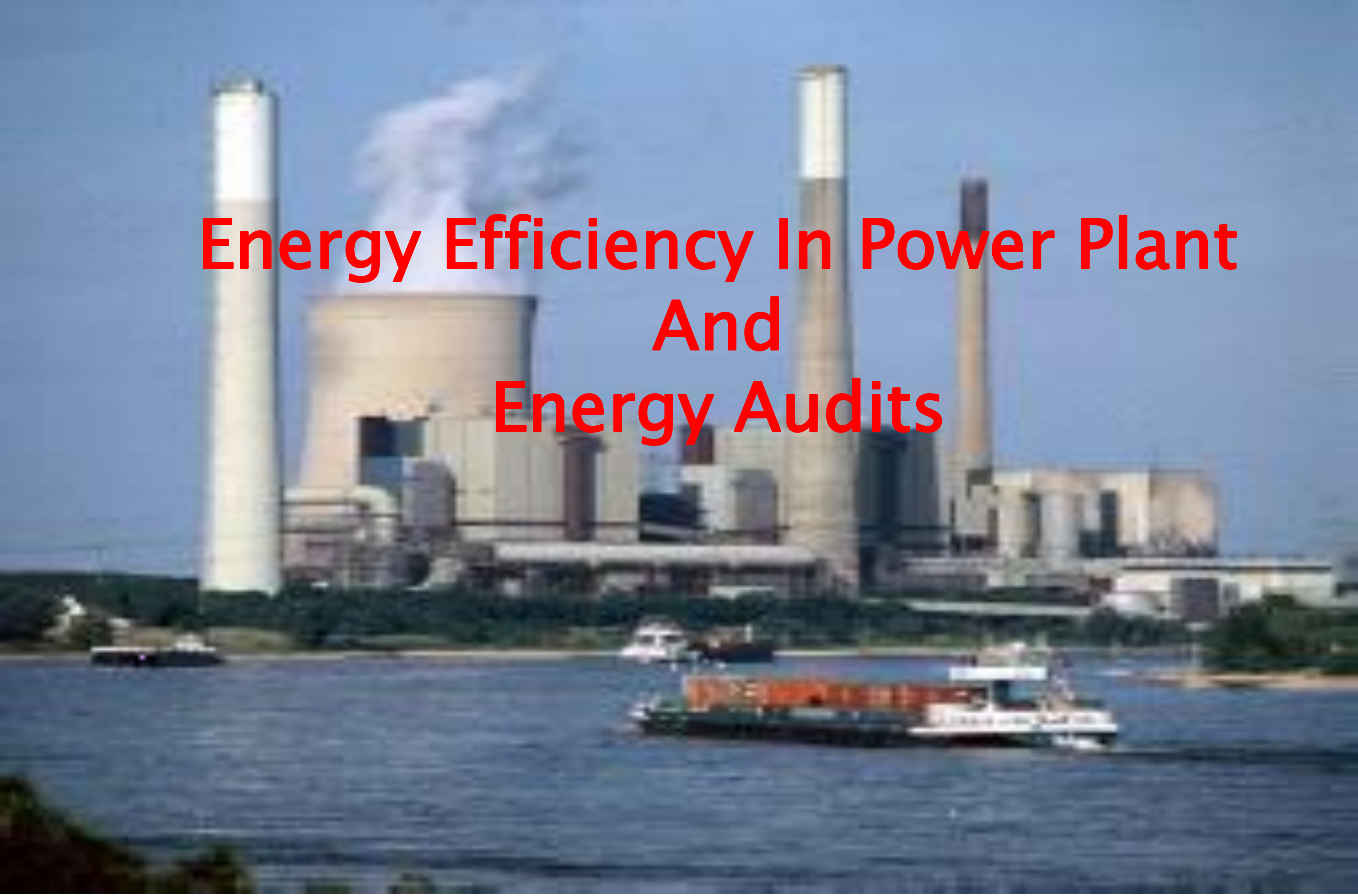

Energy Efficiency In Power Plant
And
Energy Audits

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NPTI

INDO GERMAN ENERGY PROGRAM

Carnot Efficiency

The ideal efficiency of a thermal process or 'Carnot' efficiency is a measure of the quality of the conversion of heat into work between two temperature levels.

$$\eta = 1 - \frac{T_0}{T}$$

T_0 the ambient temperature

T temperature at which the heat is yielded ortaken up

T_0 and T expressed in Kelvin $T(K) = T(^{o}C) + 273.15$

Overall efficiency

$$\eta = \frac{\text{Energy Output}}{\text{Energy Input}}$$

$\eta_{tot} = \eta_{be} \times \eta_{th} \times \eta_{el} \times \eta_{cl}$ (No dimension)

η_{tot}	total efficiency
η_{be}	boiler efficiency
η_{th}	thermal efficiency of the turbine
η_{el}	electrical efficiency
η_{cl}	losses of thermodynamic cycle

Efficiency

$$\eta = \frac{P_{gen}}{M_f * H_u}$$

η	Efficiency	--
P_{gen}	Generator capacity	KW
M_f	Mass flow of the fuel	Kg/Sec, Kg/hr
H_u	Lower heating value	KJ/Kg

In India high heating values of coal known as GCV (Gross calorific value) in kCal/Kg is taken for efficiency calculation

The degree of fuel efficiency

- Defined for cogeneration plants which generate and emit electrical and thermal energy (heat)

- The useful output consists of the sum of the generated electrical energy and the generated thermal energy.

$$\eta_{fu} = \frac{P_{gen} + \dot{Q}_{heat}}{\dot{m}_f \cdot H_u}$$

		Dimension
η_{fu}	Degree of fuel use	–
P_{gen}	Generator output	kW
$\dot{Q}_{heat}$	Useful thermal heat	kJ/kg
$\dot{m}_f$	Mass flow of the fuel	kg/s, kg/h
H_u	Lower heating value	kJ/kg

Proportional auxiliary station service

$$e = \frac{P_{own}}{P_i}$$

		Dimension
e	Proportional auxiliary consumption	–
P_i	Gross generator output	kW
P_{own}	Electrical auxiliary consumption	kW

High voltage net capacity

$$P_{net} = P_i \cdot (1 - e) \cdot \eta_{tr} \qquad [kW]$$

		Dimension
e	Proportional auxiliary consumption	–
η_{tr}	Efficiency of machine transformer	–
P_i	Gross generator output	kW
P_{net}	High-voltage side net generator output	kW

Supplied useful heat capacity

$$Q_{SG} = (Q_{SS} - Q_{FW}) + (Q_{RH} - Q_{nRH}) \qquad [kJ/s]$$

		Dimension
Q_{FW}	Feed water heat capacity supplied to the boiler	kg/s
Q_{nRH}	Heat quantity without reheating supplied to the boiler	kg/s
Q_{RH}	Reheated heat quantity supplied to the machine	kg/s
Q_{SG}	Useful thermal quantity input into the process	kg/s
Q_{SS}	Superheated steam heat quantity input into the machine	kg/s

Heat consumption of generating unit

$$q_e = \frac{Q_f}{P_{net}} = \frac{\dot{m}_f}{P_{net}} \cdot H_u \qquad [kJ/kWs \text{ or } kJ/kWh]$$

		Dimension
H_u	Lower heating value	kJ/kg
$\dot{m}_f$	Mass flow of the fuel	kg/s, kg/h
P_{net}	High-voltage side net generator output	kW
q_e	Specific net heat consumption	kJ/kWh, kJ/kWs
Q_f	Average fuel heat	kg/s, kg/h, kg/month

Overall efficiency of power plant

$$\eta_{tot} = \eta_{be} \cdot \eta_{th} \cdot \eta_{el} \cdot \eta_{cl} = \frac{3.600}{q_e} \qquad [kJ/kWh]$$

		Dimension
η_{tot}	Total efficiency	–
η_{be}	Boiler efficiency	–
η_{th}	Thermal efficiency of the turbine	–
η_{el}	Electrical efficiency	–
η_{cl}	Losses of thermodynamic cycle	–
q_e	Specific net heat consumption	kJ/kWh, kJ/kWs

Fuel consumption

$$\dot{m}_f = q_e \cdot P_e \cdot \frac{1}{H_u} \qquad [kg/s \text{ or } kg/h]$$

		Dimension
H_u	Lower heating value	kJ/kg
$\dot{m}_f$	Mass flow of the fuel	kg/s, kg/h
P_e	Net generator output	kW
q_e	Specific net heat consumption	kJ/kWh, kJ/kWs

Specific fuel consumption

$$f = \frac{\dot{m}_f}{P_e} \text{ or } \frac{q_e}{H_u} \qquad [kJ/kWh]$$

		Dimension
f	Specific fuel consumption	kg/kWh
H_u	Lower heating value	kJ/kg
$\dot{m}_f$	Mass flow of the fuel	kg/s, kg/h
P_e	Net generator output	kW
q_e	Specific net heat consumption	kJ/kWh, kJ/kWs

Relationship between efficiency and environmental issues

Savings in fuel

$$\Delta e = 1 - \frac{\eta_1}{\eta_2}$$

Reduction in waste heat

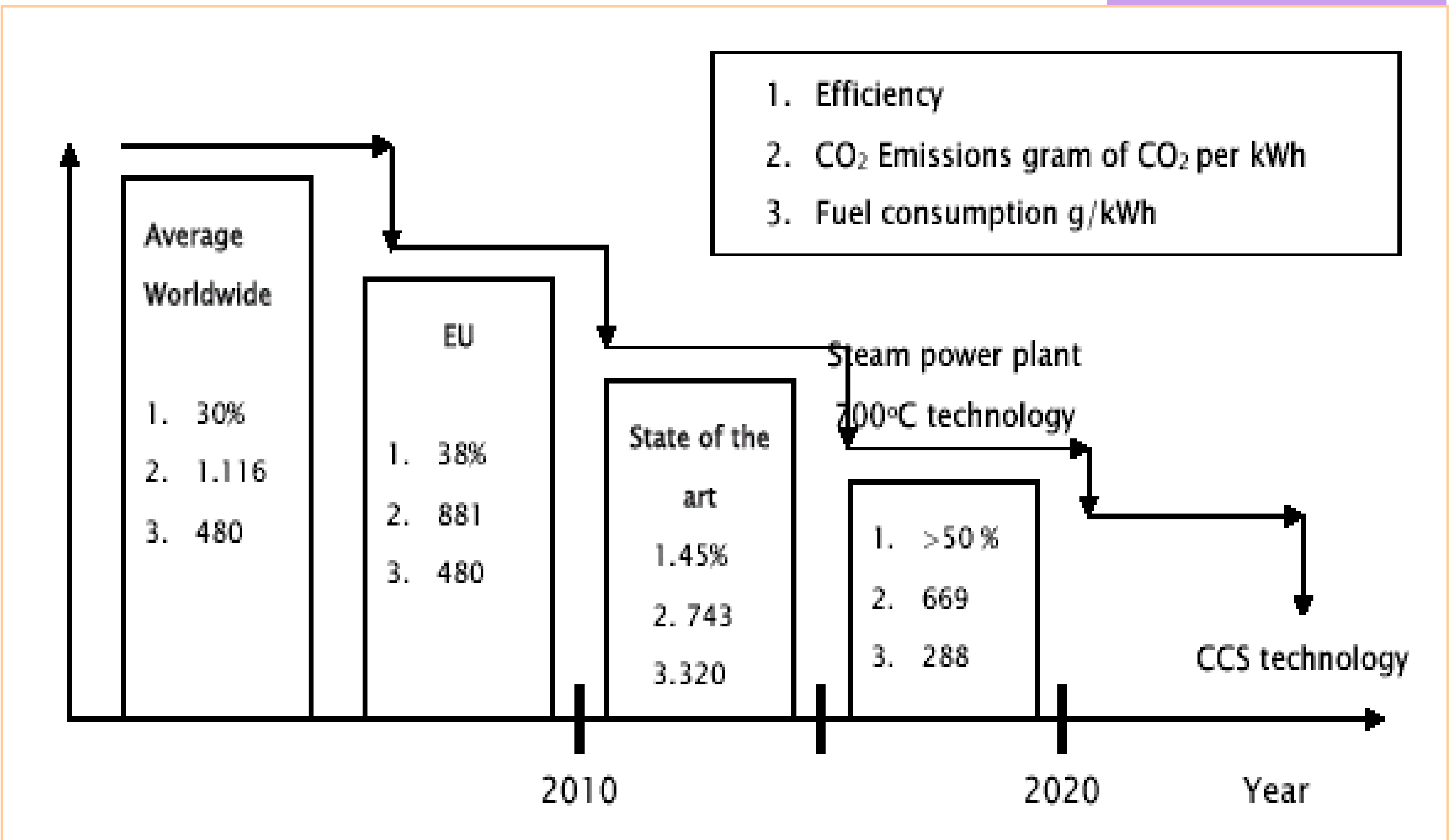
$$\Delta a = \frac{\Delta e}{1 - \eta_1}$$

		Dimension
η_1	efficiency before improvement	-
η_2	efficiency after improvement	-
VR	volume of air/kg fuel	m^3/kg
X	threshold limit value	mg/m^3
H_u	lower calorific value	MJ/kg

Reduction of CO2 emissions

$$\Delta c = 1 - \frac{\eta_1}{\eta_2}$$

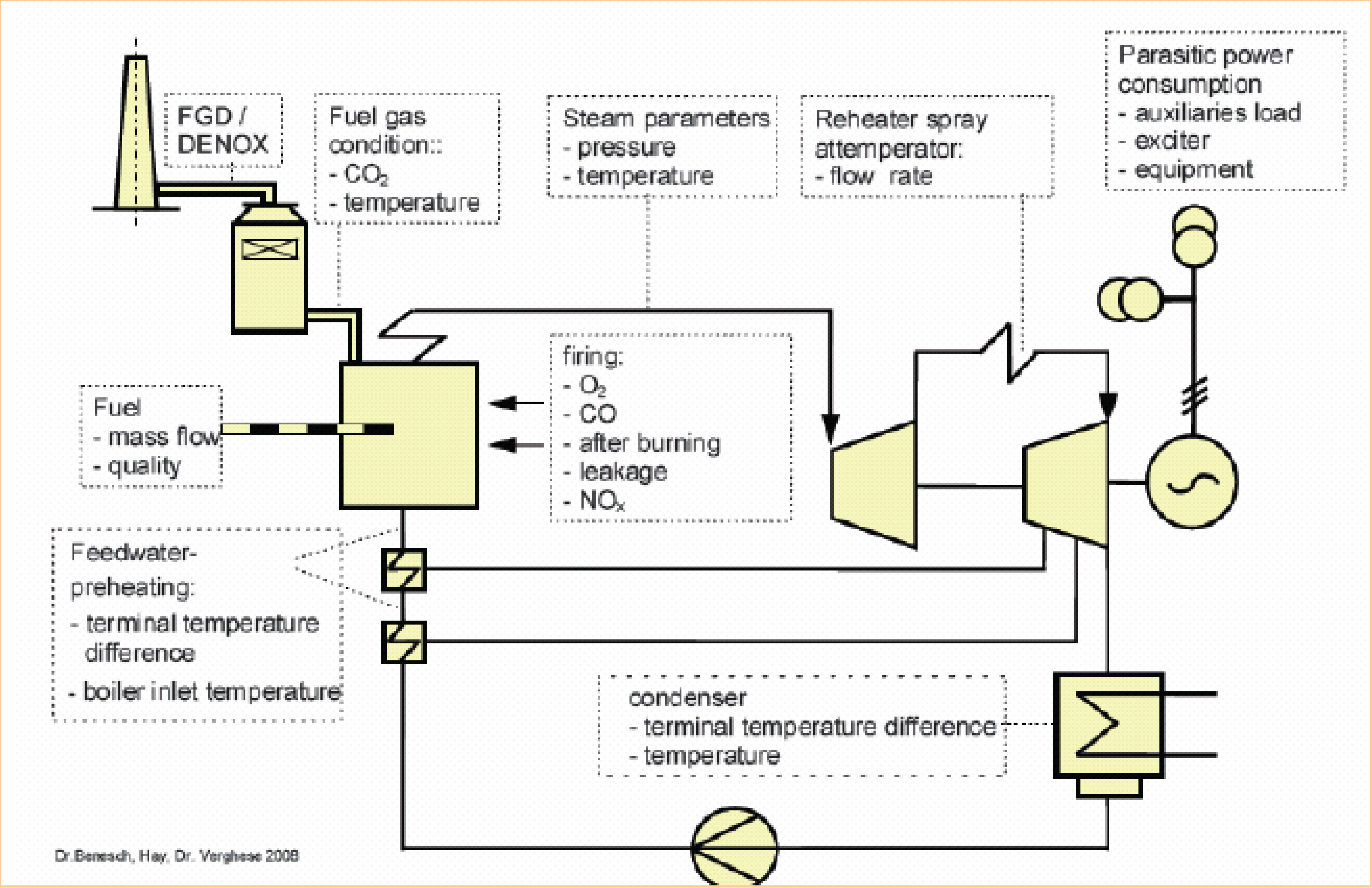
Worldwide Energy Saving Potential



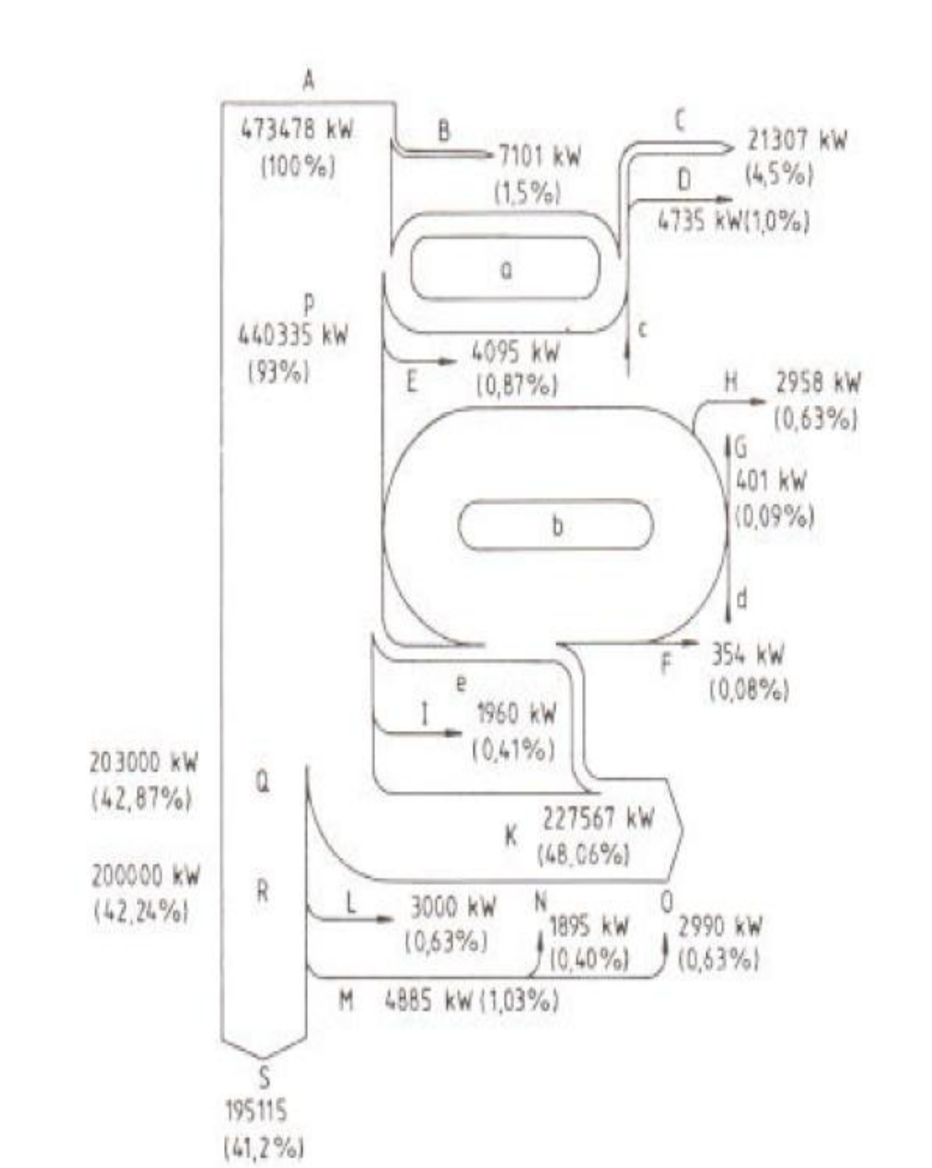
Efficiency Benchmarking

Plant	Steam conditions MPa / °C / °C	Net thermal efficiency, %	
		HHV %	LHV %
Tachibanawan (Japan)	24.1 / 600 / 610	42.1	44
Tanners Creek (USA)	24.1 / 538 / 552 / 566	39.8	42
Nordjylland 3 (Denmark)	29.0 / 582 / 580 / 580	45	47.0
Niederaussem K (Germany)	27.5 / 580 / 600	42-43	45.2

Performance monitoring of power stations



Sankey Diagram



- a) Flue gas – air preheating
- b) Feed water preheating
- c) Fresh air
- d) Make-up water
- e) Feed pump turbo set
- A) Fuel energy input
- B) Losses due to radiation and unburnt material
- C) Exhaust gas loss
- D) Ash losses
- E) Pipe losses
- F) Loss of the feed pump turbo set
- G) Heat loss of the preheating installation
- H) Circulation losses (water and steam)
- I) Turbine losses
- K) Thermodynamic cycle (water & steam)
- L) Losses of generator
- M) Auxiliary consumption, overall
- N) Auxiliary consumption of the turbine installation
- O) Auxiliary consumption of the steam generators
- P) Steam generator output
- Q) Turbine output
- R) Generator output
- S) Effective useful output

Energy flow in a 200 MW power unit, layout design:

Mass flow live steam ($\dot{m}_s$) 167.8 kg/s; 245 bar/520 °C

First intermediate superheating 78.5 bar/530 °C

Second intermediate superheating 22 bar/540 °C

Condenser pressure approx. 0.0235 bar

Feed water end preheating 303.6 °C (nine preheater stages)

Indian Scenario: Design Heat Rate Trends*

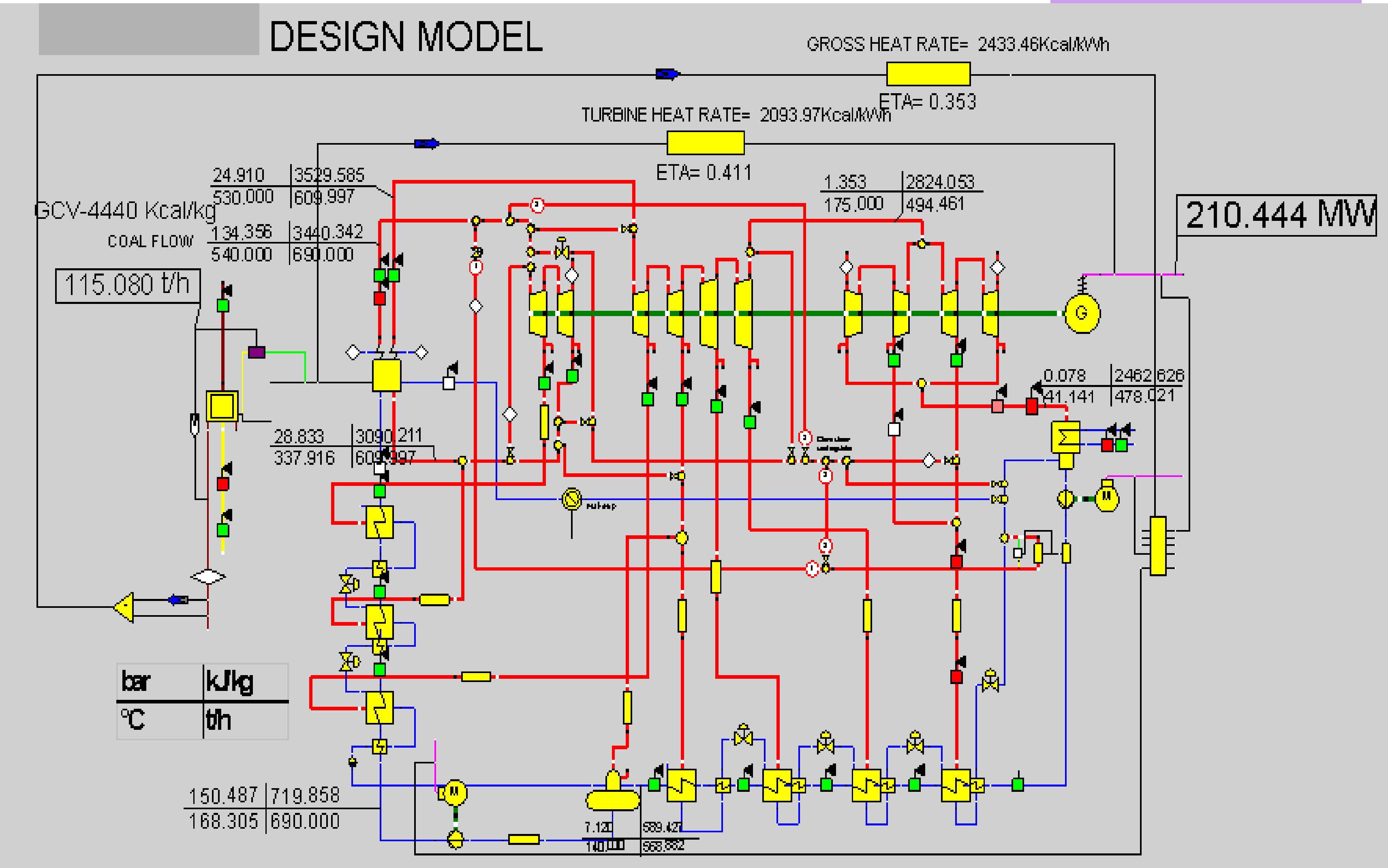
PERIOD	STEAM PRESSURE& TEMPERATURE	UNIT SIZE (MW)	TURBINE Heat Rate (Kcal/kWh)	Unit Heat Rate (Kcal/kWh)
1951-60	60 kg/cm^2, 482°C	30 – 57.5	2470	
1961-75	70 kg/cm^2, 496°C to 90 ata 538°C	60 – 100	2370	
1961-75	130 ata 535/535°C	110 – 120	2170 – 2060	2552-2423
1977-82	130 ata 535/535°C	210 (Russian)	2060	2423
1983+	150 ata 535/535°C	210 (Siemens)	2024	2335
1984+	170 ata 535/535°C	500	1950 (TDBFP)	2294
1990+	150 ata 535/535°C 170 ata 538/538 °C	210/ 250 250/ 500	1950 (MDBFP) 1950 (TDBFP)	2294 2294

*Above are best design values (design rates of individual unit varies based on reference ambient, coal quality, design and supply dates)

Mapping Studies – Progress Achieved

- **Mapping studies of 85 Thermal power generating units of the 14 States**
- **Ebsilon Software is used**
- **Deviations between design and operating parameters such as gross heat rate, turbine heat rate, boiler efficiency , specific coal consumption of the power generating units are analysed.**
- **Operating Gross Heat Rate was found to be varying from 2477 to 3084 kCal/kWh against their design values of 2321 and 2444 kCal/kWh respectively, exhibiting deviation band width of 156 kCal/kWh (6.3%) to 640 kCal/kWh (20.7%)**

Power Plant Mapping



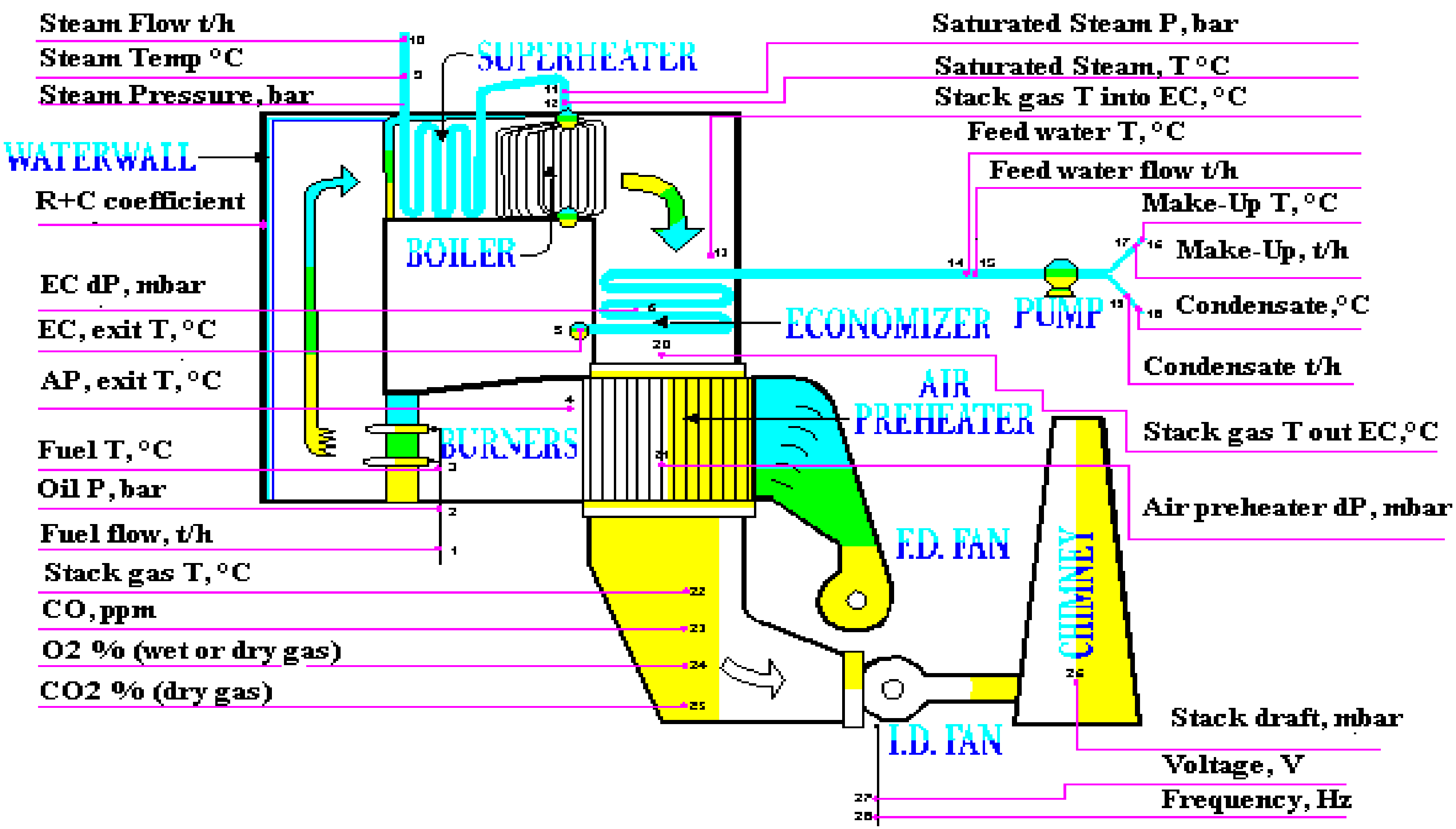
Economic Aspects Of Inefficient Machines (200 Mw)

	SHORT FALL	LOSS IN CRORES PER ANNUM
TURBINE CYCLE HEAT RATE	1.0 %	5.0
TG OUTPUT	1.0%	5.0
BOILER EFFICIENCY	1.0%	1.75
AUX. POWER CONSUMPTION	5.0 %	2.5

NOTE:

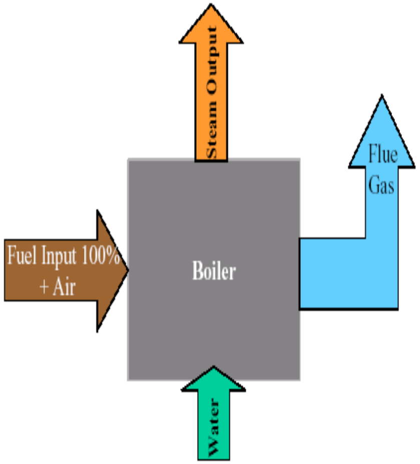
- TG CYCLE HEAT RATE IS TAKEN AS 2000 KCAL / KWh
- COAL CV IS TAKEN AS 4000 KCAL / Kg
- PRICE OF COAL TAKEN AS Rs. 2000 / TON
- LOSS INCREASES WITH MACHINE SIZE

Important Performance Parameters of Boilers



Boiler Efficiency

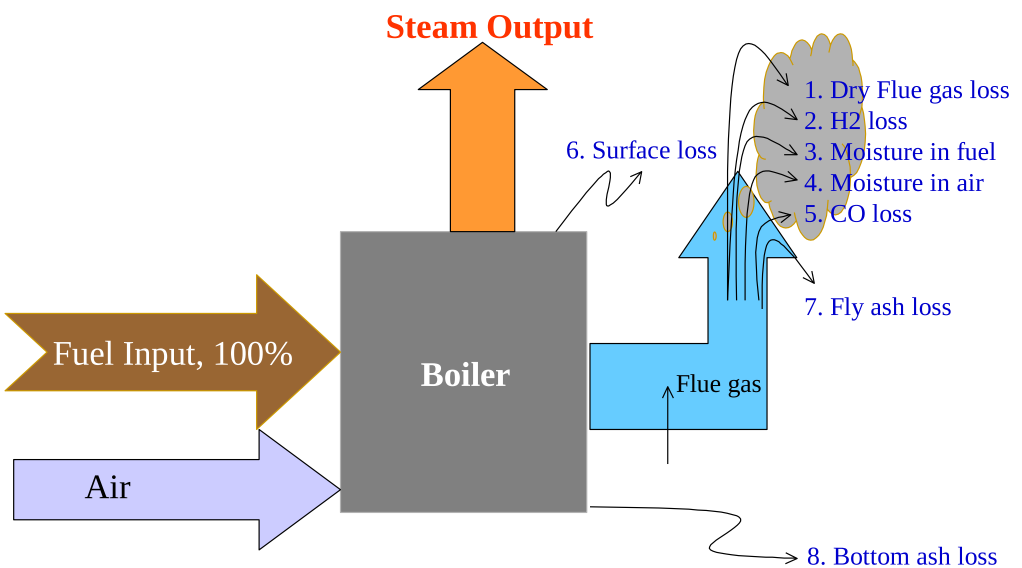
Direct Method



$$\text{Efficiency} = \frac{(\text{Heat absorbed by working fluid})}{(\text{Heat in fuel} + \text{Heat credits})} \times 100$$

Boiler Efficiency

Heat Loss Method



Efficiency = **100 – (1+2+3+4+5+6+7+8)**

(by In Direct Method)

Boiler Efficiency

Data & sample collection

- Flue gas temperature at air heater outlet.
- Dry & wet bulb temperature of ambient air.
- Flue gas analysis for O2, CO2, CO & excess air.
- Relative humidity from psychometric chart.
- Coal sampling.
- Bottom & fly ash sampling.

Boiler Efficiency Calculation

Theoretical Air Requirement

Theoretical air requirement

$$[(11.6 x C) + \{34.8 x (H_2 - O_2/8)\} + (4.35 x S)]/100 \text{ kg/kg of fuel}$$

Actual Air Requirement

Excess Air supplied (EA) $= \dfrac{O_2\%}{21 - O_{2\%}} x100$

Actual mass of air supplied/ kg of fuel (AAS) = {1 + EA/100} x theoretical air

Mass flow of Flue Gases

m = mass of dry flue gas in kg/kg of fuel

m = Combustion products from fuel: CO_2 + SO_2 + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas. (H_2O/Water vapour in the flue gas should not be considered)

Boiler Efficiency

I. Dry Flue gas Loss

$$\text{Percentage heat loss due to dry flue gas} = \frac{m\,x\,C_p\,x\,(T_f - T_a)}{GCV\ of\ fuel}\ x\ 100$$

m = mass of dry flue gas in kg/kg of fuel

m = Combustion products from fuel: CO_2 + SO_2 + Nitrogen in fuel + Nitrogen in the actual mass of air supplied + O_2 in flue gas. (H_2O/Water vapour in the flue gas should not be considered)

C_p = Specific heat of flue gas (0.23 kcal/kg ^{0}C)

II. Loss due to H2 in Fuel

Percentage heat loss due to evaporation of water formed due to H_2 in fuel

$$= \frac{9\ x\ H_2\ x\ \{584 + C_p\ (T_f - T_a\ )\}}{GCV\ of\ fuel}\ x\ 100$$

Where, H_2 – kg of H_2 in 1 kg of fuel

C_p – Specific heat of superheated steam (0.45 kcal/kg ^{0}C)

Boiler Efficiency

III Loss due to moisture present in Fuel

Percentage heat loss due to evaporation of moisture present in fuel

$$= \frac{M \times \{584 + C_p (T_f - T_a)\}}{\text{GCV of fuel}} \times 100$$

Where, M – kg of moisture in 1kg of fuel

C_p – Specific heat of superheated steam (0.45 kcal/kg)^{0}C

* 584 is the latent heat corresponding to the partial pressure of water vapour.

IV Heat Loss due to moisture present in Air

Percentage heat loss due to moisture present in air

$$= \frac{AAS \times \text{humidity factor} \times C_p \times (T_f - T_a)}{\text{GCV of fuel}} \times 100$$

C_p – Specific heat of superheated steam (0.45 kcal/kg ^{0}C)

Boiler Efficiency

V Heat Loss due to unburnt in Fly Ash

Percentage heat loss due to unburnt in fly ash

$$= \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of fly ash}}{\text{GCV of fuel}} x\,100$$

VI Heat Loss due to unburnt in bottom Ash

Percentage heat loss due to unburnt in bottom ash

$$= \frac{\text{Total ash collected / kg of fuel burnt x G.C.V of bottom ash}}{\text{GCV of fuel}} x\,100$$

VII Percentage heat loss due to radiation and other unaccounted loss of a 500 MW boiler, values between 0.2% to 1%

Efficiency of boiler (η) = 100 – (i + ii + iii + iv + v + vi + vii)

Energy Conservation Opportunities–Optimization

- **Stack Temperature**
  - Boiler Soot Deposits, High Excess Air , Air inleakages before the combustion chamber, Low Feed Water Temperature , Passing dampers and poor air heater seals , Higher elevation burners in service, Improper combustion…

- **Incomplete Combustion**
  - Poor milling i.e. Course grinding, Poor air/fuel distribution to burners, Low combustion air temperature, Low primary air temperature, Primary air velocity being very high/very low, Lack of adequate fuel/air mixing…..

Energy Conservation Opportunities– Optimization

- **Dry Flue Gas Loss**
  - Air in-leakage through man holes, peep holes, bottom seals, air heater seal leakage, uneven distribution of secondary air, Inaccurate samples/analysis
- **Poor automatic boiler** SADC, Burner tilting, O2 control….
- **Radiation and Convection Heat Loss**
  - casing radiation, sensible heat in refuse, bottom water seal operation, not much controllable but better maintenance of casing insulation can minimize the loss.

Energy Conservation Opportunities–Optimization

- **Blowdown**
  - 1 % of blow down carries a 0.17% heat added, In the boiler, 0.25% heat is required to make Up accounts to 0.42% so blow down to be adhered to the chemist requirement.
- **Scaling and Soot Losses**
  - Super heated steam with high enthalpy is used.
  - 1% of steam may be required, contains 0.62% heat content, to make up the loss another 0.25% heat to be added to feed water resulting total heat loss of 0.87%.
  - Frequency of soot blowing must be carefully planned.
- **Auxiliary Power Consumption**

Controllable Losses–Thermal Cycle

- Throttle steam temperature/pressure
- HRH temperature
- SH/RH Attempration
- Feed water temperature
- Condenser back pressure
- TTD of feed water heaters
- Variable pressure and fixed pressure operation

Heat Rate

The turbo generator performance is calculated as heat rate rather than efficiency

Heat rate

$$=[M1(h1-hg)+m2(h3-h2)]/Eg \text{ kJ/KWH}$$

M1=steam flow kg/hr

M2=steam flow to R/H kg/hr

H1=enthalpy of TSV kJ/kg

Hg=enthalpy of feed kJ/kg

H3=enthalpy of HRH kJ/kg

Eg=net load generated KW

Deterioration of Cylinder Efficiency

- HP Cylinder
- IP Cylinder
- LP Cylinder
  - Damage to the blade by debris getting past the stem strainers.This will effect the early stages most
  - Damage to tip seals
  - Deposition on the blades
  - Increase in surface roughness of blades

Effect of Condenser Vacuum on Heat Rate

10 MM HG IMPROVEMENT IN CONDENSER VACUUM LEADS TO 20 Kcal/kwh (1%) IMPROVEMENT IN HEAT RATE FOR A 210 MW UNIT

Impact of Turbine Efficiency on HR/Output

Description	Effect on TG HR	Effect on KW
1% HPT Efficiency	0.16%	0.3%
1% IPT Efficiency	0.16%	0.16%
1% LPT Efficiency	0.5 %	0.5 %

Output Sharing by Turbine Cylinders are around

HPT	28%
IPT	23%
LPT	49%

Effect of Operating parameters on Heat Rate

	Variation	Impact (kCal/kWh)	
		200 MW Unit	500 MW Unit
SH Spray	20 T/hr	0.30	0.81
RH Spray	20 T/hr	12.00	4.76
MS Pr.	10 kg	12.00	7.30
MS Temp.	10°C	6.00	6.20
RH Steam Temp	10°C	6.00	5.55
Load	10 MW	12.00	4.36
Cond. Back Pr.	5 mm Hg	8.00	6.70
FW Temp.	10°C	8.00	10

Energy Audit

"The verification,monitoring and analysis of use of energy including submission of technical report containing recommendations for improving energy efficiency with cost benefit analysis and an action plan to reduce energy consumption".

Energy Audit

Energy audit is

- Performing rigorous data collection
- Conducting performance evaluation test, if required
- Identifying faults in the system
- Suggesting appropriate measures to stop energy and/or material loss
- Suggesting appropriate technology / device to
  - Reduce energy consumption
  - Providing cost-benefit analysis for new installations outlining an implementation strategy

Purpose of Energy Audit

- ☞ Monitoring fuel & power consumption and equipment and macro level
- ☞ Monitoring energy performance parameters with reference to design Values
- ☞ Plugging leaks / wastages
- ☞ Merit rating of multiple equipment for user benefit
- ☞ Identifying impact parameters on plant Efficiency
- ☞ Means to identify Encon opportunities
- ☞ Means to identify bill reduction opportunities

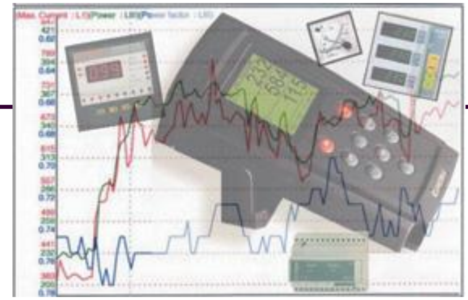
Methodology

- Historic data analysis
- Measurements
- Trials / experiments
- Consolidation of findings
- Identification of ENCON options
- Vendor data collection
- Cost benefit analysis
- Prioritization of ENCON options
- Implementation / monitoring

Potential Areas of Energy Audit

- Motors
- Boilers
- Furnaces
- Pumps
- Fans
- Air compressors
- A/c plants
- Heat exchangers
- Key process equipment
- Conveyors
- Mills, crushers, etc.
- Transformers
- Water treatment
- DG sets
- Cooling towers
- Lighting
- Switchyard energy balance
- Cooling water systems

Use necessary Energy Audit Instruments

 	**Electrical Measuring Instruments:** These are instruments for measuring major electrical parameters such as kVA, kW, PF, Hertz, kvar, Amps and Volts. In addition some of these instruments also measure harmonics. These instruments are applied on-line i.e on running motors without any need to stop the motor. Instant measurements can be taken with hand-held meters, while more advanced ones facilitates cumulative readings with print outs at specified intervals.
	**Combustion analyzer:** This instrument has in-built chemical cells which measure various gases such as CO_2, CO, NO_X, SO_X etc
	**Fuel Efficiency Monitor:** This measures Oxygen and temperature of the flue gas. Calorific values of common fuels are fed into the microprocessor which calculates the combustion efficiency.
	**Fyrite:** A hand bellow pump draws the flue gas sample into the solution inside the fyrite. A chemical reaction changes the liquid volume revealing the amount of gas. Percentage Oxygen or CO_2 can be read from the scale.
	Contact thermometer:

Energy Audit Instruments

	**Contact thermometer:** These are thermocouples which measures for example flue gas, hot air, hot water temperatures by insertion of probe into the stream. For surface temperature a leaf type probe is used with the same instrument.
	**Infrared Pyrometer:** This is a non-contact type measurement which when directed at a heat source directly gives the temperature read out. Can be useful for measuring hot jobs in furnaces, surface temperatures etc.
	**Pitot Tube and manometer:** Air velocity in ducts can be measured using a pitot tube and inclined manometer for further calculation of flows.
	**Ultrasonic flow meter:** This a non contact flow measuring device using Doppler effect principle. There is a transmitter and receiver which are positioned on opposite sides of the pipe. The meter directly gives the flow. Water and other fluid flows can be easily measured with this meter.

Energy Audit Instruments

Tachometer

Stroboscope

Speed Measurements:

In any audit exercise speed measurements are critical as thay may change with frequency, belt slip and loading.

A simple tachometer is a contact type instrument which can be used where direct access is possible.

More sophisticated and safer ones are non contact instruments such as stroboscopes.

Leak Detectors:

Ultrasonic instruments are available which can be used to detect leaks of compressed air and other gases which are normally not possible with human abilities.

Lux meters:

Illumination levels are measured with a lux meter. It consists of a photo cell which senses the light output, converts to electrical impulses which are calibrated as lux.

Format for Boiler Efficiency Testing

Sheet 3 – Format sheet for boiler efficiency testing

Date: ………………… Boiler Code No. …………………

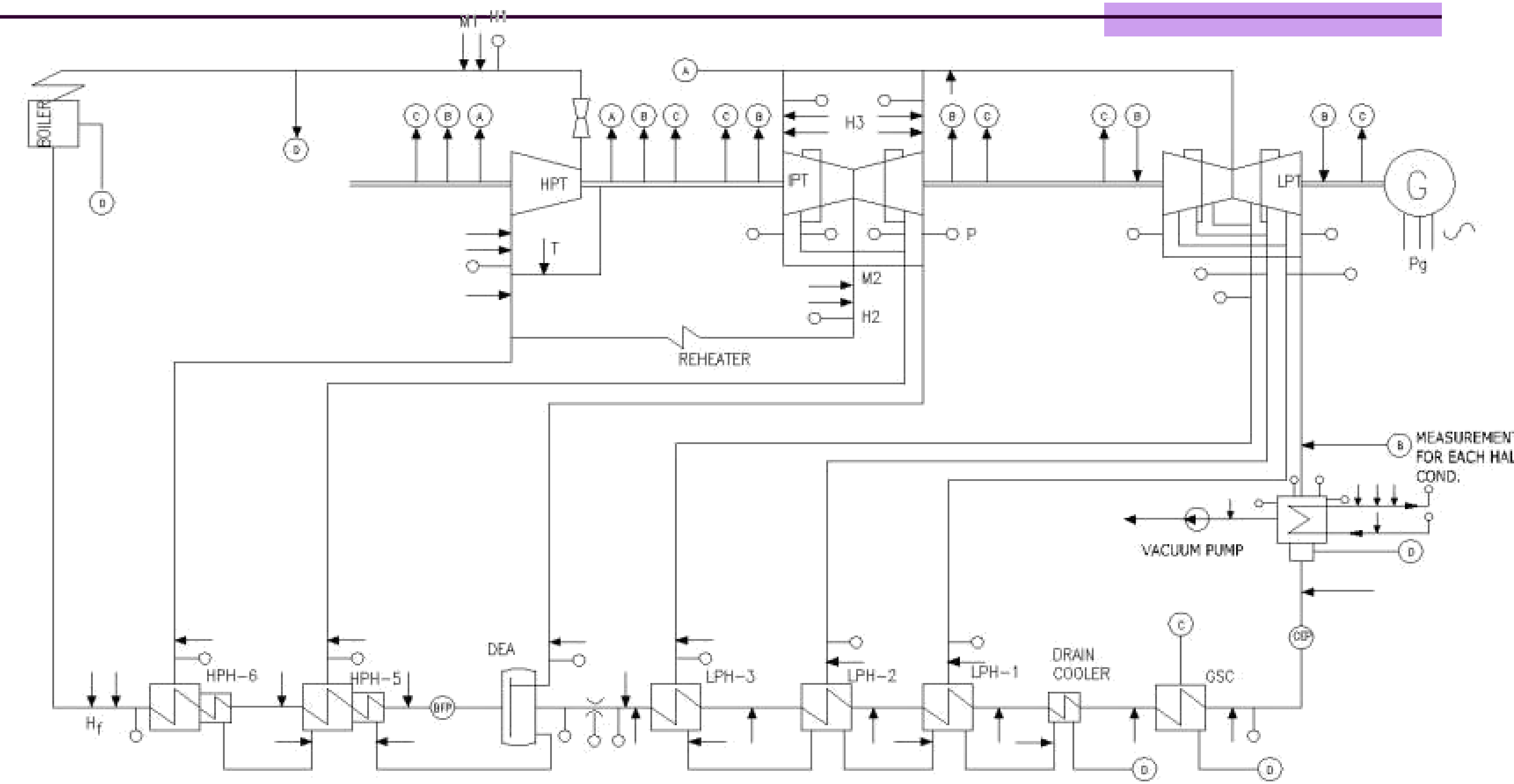
S.No	Time	Ambient air		Fuel		Feed water		Steam			Flue gas analysis				Surface Temp of boiler, °C
		Dry bulb Temp, °C	Wet Bulb Temp, °C	Flow Rate, kg/hr	Temp °C	Flow rate, m^3/hr	Temp °C	Flow rate, m^3/hr	Pressure kg/cm^2g	Temp °C	O_2 %	CO_2 %	CO %	Temp °C	
1.															
2.															
3.															
4.															
5.															
6.															
7.															
8.															

Boiler Supervisor Energy Manager Energy Auditor

Benchmark Practices

- BOILER HEAT BALANCE vs. PG values
- AIR COMPRESSORS (KWH/cu. M)
- Refrigeration plants (KW/TR)
- C.T. Effectiveness (range/approach) l/g
- Motor load analysis (% KW loading)
- Aux.Eqpt. Performance vs. PG values
- Lux Levels vs. Norms
- CHP / AHP PERFORMANCE vs. PG values
- Mills, crushers, (KWH/ton)
- Heat exchangers (effectiveness in air heaters/ECONOMISERS/condensers/LP/ hp heaters
- DG sets (KWH/LITRE)
- Auxilliary Power consumption (% of Power Generation)

Energy Audit Schematic (210MW KWU STEAM TURBINE CYCLE)



1. Condansate Flow is evaluated from ΔP of orifice after due checking its condition.
2. Main steam inlet to HP Turbine(M1) is evaluated from BFP flow at deaerator outlet which is got from heat and mass balance of deaerator
3. SH & RH spray shall also be evaluated from ΔP OF PLANT FLOW NOZZLE and accounted for in heat rate /main steam evaluation.
4. Ejector steam if provided shall be evaluated
5. Reheat flow (M2) is evaluated from main steam flow after considering gland leak flow, evaluated ext flow to HPH-6& RH injection flow.
6. Gland leak off flow is evaluated.
7. Scheme conforms to ASME PTC-6 Standard performance evaluation guidelines for determining accurate performance of TG cycle .

Turbine heat rate $= \frac{M1(H1-Hf) + M2(H2-H3)}{Pg}$

SYMBOLS:
- PRESSURE –
- TEMPERATURE –
- FLOW –
- POWER –

Energy Audit –
Auxiliary Power Consumption

: Typical break-up of auxiliary power consumption in thermal power stations

Plant capacity	500 MW			210 MW			110 MW		
	Actual load KW	% of generation	% of APC	Actual load KW	% of generation	% of APC	Actual load KW	% of generation	% of APC
BFP'S	0	0.00	0.00	5380	2.69	33.63	2793	2.94	24.50
CEP'S	1903	0.40	5.66	534	0.27	3.34	364	0.38	3.19
CW pumps	4754	0.99	14.15	1329	0.66	8.31	1197	1.26	10.50
ID fans	6289	1.31	18.72	2523	1.26	15.77	1622	1.71	14.23
PA fans	2845	0.59	8.47	1360	0.68	8.50	1648	1.73	14.46
FD fans	1368	0.29	4.07	800	0.40	5.00	243	0.26	2.13
Mills	2776	0.58	8.26	1157	0.58	7.23	789	0.83	6.92
CT fans	1083	0.23	3.22	630	0.32	3.94	456	0.48	4.00
Air compressors	385.5	0.08	1.15	249	0.12	1.56	228	0.24	2.00
A/C plant	175	0.04	0.52	150	0.08	0.94	105	0.11	0.92
Coal handling plant	591	0.12	1.76	272	0.14	1.70	275	0.29	2.41
Ash handling plant	455	0.09	1.35	266	0.13	1.66	290	0.31	2.54
Lighting	266	0.06	0.79	160	0.08	1.00	100	0.11	0.88
Others	10709.5	2.23	31.87	1190	0.60	7.44	1290	1.36	11.32
AXU. power cons	33600	7.00	100.00	16000	8.00	100.00	11400	12.00	100.00
Generation	480000	100.00		200000			95000		

Note:

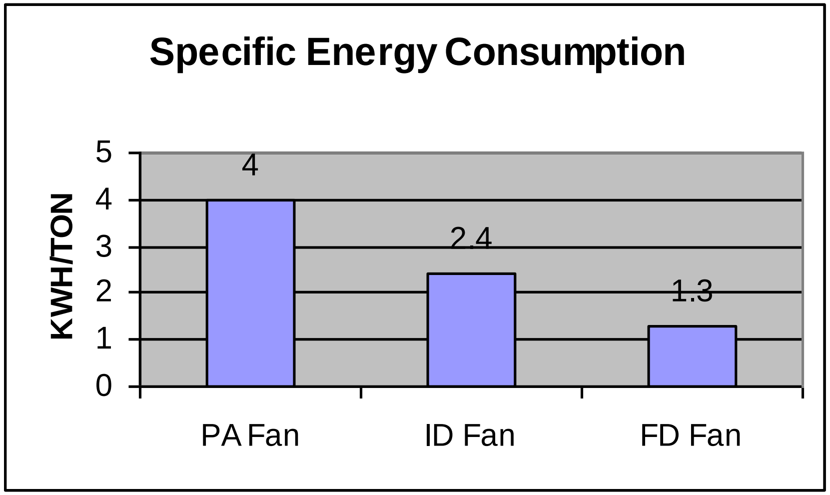
1. Others include: Raw water pumps, DM plant, ESP's, service & admin. buildings etc.

2. Power consumption in common auxiliaries like air compressors, AC Plant, CHP, AHP, lightings are divided per unit basis.

3. BFPs-Boiler Fed Pumps, CEPs-Condensate Extraction Pumps, CW-Circulating Water, ID-Induced Draft, PA-Primary Air, FD-Forced Draft, CT-Cooling Tower.

Energy Audit – Auxiliary Power Consumption

- Boiler fans account for more than 30% of the auxiliary power consumption (around 12-13 MW of power in 500 MW units).
- Experience suggests scope for improvement, potentially for at least 15-20% energy savings.
- The typical bench mark SEC values for the fans are given below:
- PA fan = 3.75 – 4kwh per ton air
  FD fan = 1.2 – 1.3kwh per ton air
  ID fan = 2.3 – 2.4kwh per ton flue gas.



Energy Audit–
Boiler Performance

Parameter	Design	measured
Excess air at boiler exit %	19.0	23.6
Excess air at APH exit %	28.0	55.6
FG temp. at APH exit 0c	146.0	167.6
Dry Flue gas loss %	5.08	8.89
Heat loss due to CO %	0	0
Heat loss due to moisture in air %	0.12	0.18
Heat loss due to moisture and H2 in fuel %	5.95	5.78
Heat loss due to unburnt in ash %	0.90	0.09
Sensible heat loss in ash %	0.56	0.59
Surface and unaccounted losses %	0.17	0.10
Design margin %	0.5	
Total heat losses %(corrected)	12.57	14.93
Thermal efficiency %	87.43	85.07

Efficiency Evaluation of 500 MW unit

Observation

- Excess Air and cold air
- Ingress also causes ID fan loading
- Excess FG temp. at APH

Possible causes

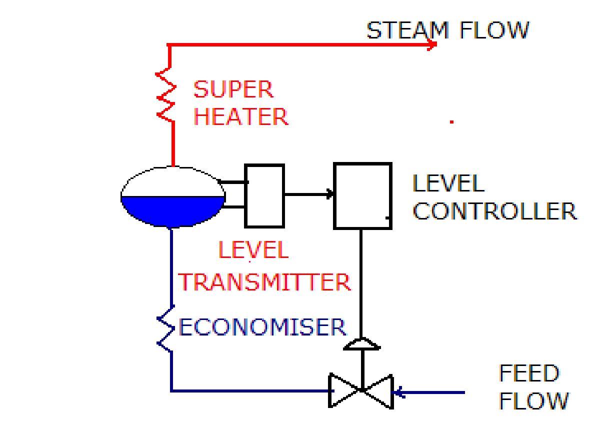
- Worn out seals and heat Transfer elements
- Leakage through peep/port holes
- Soot formation on the heat transfer area

Results

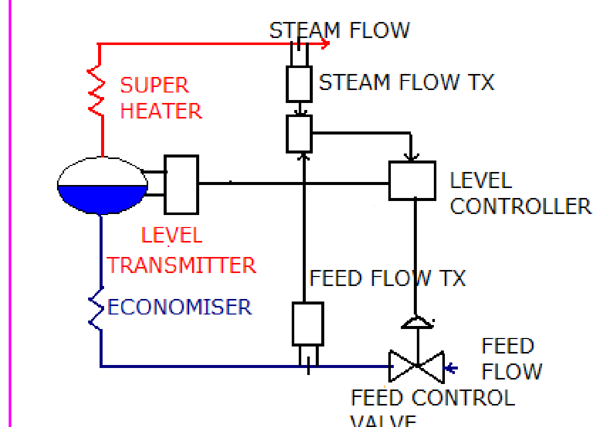
- 2.83% effciciency impr. in
- Reduction Coal consumption By 74490 T/A
- Rs.63.09 saving (Rs. 847 /T)

Energy Audit
Reducing of DP across Feed Regulating Station

- Design
  - Single element and three Element control, DP across FRS around 8 kg/cm2.
- Study
  - Loss due to drop in pressure at feed regulating station

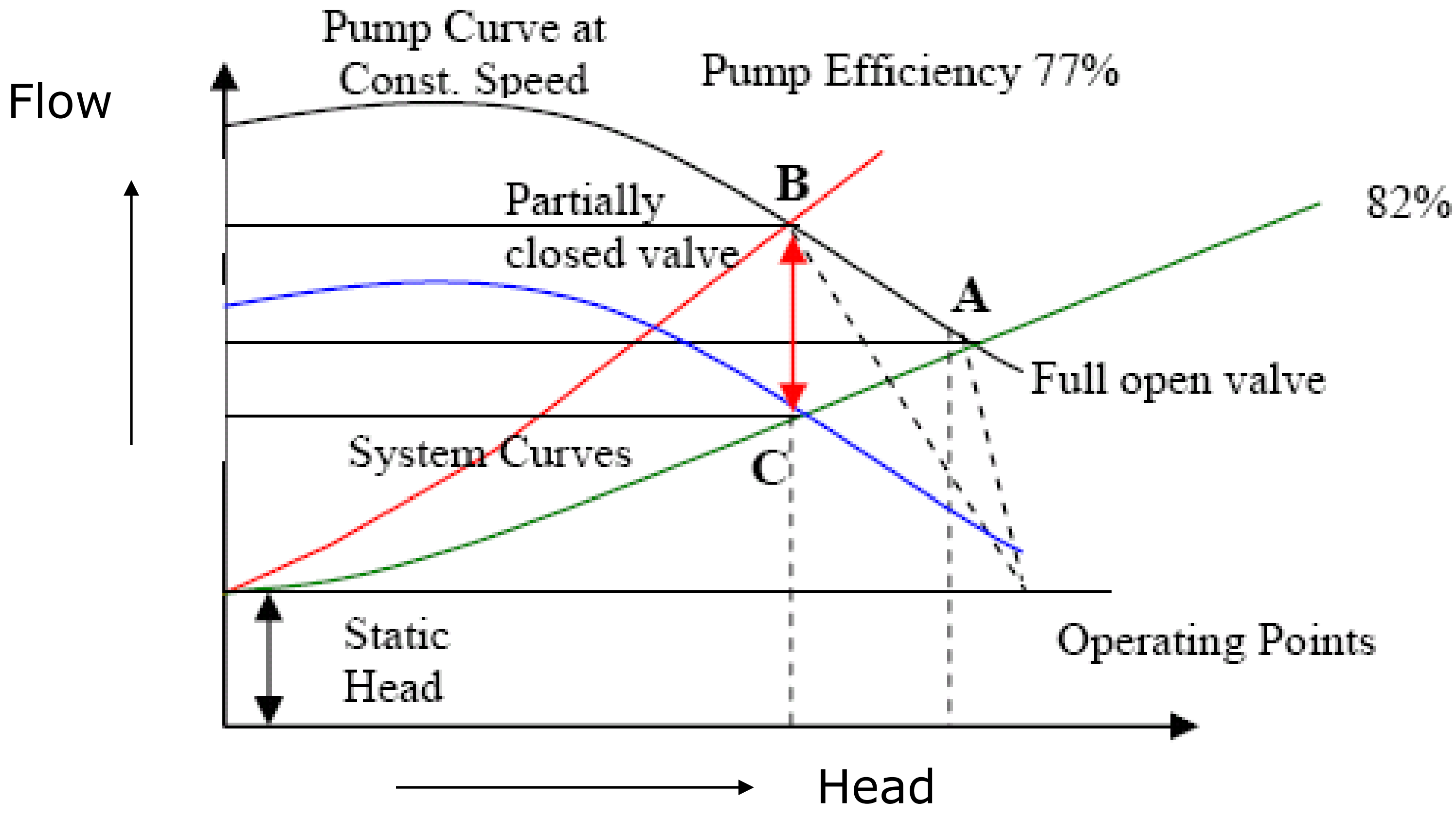


LOW RANGE SINGLE ELMENT CONTROLLER



HIGH RANGE THREE ELEMENT CONTROLLER

Effect of Throttling



Energy Audit
Reducing of DP across Feed Regulating Station

Disc Pres.(ksc)	Flow (TPH)	FRS CV (%)	DP (ksc)	Drum Pres (ksc)	Avg. Pow (kW)
185.5	320	58	08	164	2799
178	320	70	0.4	164.0	2653

- Modification
  - Drum level controller changed from DP control to scoop control.
- Observed Parameters
  - Feed water flow, metal temperatures,SH/RH attempration, BFP discharge pressure and pumping power.
- Energy saving potential
  - 21600 KWH per day or Rs. 9 million per annum in 200 MW power plant.

Energy Audit– Optimization of PA to SA

Type	Unit	PAF A	PAF B	FD A	FD B
Capacity	M3/ sec	55	55	58.4	58.4
Total design head	mm wc	1212	1212	450	450
Fan Speed	rpm	1480	1480	1480	1480
Fan regulation type		Inlet damper control	Inlet damper control	Blade pitch control	Blade pitch control
Fan motor rating	kw	900	900	400	400
Operating parameters					
Air Flow	M3/ sec	65.27	56.34	24.8	68.0
Power consumptio n	kw	920	907	78	185
System Efficiency	%	78.6	67.0	66.5	77.5
Ratio of PA		56.7		43.3	

Observation (120MW unit)
Higher PA to SA ratio

Result

Adjustment of ratio, power consumption reduced from 2090 kw to 1760 kw

Saving of Rs. 3.22 M/A, cosidering 7500 hrs/year and Rs. 1.30 per kwh

Saving Analysis with improvement in efficiency

- Fuel Saving

$$S\% = (\eta_{new} - \eta_{asis})*100/\ \eta_{new}$$

- Annual energy savings

$$S_e = \frac{MW_{installed} \bullet 8760 \bullet PLF \bullet (\eta_{new} - \eta_{as\ is})}{\eta_{as\ is} \bullet \eta_{new}} \text{ MWh/ year}$$

- Annual cost savings

$$S_{Rs} = \frac{MW_{installed} \bullet 8760 \bullet PLF \bullet (\eta_{new} - \eta_{as\ is}) \bullet C_{MWh}}{\eta_{as\ is} \bullet \eta_{new}} \text{ Rs/ year}$$

$\eta_{as\ is}$ = the actual system efficiency
CMWh = Fuel costs in Rs/MWh where MWh1 refers to energy in the fuel
PLF = plant load factor as a fraction $\frac{MWh_{generated}}{MW_{installed} * 8760}$

Energy Audit–
Achieved/Recommended Financial Savings

- 1% reduction in auxiliary power consumption for total installed capacity, yields 5000 MU approx.of energy annually, worth Rs. 1,000 crores (@ Rs. 2/kWh).

- For a typical 210 MW unit, the difference in power consumption in ID fans alone (with and without VFDs) is 500 kWh/unit, a reduction of 24% in power consumption worth around Rs. 75 lakhs per annum.

- In one 500 MW unit for instance, normal overhauling and periodic maintenance of the badly performing mills yielded energy savings to the tune of 2.77 MU per annum worth Rs. 50 lakhs/annum.

- Optimizing air to fuel ratios yielded a reduction of 3.1 MU per annum in the energy consumption of PA fans.

THANKS

Table 2: Parameters required for efficiency determination by input-output method

Parameter	Typical Influence [Note (1)]	Typical Influence [Note (2)]
Heat input from fuel	PRI	M
Fuel rate	PRI	M
Heating value of fuel	PRI	M
Fuel analysis	PRI	M
OUTPUT	PRI	M

Annexure

Efficiency Parameters

Basis for measurements and parameters to be monitored

Parameters required for efficiency determination by energy balance method (Source ASME PTC 4)

Parameter	Typical Influence [Note (1)]	Typical Influence [Note (2)]
DRY GAS LOSS	PRI	
Fuel Analysis	PRI	M
%O_2 in Flue Gas	PRI	M
Flue Gas Temperature	PRI	M
UNBURNED CARBON	SEC	M/E
% Carbon in Residue	PRI	M
Residue Split	PRI	C/M
Sorbent Analysis	PRI	M
Sorbent Rate	PRI	M
Fuel Rate	PRI	C/M
% CO_2 in Residue	PRI	M
SO_2/O_2 Flue Gas	PRI	M
WATER FROM H_2 IN FUEL LOSS	PRI	M
Fuel Analysis	PRI	M
Flue Gas Temperature	PRI	M
WATER FROM H_2O IN FUEL LOSS	PRI	M
Fuel Analysis	PRI	M
Flue Gas Temperature	PRI	M
MOISTURE IN AIR LOSS	SEC	M/E
Fuel Analysis	PRI	M
Flue Gas O_2	PRI	M
Dry-Bulb Temperature	PRI	M
Wet-Bulb Temperature	PRI	M
Or Relative Humidity	PRI	M
Barometric Pressure	SEC	M
Flue Gas Temperature	PRI	M
UNBURNED CARBON RESIDUE LOSS	PRI	M
Fuel Analysis	PRI	M
% Carbon in Residue	PRI	M
Residue Split	PRI	M
Sorbent Analysis	PRI	M
Sorbent Rate	PRI	C/M
% CO_2 in Residue	PRI	M
SO_2/O_2 in Flue Gas	PRI	M
UNBURNED H_2 IN RESIDUE LOSS	SEC	E
%H_2 in residue	PRI	M
CO IN FLUE GAS LOSS	SEC	M/E
Items for excess air	PRI	M
CO in flue gas	PRI	M

Parameter	Typical Influence [Note (1)]	Typical Influence [Note (2)]
PULVERIZER REJECTS LOSS	SEC	E
Pulverizer Rejects Rate	PRI	M/E
Pulverizer Rejects Analysis	PRI	M/E
Pulverizer Outlet Temperature	PRI	M
Fuel Rate	PRI	C/M
Fuel Analysis	PRI	M
UNBURNED HYDROCARBONS IN FLUE GAS LOSS	SEC	E
Hydrocarbons in Flue Gas	PRI	M
HHV of Reference Gas	PRI	M
Sensible heat of residue loss	PRI	M/E
Residue split	PRI	M/C/E
Temp of residue	PRI	M
Hot air quality control equipment loss	PRI	M
Flue gas temperature entering	PRI	M
Flue gas temperature leaving	PRI	M
$\%O_2$ in flue gas entering	PRI	M
$\%O_2$ in flue gas leaving	PRI	M
Wet gas weight entering	PRI	C
Wet gas weight leaving	PRI	C
Air inflation loss	SEC	M
Inflation airflow	PRI	M
Inflation air temperature	PRI	M
Exit gas temperature	PRI	M
Formation of NO_x loss	SEC	M/E
NO_x in flue gas	PRI	M/E
Wet gas weight	PRI	C
Radiation and convention l0ss	PRI	M/E
Stream generator surface area	PRI	C
Local ambient air temperature	PRI	M/E
Local surface temperature	PRI	M/E
Local surface air velocity	PRI	E
Additional moisture loss	SEC	M/E
Mass flow of moisture	PRI	M/E
Flue gas temperature	PRI	M
Feed water pressure	SEC	M
Feed water temperature	PRI	M
Fuel flow	PRI	C/M
Calcination dehydration of sorbent loss	PRI	M
Sorbent analysis	PRI	M
Fuel rate	PRI	C/M
% carbon in residue	PRI	M

Parameter	Typical Influence [Note (1)]	Typical Influence [Note (2)]
% CO_2 in residue	PRI	M
Residue split	PRI	M/E
SO_2/O_2 in flue gas	PRI	M
Water in sorbent loss	SEC	M
Sorbent analysis	PRI	M
Flue gas temperature	PRI	M
Wet ash pit loss	SEC	E
Recycled streams loss	SEC	M
Recycled flow	PRI	M/E
Recycle temperature entering	PRI	M
Recycle temperature leaving	PRI	M
COOLING WATER LOSS	SEC	M/E
Cooling water Flow Rate	PRI	M/E
Temperature Water Entering	PRI	M
Temperature Water Leaving	PRI	M
Fuel Rate	PRI	C/M
Air preheat coil loss (energy supplied from within boundary)	SEC	M
APC condensate flow rate	PRI	M/C
APCcondensate temperature	PRI	M
APC condensate pressure	PRI	M
Feed water temperature	PRI	M
Feed water pressure	SEC	M
Entering dry air credit	PRI	M
Entering air temperature	PRI	M
Excess air	PRI	M
Fuel analysis	PRI	M
Unburned carbon	SEC	M/E
Sulfur capture	PRI	M
Moisture in entering air credit	SEC	M/E
Moisture in air	PRI	M/E
Dry –bulb temperature	PRI	M
Wet– bulb temperature or relative humidity	PRI	M
Barometric pressure	SEC	M
Sensible heat in fuel credit	SEC	M
Fuel analysis	PRI	M
Fuel temperature entering	PRI	M/E
Sulfation credit	PRI	M
SO_2/O_2 in fuel gas	PRI	M
Fuel analysis	PRI	M
Sorbent rate	PRI	M
Fuel rate	PRI	C/M

Parameter	Typical Influence [Note (1)]	Typical Influence [Note (2)]
% Carbon in residue	PRI	M
% CO_2 in residue	PRI	M
Auxiliary equipment power credit	SEC	M/C/E
Steam driven equipment		
Mass flow of steam	PRI	M
Entering steam pressure	PRI	M
Entering steam temperature	PRI	M
Exhaust pressure	PRI	M
Drive efficiency	PRI	E/M
Electrical driven equipment		
For large motors:		
Watt-hour reading	PRI	M
Drive efficiency	PRI	E/M
For small motors:		
Volts	SEC	M
Amps	SEC	M
Sensible heat in sorbet credit	SEC	M
Sorbent rate	PRI	M
Sorbent temperature	PRI	M
Energy supplied by additional moisture credit	SEC	M/E
Mass flow rate	PRI	M
Entering temperature	PRI	M
Entering pressure	PRI	M

NOTES:

(1) Typical influence: PRI = Primary, SEC = Secondary

(2) Typical Source: M = Measured, C= Calculated, E = Estimated.