International Refereed Journal of Engineering and Science (IRJES)
ISSN (Online) 2319-183X, (Print) 2319-1821
Volume 5, Issue 10 (October 2016), PP.36-50

Cost Control of Unit Generation by Improvement of Gross Heat Rate in Coal Based Thermal Power Plant

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Abstract: Performance optimization for lowest unit cost of generation is the key objective of all progressive utilities of the world. Awareness for early implementation of "Efficiency and heat rate improvement programme" is increasing due to competitive prices as well as growing concern for sustainable development and eco-friendly power generation. Heat rate improvement is one of source reduce the unit generation cost by effective utilisation of heat generation and minimisation of the losses.

I. INTRODUCTION

1.1.Necessity of Unit generation cost reduction:

Energy charges are nothing but the cost of fuel used by a power company to generate electricity. On top of this, is added a fixed cost which is essentially the cost of building the system, to arrive at a final charge for buyer.

Adherence to recently announced emission norms for coal-based power plants would heavily burden the consumers but refused to quantify it, Industries are still in the process of assessing cost impact of the new emission norms

The cost of compliance for coal-based power producers with strict norms for Sulphur dioxide and nitrogen oxide was likely to be nearly R2.4 lakh crore for the total installed capacity in the country.

The variable cost for power primarily accounts for fuel cost which is passed through to the consumers. Power cost also includes 'fixed' cost which corresponds to return on investment for the operator and remains unchanged through a project's life

Energy efficiency is a key to delivering India's climate change goals, higher efficiency maximises output from coal, saving fuel and reinforcing energy security, as industry and consumers become more sensitive to the cost of energy ,supply-side energy efficiency will become commercially important as well as an environmental imperative.

1.2. Heat Rate improvement role in unit generation cost reduction:

The purpose of a heat rate monitoring and subsequent improvement is to reduce the heat rate of a unit. This result in several benefits:

The amount of money spent for fuel will be reduced, this lowers the cost of generation of electricity.

Because less fuel is required to produce the same amount of electricity, the amount of wear and tear on equipment such as pulverizes, coal pipes and nozzles, CHP and AHP equipment's etc., is reduced. Also, along with reduced fuel flows, the airflow is reduced, thereby reducing velocities through the boiler, which in turn causes less erosion and reduced fan power consumption.

Heat rate improvement results in an increase in the generation of the unit, allowing the unit to run at a higher plant load factor. This advantage can be very valuable, especially during summer when the condenser cooling water inlet temperatures and ambient air temperatures are high, which sometimes results in generation being limited due to higher condenser back pressure or running out of fan(s) capacity.

II. PERFORMANCE CALCULATIONS WITH OPERATION DATA:

2.1. Input Data

Table 1. Process data.

S.No	Description of Parameter	UOM	Value
1	Generation	MW	150
2	Feed Water Flow	TPH	447.03
3	Super Heater Flow	TPH	34.55
4	Re heater spray	TPH	8.62
5	Fixed Carbon	%wt	29.40 (By Proximate Analysis)
6	Volatile matter	%wt	32.01
7	Ash	%wt	4.05
8	Sulphur	%wt	0.16
9	Bottom Ash	%	30

10	Fly Ash	%	70
11	GCV of coal	kcal/kg	4137
12	Furnace Oxygen	%	4.5
13	Vacuum	$Kg.cm^2$	-0.91
14	Fuel Price	Rs/MT	3100
15	Leakages	TPH	18 (As per design)
16	HP Heater-2 feed water inlet pressure	Kg/cm^2	168.69
17	HP Heater-2 feed water inlet temperature	^oC	224.72
18	HP Heater-2 feed water outlet pressure	Kg/cm^2	167.95
19	HP Heater-2 feed water outlet temperature	^oC	240.53
20	Extraction 1 steam inlet pressure	Kg/cm^2	29.31
21	Extraction 1 steam inlet temperature	^oC	332.77
22	HP Heater-2 drain water pressure	Kg/cm^2	37.15
23	HP Heater-2 drain water temperature	^oC	228.44
24	HP Heater-1 feed water inlet pressure	Kg/cm^2	169.39
25	HP Heater-1 feed water inlet temperature	^oC	171.90
26	HP Heater-1 feed water outlet pressure	Kg/cm^2	168.69
27	HP Heater-1 feed water outlet temperature	^oC	224.72
28	Extraction 2 steam inlet pressure	Kg/cm^2	36.58
29	Extraction 2 steam inlet temperature	^oC	329.08
30	HP Heater-1 drain water pressure	Kg/cm^2	26.57
31	HP Heater-1 drain water temperature	^oC	194.11
32	CRH Pressure	Kg/cm^2	30.67
33	CRH temperature	^oC	334.70
34	HRH pressure	Kg/cm^2	27.12
35	HRH temperature	^oC	536.19
36	Main steam pressure	Kg/cm^2	138.22
37	Main steam temperature	^oC	537.12

Turbine Heat Rate (Kcal/kwh):
Formula:
Main Steam Flow (Enthalpy of main steam - Enthalpy of feed water) + HRH Flow (Enthalpy of HRH - Enthalpy of CRH) + Reheater spray (Enthalpy of HRH - Enthalpy of BFP discharge)
Power generation
MS Flow = Feed water flow + Super Heater Spray
HRH Flow = CRH Flow + Re heater spray
CRH Flow = Main Steam Flow - Extraction 1 Flow - Extraction 2 Flow - Leakages
Extraction -1 Flow:
(Enthalpy of HP Heater-2 feed water outlet -Enthalpy of HP heater -2 feed water inlet) x MS Flow
(Enthalpy of Extraction 1 steam Inlet - Enthalpy of HP Heater-2 drain water)
Extraction -2 flow:
MS Flow x (Enthalpy of HP Heater-1 feed water outlet -Enthalpy of HP heater -1 feed water inlet) - Extraction 1 flow (Enthalpy of HP heater 2 drain - Enthalpy of HP heater 1 drain)
(Enthalpy of Extraction 2 steam Inlet - Enthalpy of HP Heater-1 drain water)

2.2. Main Steam Flow:Feed water flow + Super Heater Spray
Feed Water Flow = 447.03 TPH
Super Heater Spray = 34.55 TPH
MS flow = 481.58 TPH

2.3. Extraction -1 Flow:
(Enthalpy of HP Heater-2 feed water outlet -Enthalpy of HP heater -2 feed water inlet) x MS Flow
(Enthalpy of Extraction 1 steam Inlet - Enthalpy of HP Heater-2 drain water).

Table 2. Parameters

S NO	PARAMETER	PRESSUE IN Kg/cm^2	TEMPERATURE ^OC	ENTHALAPY KJ/Kg
1	HP Heater-2 feed water outlet	167.95	240.53	1041.93
2	HP heater -2 feed water inlet	168.69	224.72	969.47
3	Extraction 1 steam Inlet	29.31	332.77	3076.82
4	HP Heater-2 drain water	37.15	228.44	983.10

= ((1041.93-969.47)/ (3076.82-983.10)) * 481.58
Extraction -1 Flow = 16.66 TPH

2.4. Extraction -2 flow:
MS Flow x (Enthalpy of HP Heater-1 feed water outlet -Enthalpy of HP heater -1 feed water inlet) - Extraction 1 flow (Enthalpy of HP heater 2 drain - Enthalpy of HP heater 1 drain)
(Enthalpy of Extraction 2 steam Inlet - Enthalpy of HP Heater-1 drain water)

Table 3. Parameters

S No	Parameter	Pressue In Kg/Cm^2	Temperature ^oc	Enthalapy Kj/Kg
1	Hp Heater-1 Feed Water Outlet	168.69	224.72	969.47
2	Hp Heater -1 Feed Water Inlet	169.39	171.90	736.45
3	Hp Heater 2 Drain	37.15	228.44	983.10
4	Hp Heater 1 Drain	26.57	194.11	826.49
5	Extraction 2 Steam Inlet	36.58	329.08	3049.49

= (481.58 * (969.47-736.45)) - (16.66(983.10-826.49)) / (3049.49-826.49)
Extraction -2 flow= 49.30 TPH
Leakages: 18 TPH (As per OEM data)

2.5. CRH Flow = Main Steam Flow - Extraction 1 Flow - Extraction 2 Flow - Leakages
= 481.58 - 16.66 - 49.30 -18
CRH Flow = 397 TPH

2.6. HRH Flow = CRH Flow + Re heater spray
HRH Flow = 405.62 TPH

2.7. Turbine Heat Rate (kcal/kwh):
Main Steam Flow (Enthalpy of main steam - Enthalpy of feed water) + HRH Flow (Enthalpy of HRH - Enthalpy of CRH) + Reheater spray (Enthalpy of HRH - Enthalpy of BFP discharge)
Power generation
Main Steam Flow: 481.58 TPH

Table 4. Parameters

S No	Parameter	Pressue In Kg/Cm^2	Temperature ^oc	Enthalapy Kcal/Kg
1	Main Steam	138.22	537.12	820.19
2	Feed Water	167.95	240.53	249.26
3	Hrh	27.12	536.19	847.19
4	Crh	30.07	334.70	736.74
5	Bfp Discharge	169.39	171.90	176.18

HRH Flow: 424.24 TPH
Re heater spray: 8.62 TPH
Power generation: $150 * 10^3$ kWhr

$$= \frac{(481.58*(820.19 - 249.26) + 405.62 * (847.19 - 736.74) + 8.62 * (847.19 - 176.18)) * 1000}{(150 * 10^3)}$$

Turbine Heat Rate= 2170 Kcal/kWhr

2.8. Boiler efficiency:
η_{boiler}= 100 - losses

2.8.1.Losses:
L1: Dry flue gas loss
L2: evaporation of water formed due to H2 in fuel
L3: moisture present in fuel

L4: moisture present in air
L5: unburnt in fly ash
L6: unburnt in bottom ash
□$_{\mathbf{boiler}}$= 100 - (L1+L2+L3+L4+L5+L6)

2.8.2. Proximate Analysis of Coal:-

a. Fixed Carbon : 29.40 %
b. Volatile Matter : 32.01 %
c. Total Moisture : 34.55%
d. Ash : 4.05%
e. Sulphur: 0.16 %

2.8.3. Conversion formulas from proximate to ultimate analysis:

% Carbon:
(0.97 * % FIXED CARBON) + 0.7 (% VOLATILE MATTER + 0.10 * % ASH) - % MOISTURE (0.6 - 0.01 * % MOISTURE)
= (0.97*29.40) + (0.7 * (32.01 + (0.1*4.05)) - (34.55 * (0.6 - (0.01*34.55)))
C = 42.41 %

% Hydrogen:
0.036 * % FIXED CARBON + 0.086 (% VOLATILE MATTER - (0.1 * % ASH)) - (0.0035* % MOISTURE^2 (1-(0.02 * % MOISTURE)))
= (0.036*29.40) + (0.086*(32.01 - (0.1*4.05))) - ((0.0035 * 34.55^2) * (1-(0.02*34.55)))
H_2 = 2.478 %

% Nitrogen:
2.10 - 0.020 VOLATILE MATTER
= 2.10 - (0.020*32.01)
N_2 = 1.4598

% Oxygen:
100 - (% CARBON - % HYDROGEN - % NITROGEN - % SULPHUR - % MOISTURE)
= 100 - (42.41 - 2.478 - 1.4598 - 34.55)
O_2= 19.10 %

GCV of Coal:4137kcal / Kg
Gross calorific value of coal taken from Bomb calorimeter analysis results

2.8.4. Theoretical air:

$$\frac{((11.6 \text{ x Carbon}) + 34.8 * (H2 - O_2/8) + 4.35 * \text{Sulphur})}{100} \quad \text{Kg/Kg of fuel}$$

$$= \frac{(11.6 * 42.41) + (34.8 * (2.478 - (19.10/8)) + (4.35 * 0.16)}{100}$$

= 4.95 kg/kg of coal

2.8.5. *Excess* air:

$$\frac{O_2}{21- O_2} * 100$$

O_2 = 4.5 % (Taken from O_2 analyzer)

$$= \frac{4.5}{(21 - 4.5)} * 100$$

= 27.27 %

2.8.6. Actual Mass of air supplied:

(1 + (% Excess air / 100) * Theoretical air

$$= \left(1 + \frac{27.27}{100} \right) * 4.958$$

= 6.31 kg

Losses:

2.8.7. Dry flue gas loss % :

$m* C_P* (T_f - T_a)$ * 100

GCV of Coal
Where

m: 6.31 kg - Mass of actual air supplied Kg/Kg of fuel
C_P: 0.24 kcal ^oC - Specific heat of flue gas in Kcal/Kg ^oC
T_f: 142.6 ^oC - Flue gas temperature in ^oC
T_a: 33.66 ^oC - Ambient air temperature in ^oC
GCV of Coal: 4137 kcal / Kg

$$= \frac{6.31*0.24*(142.6 - 33.66)}{4137} * 100$$

Dry flue gas loss = 3.98 %

2.8.8. Heat loss due to evaporation of water formed due to H2 in fuel (%):

$$\frac{9* H_2 * (584 + C_P(T_f - T_a))}{\text{GCV of Coal}} * 100$$

Where

H_2: 2.478 - kg of hydrogen present in coal on 1 Kg
C_P:0.43 - Specific heat of super-heated steam in Kcal/Kg ^oC
T_f: 142 - Flue gas temperature in ^oC
T_a: 33.66 - Ambient air temperature in ^oC
584: Latent heat corresponding to partial pressure of water vapour

$$= \frac{9*(2.478/100) * (584 + 0.43 * (142.6 - 33.66))}{4137} * 100$$

Loss due to H2 in fuel =3.40 %

2.8.9. Heat loss due to moisture present in fuel %:

$$\frac{M * (584 + C_P(T_f - T_a))}{\text{GCV of Coal}} * 100$$

M: 34.55% - Kg moisture in fuel on 1 Kg basis
C_P:0.43 - Specific heat of super-heated steam in Kcal/Kg ^oC
T_f: 142.6 - Flue gas temperature in ^oC
T_a: 33.66 - Ambient air temperature in ^oC
584- Latent heat corresponding to partial pressure of water vapour

$$= \frac{(34.55/100) * (584+ 0.43 (142.6 - 33.66)}{4137} * 100$$

Moisture present in fuel = 4.35 %

2.8.10. Heat loss due to moisture present in air %:

$$\frac{AAS* \text{Humidity factor} * C_P * (T_f - T_a)}{\text{GCV of Coal}} * 100$$

Where:

AAS - 6.31 % - Actual mass of air supplied per Kg of fuel
Humidity factor: 0.0204 - Kg of water / Kg of dry air
C_P: 0.43 - Specific heat of super-heated steam in Kcal/Kg ^oC
T_f: 142.6 - Flue gas temperature in ^oC
T_a: 33.6 - Ambient air temperature in ^oC

$$= \frac{6.31 * 0.0204 * 0.43 *(142.6 - 33.6)}{4137} * 100$$

Moisture present in air = 0.145 %

2.8.11. Heat loss due to unburnt in fly ash %:

Plant design for Ash generation:
Bottom Ash - 30 %
Fly Ash - 70 %
Fly ash generation = Ash contain coal * Boiler designed fly ash

$$= \frac{4.05}{100} * \frac{70}{100}$$

= 0.028 kg

GCV of fly ash: 450 kcal/kg
Heat loss due to fly ash: fly ash generation * GCV of ash
: 0.028 * 450
: 12.66 kcal/kg of coal
% heat loss in fly ash : heat loss * 100
GCV of coal
: 12.66 * 100
4137
: 0.30 %

2.8.12. Heat loss due to unburnt in bottom ash %:
Bottom ash generation = Ash contain coal * Boiler designed bottom ash
= 4.05 * 30
100 100
= 0.012 Kg
GCV of fly ash: 280 Kcal/Kg
Heat loss due to bottom ash: Bottom ash generation * GCV of ash
: 0.012 * 280
: 3.402 Kcal/Kg of coal
% heat loss in bottom ash : heat loss * 100
GCV of coal
: 3.402 * 100
4137
: 0.082 %

2.9. □$_{\textbf{boiler}}$= 100 - (L1+L2+L3+L4+L5+L6)
L1 = 3.98 %
L2 = 3.40 %
L3 = 4.35 %
L4 = 0.145 %
L5 = 0.30 %
L6 = 0.08 %
= 100 - (3.98 + 3.40 + 4.35 + 0.14 + 0.30 + 0.08)
= 100 - 12.25
= 87.74%

Boiler efficiency by indirect method: = 87.74%

2.10. Station Heat Rate (Kcal/kWhr) :
Turbine Heat Rate
Boiler Efficiency
Turbine heat rate = 2170 Kcal/kWh
Boiler Efficiency = 87.74 %
= 2170 *100
87.74
= 2473.21 Kcal/kWh

2.11. Unit Generation Cost:
= Fuel cost (Rs)
Generation (Units)

Fuel cost = Fuel consumption * Fuel Price

Fuel consumption = Generation * Specific fuel consumption

2.12. Specific fuel consumption:

= Station heat rate* Generation
GCV of fuel

Station Heat Rate= 2473.21 Kcal/kWh
GCV of coal = 4137 Kcal/Kg

Generation = 150 x 10^3 per hour

= $\frac{2473.21}{4137}$ * $150*10^3$

= 89.55MT/hr

Coal consumption per hour = 89.55 MT/hr
Coal cost = Coal consumption * Coal Price
Coal Price= Rs.3100 MT
= 89.55 * 3100
= Rs.277605

2.13.Unit generation cost*:*

= Fuel cost (Rs) / Generation (Units)

= $\frac{277605}{150*10^3}$

Unit Generation Cost = Rs.1.85

2.14. Unit Generation cost per day: Unit price * day generation
= 1.85 * $3.58*10^6$
= Rs.66, 23,000

III. EFFECT OF UNIT GENERATION COST BY IMPROVING HEAT RATE:

1. Increase the vacuum from - 0.91 Kg/cm^2 to -0.92 Kg/cm^2
2. Decrease the excess air 27.27 % to 20%
3. Increase the steam inlet temperature from 537 ^oC to 547 ^{o} C
4. Decrease the flue gas temperature from 142^o C to 132 ^{o} C
5. Reduction of reheater spray from 16 TPH to 8.62 TPH

3.1. Increase the vacuum from - 0.91 to - 0.92 Kg/cm^2:Performance calculations:

Main Steam flow with vacuum of - 0.92 Kg/cm^2 = 478.58 TPH

3.1.1. Extraction -1 Flow:

(Enthalpy of HP Heater-2 feed water outlet -Enthalpy of HP heater -2 feed water inlet) x MS Flow / (Enthalpy of Extraction 1 steam Inlet - Enthalpy of HP Heater-2 drain water)

= (478.58 * (969.47-736.45)) - (16.66(983.10-826.49)) / (3049.49-826.49)
= 16.55 TPH

3.1.2. Extraction -2 flow:

MS Flow x (Enthalpy of HP Heater-1 feed water outlet -Enthalpy of HP heater -1 feed water inlet) - Extraction 1 flow (Enthalpy of HP heater 2 drain - Enthalpy of HP heater 1 drain) / (Enthalpy of Extraction 2 steam Inlet - Enthalpy of HP Heater-1 drain water)

= (478.58 * (969.47-736.45)) - (16.55(983.10-826.49)) / (3049.49-826.49)
= 48.99 TPH

3.1.3. CRH Flow = Main Steam Flow - Extraction 1 Flow - Extraction 2 Flow - Leakages
= 478.58 - 16.55 - 48.99 - 18
= 395.04 TPH

3.1.4. HRH Flow = CRH Flow + Re heater spray
= 395.04 + 8.62
= 403.66 TPH

3.1.5. Turbine Heat Rate (Kcal/kwh):

Main Steam Flow (Enthalpy of main steam - Enthalpy of feed water) + HRH Flow (Enthalpy of HRH - Enthalpy of CRH) + Reheater spray (Enthalpy of HRH - Enthalpy of BFP discharge) / Power generation

$$= \frac{(478.58*(820.19 - 249.26) + 403.66 * (847.19 - 736.74) + 8.62 * (847.19 - 176.18)) * 1000}{(150 * 10^3)}$$

Turbine Heat Rate = 2157.36 kcal/kWhr

3.1.6. Station Heat Rate (kcal/kWhr) :

$$\frac{\text{Turbine Heat Rate}}{\text{Boiler Efficiency}}$$

Turbine heat rate = 2157.36 kcal/kWh

Boiler Efficiency = 87.74 %

$$= \frac{2157.36}{87.74} * 100$$

= 2458.81 kcal/kWh

3.1.7. Specific fuel consumption:

$$= \frac{\text{Station heat rate}}{\text{GCV of fuel}} * \text{Generation}$$

$$= \frac{2458.81}{4137} * 150*10^3$$

= 89.15 T/hr

3.1.8. Coal cost = Coal consumption * Coal Price

= 89.15 * 3100

= Rs.276365

3.1.9. Unit generation cost:

$$= \frac{\text{Fuel cost (Rs)}}{\text{Generation (Units)}}$$

$$= \frac{276365}{150*10^3}$$

Unit Generation Cost = Rs.1.84

3.1.10. Generation cost per day*:*Unit price * day generation

$= 1.84 * 3.58*10^6$

= Rs.65, 87,200

Unit generation cost with -0.91 kg/cm^2 vacuum = Rs.1.85

Unit generation cost with -0.92 kg/cm^2 vacuum = Rs.1.84

Cost Saving per unit = Rs.0.01

Generation cost per day with -0.91 kg/cm^2 vacuum = Rs.66, 23,000

Generation cost per day with -0.92 kg/cm^2 vacuum = Rs.65, 87,200

Saving per day = Rs.35800

3.2. Decrease the excess air 27.27 % to 20%:Performance calculations:

Boiler furnace O_2 reduced from 4.5 to 3.5

3.2.1. Excess air:

$$\frac{O_2}{21 - O_2} * 100$$

O_2 = 3.5 % (Taken from O_2 analyzer)

$$= \frac{3.5}{(21 - 3.5)} * 100$$

= 20 %

3.2.2. Actual Mass of air supplied:

(1 + (% Excess air / 100) * Theoretical air

$$= \left(1 + \frac{20}{100}\right) * 4.958$$

= 5.94 Kg

3.2.3. Dry flue gas loss % :

$\underline{m* C_P* (T_f - T_a)}$ * 100

GCV of Coal

Where

m: 5.94 Kg - Mass of actual air supplied Kg/Kg of fuel
C_P: 0.24 Kcal ^oC - Specific heat of flue gas in Kcal/Kg ^oC
T_f: 142.6 ^oC - Flue gas temperature in ^oC
T_a: 33.66 ^oC - Ambient air temperature in ^oC
GCV of Coal: 4137 kcal / kg

$$= \frac{5.94*0.24*(142.6 - 33.66)}{4137} * 100$$

= 3.75%

3.2.4. Heat loss due to moisture present in air %:

$$\frac{AAS* \text{Humidity factor} * C_P * (T_f - T_a)}{\text{GCV of Coal}} * 100$$

Where:

AAS - 5.94 % - Actual mass of air supplied per Kg of fuel
Humidity factor: 0.0204 - kg of water / kg of dry air
C_P: 0.43 - Specific heat of super-heated steam in kcal/kg ^oC
T_f: 142.6 - Flue gas temperature in ^oC
T_a: 33.6 - Ambient air temperature in ^oC

$$= \frac{5.94 * 0.0204 * 0.43 *(142.6 - 33.6)}{4137} * 100$$

=0.137%

3.2.5. η_{boiler}= 100 - (L1+L2+L3+L4+L5+L6)

L1 = 3.75 %
L2 = 3.40 %
L3 = 4.35 %
L4 = 0.13 %
L5 = 0.30 %
L6 = 0.08 %
= 100 - (3.75 + 3.40 + 4.35 + 0.13 + 0.30 + 0.08)
= 87.99%

3.2.6. Station Heat Rate (kcal/kWhr) :

$$\frac{\text{Turbine Heat Rate}}{\text{Boiler Efficiency}}$$

Turbine heat rate = 2170 kcal/kWh
Boiler Efficiency = 87.99 %

$$= \frac{2170}{87.99} *100$$

= 2466.18 kcal/kWh

3.2.7. Specific fuel consumption:

$$= \frac{\text{Station heat rate} * \text{Generation}}{\text{GCV of fuel}}$$

$$= \frac{2466.18 * 150*10^3}{4137}$$

= 89.41 T/hr

3.2.8. Coal cost = Coal consumption * Coal Price
= 89.41 * 3100
= Rs.277200

3.2.9. Unit generation cost:

$$= \frac{\text{Fuel cost (Rs)}}{\text{Generation (Units)}}$$

$$= \frac{277200}{150*10^3}$$

Unit Generation Cost = Rs.1.848

3.2.10. Generation cost per day:Unit price * day generation
= 1.848 * $3.58*10^6$
= Rs.66,15,840
Unit generation cost with 27.27% of excess air = Rs.1.85
Unit generation cost with 20% of excess air = Rs.1.84
Cost Saving per unit = Rs.0.01
Generation cost per day with 27.27% of excess air = Rs.66, 23,000
Generation cost per day with 20% of excess air = Rs.66,15,840
Saving per day = Rs.7160

3.3. Increase the steam inlet temperature from 537 ^{o} C to 542^o CPerformance calculations:
Turbine steam consumption reduced from 481.58 TPH to 476.28 TPH
Main Steam flow: 476.28 TPH

3.3.1. Extraction -1 Flow:
(Enthalpy of HP Heater-2 feed water outlet -Enthalpy of HP heater -2 feed water inlet) x MS Flow
(Enthalpy of Extraction 1 steam Inlet - Enthalpy of HP Heater-2 drain water)

= (476.28 * (969.47-736.45)) - (16.66(983.10-826.49)) / (3049.49-826.49)
= 16.47 TPH

3.3.2. Extraction -2 flow:
MS Flow x (Enthalpy of HP Heater-1 feed water outlet -Enthalpy of HP heater -1 feed water inlet) - Extraction 1 flow (Enthalpy of HP heater 2 drain - Enthalpy of HP heater 1 drain)
(Enthalpy of Extraction 2 steam Inlet - Enthalpy of HP Heater-1 drain water)
= (476.28 * (969.47-736.45)) - (16.47(983.10-826.49)) / (3049.49-826.49)
= 48.76 TPH

3.3.3. CRH Flow = Main Steam Flow - Extraction 1 Flow - Extraction 2 Flow - Leakages
= 476.28 - 16.47 - 48.76 - 18
= 393.05TPH

3.3.4. HRH Flow = CRH Flow + Re heater spray
= 393.05 + 8.62
= 401.67 TPH

3.3.5. Turbine Heat Rate (Kcal/kwh):
Main Steam Flow (Enthalpy of main steam - Enthalpy of feed water) + HRH Flow (Enthalpy of HRH - Enthalpy of CRH) + Reheater spray (Enthalpy of HRH - Enthalpy of BFP discharge)
Power generation

$$= \frac{(476.28*(820.19 - 249.26) + 401.67 * (847.19 - 736.74) + 8.62 * (847.19 - 176.18)) * 1000}{(150 * 10^3)}$$
Turbine Heat Rate = 2147.14 kcal/kWhr

3.3.6. Station Heat Rate (kcal/kWhr) :
Turbine Heat Rate
Boiler Efficiency
Turbine heat rate = 2147.16 kcal/kWh
Boiler Efficiency = 87.74 %
$$= \frac{2147.16}{87.74}*100$$
= 2447.16 kcal/kWh

3.3.7. Specific fuel consumption:
$$= \frac{\text{Station heat rate}}{\text{GCV of fuel}} * \text{Generation}$$
= 2447.16 * $150*10^3$

4137
= 88.72 T/hr

3.3.8. Coal cost = Coal consumption * Coal Price
= 88.72 * 3100
= Rs.275032

3.3.9. Unit generation cost:
$= \frac{\text{Fuel cost (Rs)}}{\text{Generation (Units)}}$
$= \frac{275032}{150*10^3}$
Unit Generation Cost = Rs.1.83

3.3.10. Generation cost per day: Unit price * day generation
$= 1.83 * 3.58*10^6$
= Rs.65, 640,97

Unit generation cost with 537°C of Inlet Steam Temp = Rs.1.85
Unit generation cost with 547°C of Inlet Steam Temp = Rs.1.83
Cost Saving per unit = Rs.0.02
Generation cost per day with 537oC of Inlet Steam Temp = Rs.66, 23,000
Generation cost per day with 547°C of Inlet Steam Temp = Rs.65, 64097
Saving per day = Rs.58,903

3.4. Decrease the flue gas temperature from142 ° C to 132 ° C
Performance calculations:
Losses:

3.4.1. Dry flue gas loss % :
$\frac{m* C_P* (T_f - T_a)}{\text{GCV of Coal}} * 100$
Where
m: 6.31 Kg - Mass of actual air supplied Kg/Kg of fuel
C_P: 0.24 Kcal °C - Specific heat of flue gas in Kcal/Kg °C
T_f: 132.6 °C - Flue gas temperature in °C
T_a: 33.66 °C - Ambient air temperature in °C
GCV of Coal: 4137 kcal / kg
$= \frac{6.31*0.24*(132.6 - 33.66)}{4137} * 100$
Dry flue gas loss = 3.62 %

3.4.2. Heat loss due to evaporation of water formed due to H2 in fuel (%):
$\frac{9* H_2* (584 + C_P(T_f - T_a))}{\text{GCV of Coal}} * 100$
Where
H_2: 2.478 - Kg of hydrogen present in coal on 1 Kg
C_P: 0.43 - Specific heat of super-heated steam in Kcal/Kg °C
T_f: 132.6 - Flue gas temperature in °C
T_a: 33.66 - Ambient air temperature in °C
584: Latent heat corresponding to partial pressure of water vapour

$= \frac{9*(2.478/100) * (584 + 0.43 * (132.6 - 33.66))}{4137} * 100$
Loss due to H2 in fuel =3.37 %

3.4.3. Heat loss due to moisture present in air %:
$\frac{AAS* \text{Humidity factor} * C_P * (T_f - T_a)}{\text{GCV of Coal}} * 100$
Where:
AAS - 6.31 % - Actual mass of air supplied per Kg of fuel

Humidity factor: 0.0204 - Kg of water / Kg of dry air
C_P: 0.43 - Specific heat of super-heated steam in Kcal/Kg ^oC
T_f: 132.6 - Flue gas temperature in ^oC
T_a: 33.6 - Ambient air temperature in ^oC

$$= \frac{6.31 * 0.0204 * 0.43 *(132.6 - 33.6)}{4137} * 100$$

Moisture present in air = 0.132 %

3.4.4. Heat loss due to unburnt in bottom ash %:

Bottom ash generation = Ash contain coal * Boiler designed bottom ash

$$= \frac{4.05}{100} * \frac{30}{100}$$

= 0.012 Kg

GCV of fly ash: 280 Kcal/Kg

3.4.5. Heat loss due to bottom ash*:* Bottom ash generation * GCV of ash
: 0.012 * 280
: 3.402 kcal/kg of coal

% heat loss in bottom ash : $\frac{\text{heat loss}}{\text{GCV of coal}} * 100$

: $\frac{3.402}{4137} * 100$

: 0.082 %

3.4.6. $\eta_{\textbf{boiler}}$= 100 - (L1+L2+L3+L4+L5+L6)

L1 = 3.62 %
L2 = 3.37 %
L3 = 4.35 %
L4 = 0.132 %
L5 = 0.30 %
L6 = 0.08 %
= 100 - (3.62 + 3.37 + 4.35 + 0.13 + 0.30 + 0.08)
= 88.15%

Boiler efficiency by indirect method: = 88.15%

3.4.7. Station Heat Rate (kcal/kWhr) :

$$\frac{\text{Turbine Heat Rate}}{\text{Boiler Efficiency}}$$

Turbine heat rate = 2170 kcal/kWh
Boiler Efficiency = 88.15 %

$$= \frac{2170}{88.15} *100$$

= 2461.7 kcal/kWh

3.4.8. Specific fuel consumption:

$$= \frac{\text{Station heat rate} * \text{Generation}}{\text{GCV of fuel}}$$

$$= \frac{2467.7 * 150*10^3}{4137}$$

= 89.25 T/hr

3.4.9. Coal cost = Coal consumption * Coal Price
= 89.25 * 3100
= Rs.276675

3.4.10. Unit generation cost:

$$= \frac{\text{Fuel cost (Rs)}}{\text{Generation (Units)}}$$

$$= \frac{276675}{150*10^3}$$

Unit Generation Cost = Rs.1.84

3.4.11. Generation cost per day: Unit price * day generation
= 1.84 * 3.58*10^6
= Rs.65, 87,200

Unit generation cost with 537°C of Inlet Steam Temp = Rs.1.85
Unit generation cost with 547°C of Inlet Steam Temp = Rs.1.84
Cost Saving per unit = Rs.0.01
Generation cost per day with 537oC of Inlet Steam Temp = Rs.66, 23,000
Generation cost per day with 547°C of Inlet Steam Temp = Rs.65, 87,200
Saving per day = Rs.35, 800

3.5.Reduction of reheater spray from 16 TPH to 8.62 TPH by trimming the CRH coils

3.5.1. HRH Flow = CRH Flow + Re heater spray

CRH Flow: 397 TPH
Re heater spray: 16 TPH
HRH Flow = 397 + 16
HRH Flow = 413 TPH

3.5.2. Turbine Heat Rate (Kcal/kwh):

$$\frac{\text{Main Steam Flow (Enthalpy of main steam - Enthalpy of feed water) + HRH Flow (Enthalpy of HRH - Enthalpy of CRH) + Reheater spray (Enthalpy of HRH - Enthalpy of BFP discharge)}}{\text{Power generation}}$$

$$= \frac{(478.58*(820.19 - 249.26) + 413 * (847.19 - 736.74) + 16 * (847.19 - 176.18)) * 1000}{(150 * 10^3)}$$

Turbine Heat Rate = 2157.36 kcal/kWhr

3.5.3. Station Heat Rate (kcal/kWhr):

$$\frac{\text{Turbine Heat Rate}}{\text{Boiler Efficiency}}$$

Turbine heat rate = 2175.65 Kcal/kWh
Boiler Efficiency = 87.74 %

$$= \frac{2175.65}{87.74} *100$$

= 2479.66 kcal/kWh

3.5.4. Specific fuel consumption:

$$=\frac{\text{Station heat rate} * \text{Generation}}{\text{GCV of fuel}}$$

$$= \frac{2479.66 * 150*10^3}{4137}$$

= 89.88 T/hr

3.5.5. Coal cost = Coal consumption * Coal Price
= 89.88 * 3100
= Rs.278640

3.5.6. Unit generation cost:

$$= \frac{\text{Fuel cost (Rs)}}{\text{Generation (Units)}}$$

$$= \frac{278640}{150*10^3}$$

Unit Generation Cost = Rs.1.857

3.5.7. Generation cost per day: Unit price * day generation
= 1.857 * 3.58*10^6
= Rs.66, 48,060

Unit generation cost with 16 TPH reheater spray = Rs.1.857
Unit generation cost with 8.62 reheater spray = Rs.1.85
Cost Saving per unit = Rs.0.007
Generation cost per day with 537oC of Inlet Steam Temp = Rs.66, 48,060
Generation cost per day with 547°C of Inlet Steam Temp = Rs.66, 23,000

Saving per day = Rs.25, 060

IV. CONCLUSIONS

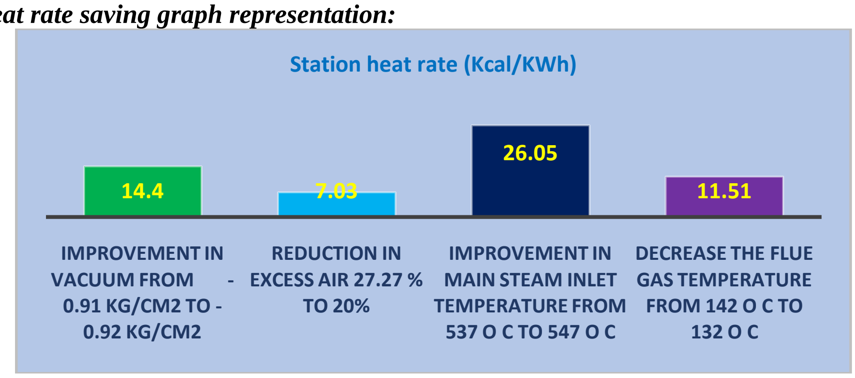
In this project an attempt has been made to reduce unit generation cost by using different heat rate improvement methods

4.1. Table 5. Saving results

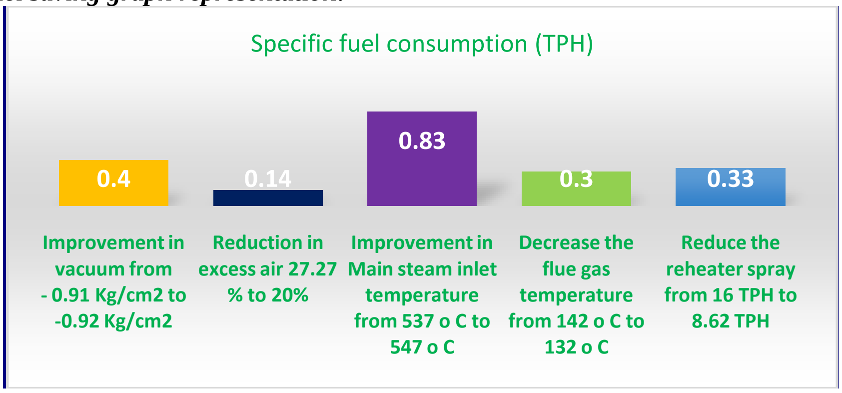
S.No	Description of improvement	Savings			
		Station heat rate (Kcal/KWh)	Specific fuel consumption(TPH)	Unit generation cost (Rs)	Generation cost per day (Rs)
1	Improvement in vacuum from - 0.91 Kg/cm^2 to -0.92 Kg/cm^2	14.4	0.4	0.01	35,800
2	Reduction in excess air 27.27 % to 20%	7.03	0.14	0.01	7160
3	Improvement in Main steam inlet temperature from 537 ^{o} C to 547 ^{o} C	26.05	0.83	0.02	58903
4	Decrease the flue gas temperature from 142^o C to 132 ^{o} C	11.51	0.3	0.01	35800
5	Reduce the reheater spray from 16 TPH to 8.62 TPH	6.45	0.33	0.01	25060

4.2.Charts representation for Performance results:

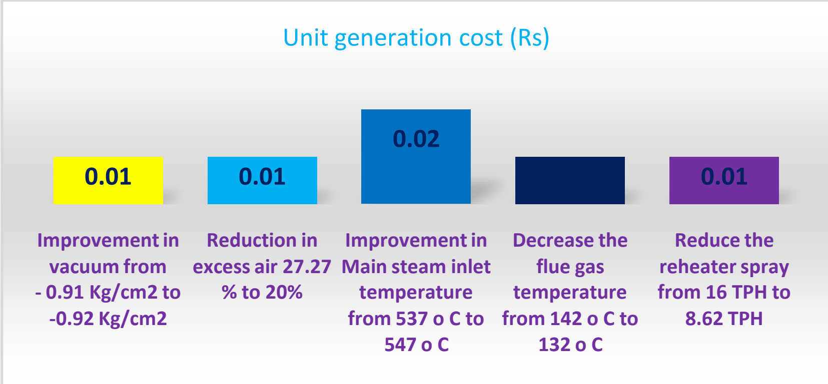
4.2.1.Station heat rate saving graph representation:



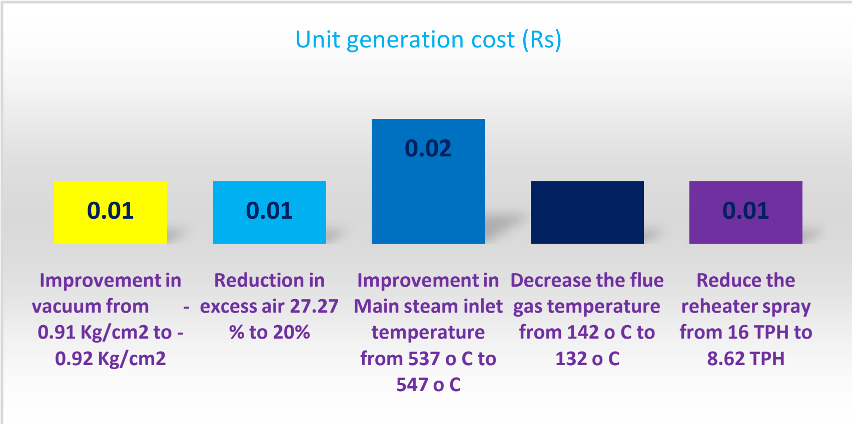
4.2.2. Specific fuel saving graph representation:



4.2.3. Unit generation cost saving graph representation:



4.2.4. Unit Generation cost per day saving graph representation:



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[3]. Journals of Energy Conservation
[4]. News Letters of Power Industry

Nomenclature:

H_2 - Kg of hydrogen present in coal on 1 Kg
C_P- Specific heat of super-heated steam in Kcal/Kg ^oC
T_f- Flue gas temperature in ^oC
T_a- Ambient air temperature in ^oC
M - Kg moisture in fuel on 1 Kg basis
AAS - Actual mass of air supplied per Kg of fuel
Humidity factor - Kg of water / Kg of dry air
h- Enthalpy
Heat rate - Kcal/kWhr
m - Mass of actual air supplied Kg/Kg of fuel
1 Kwhr - 860 Kcal
1 Kwhr - 3600 KJ
SFC - Specific Fuel Consumption
MW - Megawatt
MU - Million Units
MT - Metric Tons
TPH - Tons per hour