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Computational Approach of Green House Gases in Thermal Power Plant (An Energy Audit Approach) - Process Model

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Abstract **-- In this paper carbon di oxide, Sulphur di oxide & water vapor liberated from coal based plant process is calculated with the help of visual basic programming language. The basic theme behind this calculation is detail engineering based on basic principles of combustion & their thermodynamics, strongest way to reduce emission and to improve efficiency of combustion process optimization and is mostly conducted through fuel and air flow regulation. This paper also shows SEC can be reduced by regulating other parameter of Boiler and turbine.**

Keywords -- SEC (Specific Coal Consumption in Kg/KWh), GUHR (Gross Unit Heat Rate in Kcal/KWh), NUHR (Net Unit Heat Rate in Kcal/KWh), Gross unit efficiency, THR (Turbine Heat rate in Kcal/KWh), GCV (Gross Calorific Value of coal in Kcal/Kg), PLF (Plant Load Factor), η (Efficiency), NCV (Net Calorific Value of coal in Kcal/Kg.)

I. INTRODUCTION

In a thermal power plant various processes are carried out. The coal is conveyed then it is crushed to a smaller size. Coal mills are provided to pulverise the coal to 200 mesh size and carried in a very fine powdered form to the boiler which produces steam. Feed water for boiler is preheated to get better cycle efficiency. Steam covering out from the boiler is super heated before admitting to the turbine. After performing work in a high pressure turbine the exhaust steam is again reheated to 540 ^{0}C and then admitted in intermediate pressure turbine from intermediate pressure turbine steam goes to low pressure turbine and then exhaust steam is condensed to water and this water is again used as a feed water for the boiler. Whole process of steam generation is explained in fig (1).

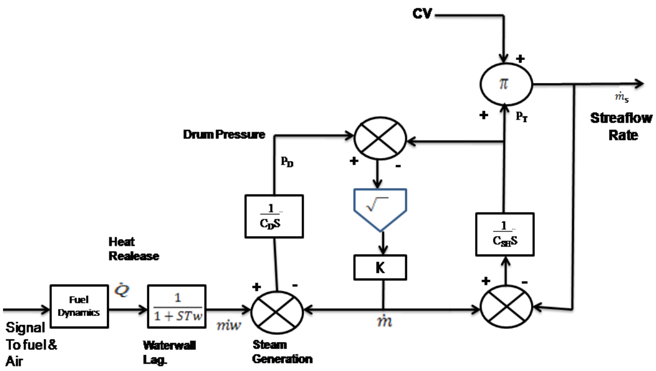

Fig.(1)
Simple Non Linear model of a drum type Boiler

II. DYNAMIC STATE SPACE BOILER MODEL

A. Inputs

SIG = Signal to fuel and air regulators
CV = Governor valve flow area

B. Parameters

T_W = Water wall time constant.
C_D = Drum storage capacitance
C_{SH} = Super heater storage capacitance
K = Friction drop coefficient
τ_f = Fuel system dead time
T_f = Fuel system time constant

C. States

$\dot{Q}$ = Furnace Heat release
$\dot{m}_w$ = Mass flow rate of steam generated in water walls (riser) entering the drum.
P_T = Super heater steam pressure at governor valve.
P_D = Saturated steam pressure in the drum.

D. Internal Variables

m = Mass flow rate of steam from drum to superheater.

E. Algebraic Equations

$$\dot{m} = K\sqrt{P_D - P_T}$$

$\dot{m}_s = CV * P_T$

F. Dfferential Equations

$$\frac{d}{dt}\dot{Q} = \frac{1}{T_f}\left[SIG\,(t - T_f) - \dot{Q}\right]$$

$$\frac{d}{dt}\dot{m}_w = \frac{1}{T_w}\left[\dot{Q} - \dot{m}_w\right]$$

$$\frac{d}{dt}P_T = \frac{1}{C_{SH}}\left[\dot{m} - \dot{m}_s\right]$$

$$\frac{d}{dt}P_D = \frac{1}{C_D}\left[\dot{m}_w - \dot{m}\right]$$

G. Outputs

$\dot{m}_s$ =Superheated Steam mass flow rate to high pressure turbine stage from the above, by setting the state time derivatives to zero it is straight forward to obtain the condition for steady state equilibrium as.

H. Steady State Boiler Model

$\dot{Q} = \dot{m}_w = \dot{m} = \dot{m}_s = SIG$

$P_T = SIG / CV$

$P_D = (SIG/K)^2 + SIG/CV.$

Main assumption and features of the model along with some components on these follow. [1, 2, 3]

1) Heat release in the furnace as a function of the fuel and air input signal is determined by the fuel system dynamics lags and dead-times associated with coal feeder and pulverizes.
2) The mass flow of steam from the drum to the super heater is proportional to the square root of the pressure drop between the drum and the Super heater.
3) The steam mass flow to the high pressure turbine stage is regulated by the governor valve.

III. AIR ENVIRONMENT

The air pollutants relevant to the activities of TPS were identified as CO_2, SPM, RPM, SO_2, NOX & CO. The 98% values of SPM during winter season varied between 151-245 µg/m3. Higher levels of SPM were contributed due to unpaved roads and heavy transportation activities. The repairable particulate matter (98%) varied from 61-123 µg/m3. A 500MW plant using coal with 2.5% sulphur (S),16% ash and 30,000 kilojoules/kilogram (kj/kg) heat cotent will emit each day 200 metric tons of sulphur dioxide (SO2),70 tons of nitrogen dioxide (N2O)and 500 tons of fly ash if no controls are present. In addition the plant will generate about 500 tones of solid waste and about 17 giga watt hour (GWH) of thermal discharge. Other significant air pollutants are respirable and suspended particulates, contributed mainly due to power plants and stone crushers. The wide spread disposal of fly ash and stone rejects, too contribute in making the ash /dust air born and inflicting air with poor visibility analysis of various data collected for power plant is based on certain relationship

IV. CALCULATION OF HEAT RATE

Heat rate monitoring give the idea where the wastage of energy exists. Heat rate calculation gives new ideas for better design, modernization and innovative ideas. The result of this study can be handled for getting a design with better efficiency while other efficiency improvement measures are being taken simultaneously.
Heat rate calculation is carried out in two stages

$$NUHR = \frac{\text{Coal Cons x GCV +Oil Cons x its Calorific Value}}{\text{Generation measured by bus bar}}$$

Where, Coal is primary fuel and oil is used as secondary fuel.

Normal practice of calculation
Gross unit efficiency = Boiler $_\eta$ x Turbine $_\eta$ x Generator $_\eta$

A. Boiler Efficiency (By Indirect Method)

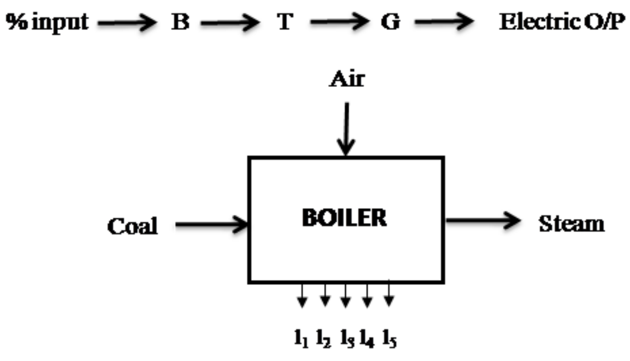

Fig.(2)

Boiler (Efficiency)η = 100 – ($l_1 + l_2 + l_3 + l_4 + l_5$) Eq. – 1

l_1 = Loss due to flue gas
l_2 = Loss due to H_2 in Fuel
l_3 = Loss due to Moisture in Fuel
l_4 = Loss due to Unburnt
l_5 = Loss due to radiation, conserve action & unaccounted losses.

For calculation the losses in equation 1 theoretical air and excess air requirement calculation is carried out is as follows.

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(1) Theoretical air requirement for combustion in Kg/Kg of coal

$$= \frac{(11.6 \times C) + 34.8 (H_2 - O_2/8) + 4.35S}{100}$$

Where,

C, H_2, O_2 and S are the percentage of carbon, hydrogen, oxygen and Sulphur present in fuel.

(2) % excess air supplied $= \frac{O_2\ \%}{21 - O_2\ \%} \times 100$

Where, $O_2\%$ = O_2 in flue gas

(3) Actual mass of air supplied (AAS)

$$= \left(1 + \frac{EA}{100}\right) \times \text{Theoretical air required}$$

(4) $$l_1 = \frac{M \times CPg \times (Tf - Ta)}{GCV} \times 100$$

Where: M = mass of dry flue gas in Kg/Kg of fuel (combustion product from fuel $CO_2 + SO_2 + N_2 + O_2$ in flue gas)

= AAS + 1 Kg of fuel.

CPg = 0.24 (Specific Heat of flue gas in Kcal/Kg ^{0}C.

Tf = Flue gas temperature in ^{0}C.

Ta = ambient temperature in ^{0}C.

(5) $$l_2 = \frac{9H_2 \{584 + CPs \times (Tf - Ta)}{GCV} \times 100$$

Where, H_2 = % of H_2 in fuel

CPs = 0.45 (Specific Heat of superheated steam in Kcal / Kg ^{0}C

584 = Latent heat corresponding to partial pressure of water vapour.

(6) $$l_3 = \frac{m \times \{584 + CPs \times (Tf - Ta)}{GCV} \times 100$$

Where, m = mass of moisture in flue gas

CPs = 0.45 (Specific Heat of superheated steam in Kcal / Kg ^{0}C

(7) $$l_4 = \frac{\%CO \times C}{\%\ CO + \%\ CO_2} \times \frac{5744}{GCV} \times 100$$

Where %CO = %CO in flue gas leaving economiser

C = % Carbon in flue gas

(8) l_5 = 1.6 to 2 %

All values of l_1, l_2, l_3, l_4, l_5 is used to calculate boiler efficiency from equation number.

B. Turbine Efficiency

$$\text{Gross Unit Efficiency} = \frac{860}{UHR} = B\eta \times \frac{860}{THR} \times G\eta \qquad \text{Eq. –2}$$

Where,

UHR = Unit heat rate in Kcal // KWH

THR = Thermal heat rate in Kcal / KWH

C. Generator Efficiency → *Assumed as 98to 99%*

$$GUHR = \frac{860}{\text{Gross Unit Efficiency}}$$

In case of Turbine with HP heater and reheater

$$THR = \frac{\text{M.S. flow (M.S. enthalpy – F/W/ enthalpy) + CRH flow (HRH enthalpy – CRH enthalpy}}{\text{KWH Generation}} \qquad \text{Eq. –3}$$

Where,

M.S. Flow = Main Steam Flow in Kg/hr

M.S. Enthalpy = Main steam enthalpy in Kcal / Kg

F/W/ enthalpy = Feed Water enthalpy in Kcal / Kg

CRH flow = Cold reheat flow in Kg/hr. (i.e. CRH flow = 14 % of M.S. flow for 210 mw)

HRH enthalpy = Hot reheat enthalpy in Kcal / Kg

$$\text{Turbine Efficiency} = \frac{860}{THR}$$

The value of temperature, pressure and flow rate are known from instrumentation and specific enthalpy can be known from steam tables. The values of generation is known from energy meters. If the reading of energy meter connected to generator terminal is considered in this formula number (3). The heat rate obtained is gross unit heat rate and if that from bus bar energy meter is considered then it is NUHR from following equation.

$$NUHR = \frac{\text{GUHR X Gross MW}}{\text{Net MW}} \qquad \text{Eq. –4}$$

Where,

Net MW → (Gross MW – Auxiliary consumption)

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Auxiliary consumption → energy consumed by various auxiliaries like ID (Induced Draft Fan, FD (Forced draft Fan) PA (Primary air Fan) , BFP (Boiler Feed Pump) and other LT /HT auxiliary .

$$SEC = \frac{GUHR}{GCV} = \frac{Kcal/\ KWh}{Kcal\ /\ Kg} = Kg/\ KWh$$

Eq. –5

From equation (5)

SEC can be reduced

1. By improving quality of coal
2. By improving gross unit efficiency (i.e.by reducing losses in Boiler, Turbine and Generator)

V. ENVIRONMENT MANAGEMENT PLAN

Environment is defined as " Surroundings in which the organization operates including air, water, land, human and their interaction. Five techniques are available for alleviating environmental degeneration in the context of coal fired thermal power plants viz.

1. Supply of low Sulphur coal.
2. Removal contaminants before combustion.
3. Removal of contaminates after combustion.
4. Dilution of air pollutions by taller stack and permitting greater dispersion.
5. Reduction of coal consumption by reducing SEC

Present study paper is related with point number 5 "Calculation of environmental Impact"
Considering sample of 1 Kg of coal Chemical reaction are

(1) $C + O_2 = CO_2$

Eq. –6

$12 + 32 = 44$

1 Kg of carbon takes 2.67 Kg of O_2 to from 3.67 Kg of CO_2

(2) $S + O_2 = SO_2$

Eq. –7

$32 \quad 32 = 64$

1 Kg of Sulphur takes 1 Kg of O_2 to form 2 Kg of SO_2

(3) $H_2 + ½ O_2 = H_2O$

Eq. –8

$02 + 16 = 18$

$01 + 08 = 9$

1 Kg of Hydrogen takes 8 Kg of O_2 to form 9 Kg of H_2O vapour

Coal is pollutant and when burnt it produces CO2 and CO, extensive use of coal as a source of energy is likely to disturb the ecological balance as the vegetations are not capable of absorbing such large proportions of CO2 produced by burning of large quantity of coal. Reduction in SEC helps to maintain ecological balance, by reducing air from atmosphere and reduction in CO_2, SO_2, H_2O vapour , CO , NOx etc.

d) From equation (6) CO_2 liberated in atmosphere cab be calculated as

$$CO_2 = \frac{\%\ C}{100} \text{ x SEC x 3.67 x load } T/_{Hr}$$

From equation (7)

$$SO_2 = \frac{\%\ S}{100} \text{ x SEC x 2 x load } T/_{Hr}$$

From equation (8)

$$H_2O = \frac{\%\ H_2}{100} \text{ x SEC x 9 x load } T/_{Hr}$$

From above formulae, we can conclude that with reduction in SEC corresponding values for CO_2, SO_2 and H_2O vapour liberated in atmosphere can be reduced.

VI. ABOUT SOFTWARE PREPARED

Calculation of various losses in Boiler, Turbine and Generator, their efficiency, overall unit efficiency, Gross unit heat rate (GUHR), Net unit heat rate (NUHR) is calculated with the help of Visual Basic software for which input for various parameters is given. Environmental impact with respect to SO2, CO2, H2O vapour liberated in atmosphere can be calculated. Flow chart for SEC calculation is shown as follows. (6)

A Flow Chart For Calculations of SEC

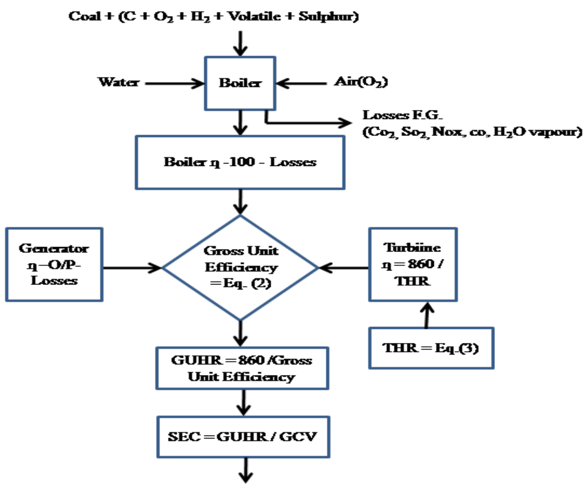

Fig.(3)

A. *Login Form*

Fig.(4)

B. *Proximate to ultimate analysis [5]*

$$C = 0.97f + 0.70\,(V - 0.1A) - 0.6M$$
$$H = 0.036f + 0.091\,(V - 0.1\,A) - 0.05\,M$$

C = Carbon content of coal
F = fixed carbon
V = Volatile Matter
A = Ash
M = Moisture

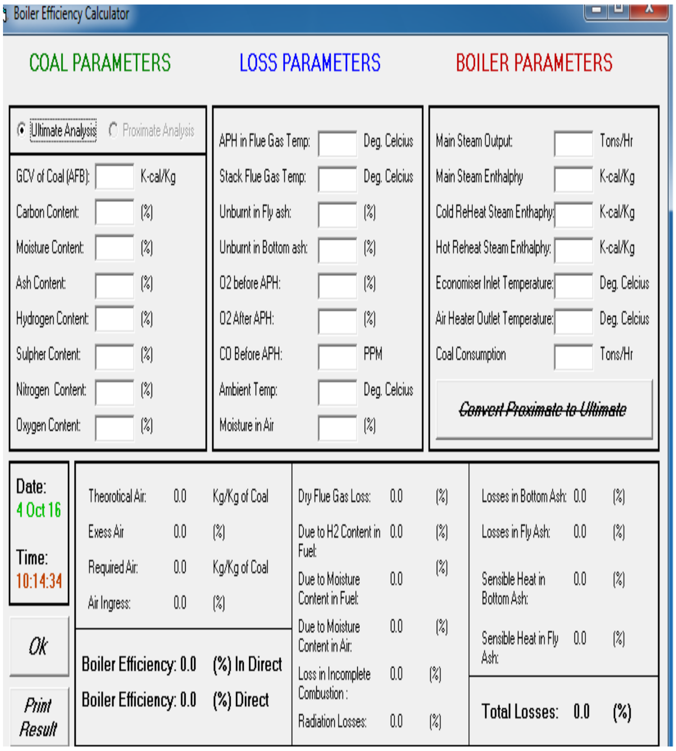

Fig.(5)

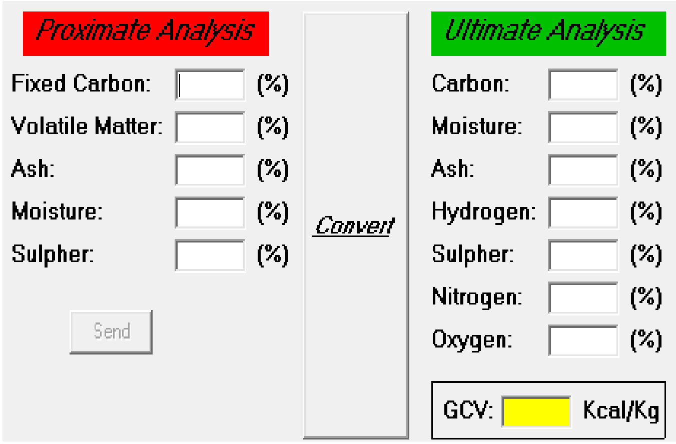

Fig.(6)

C. *Boiler Efficiency Calculation*

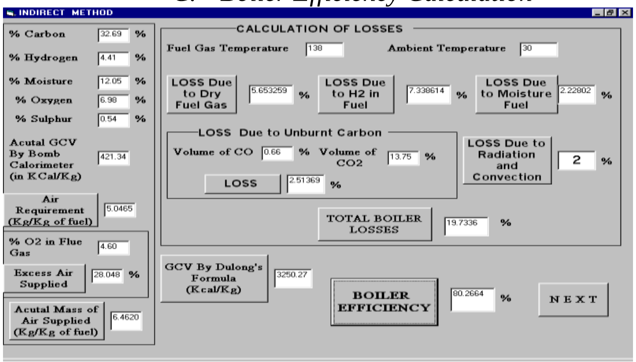

Fig.(7)

D. *Turbine Efficiency Calculation*

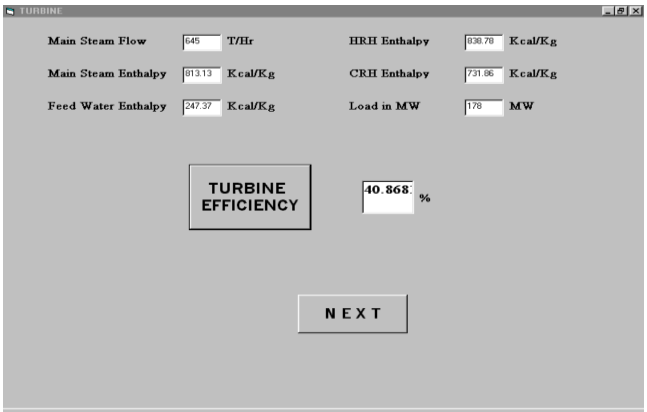

Fig.(8)

E. *Generator Efficiency (From efficiency V/s Load graph)*

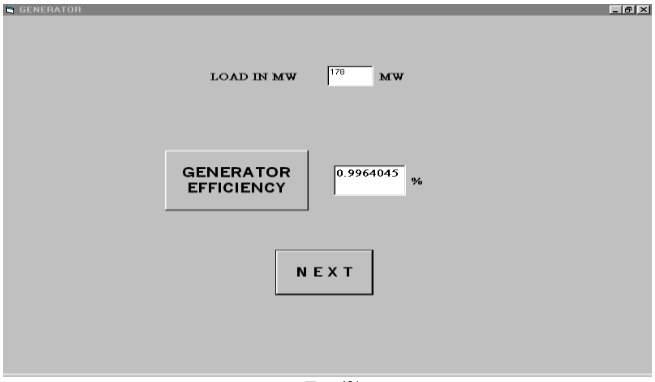

Fig.(9)

F. SEC Calculation.

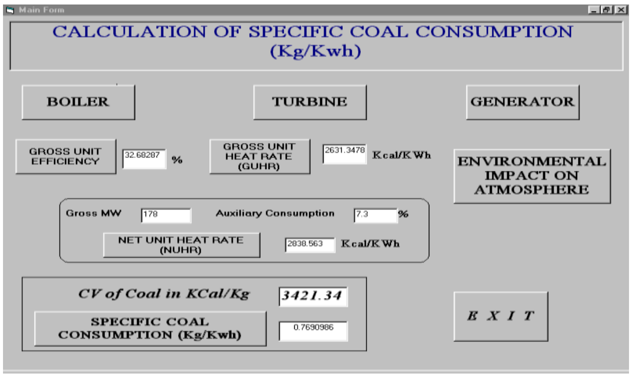

Fig.(10)

G. Environmental impact calculation

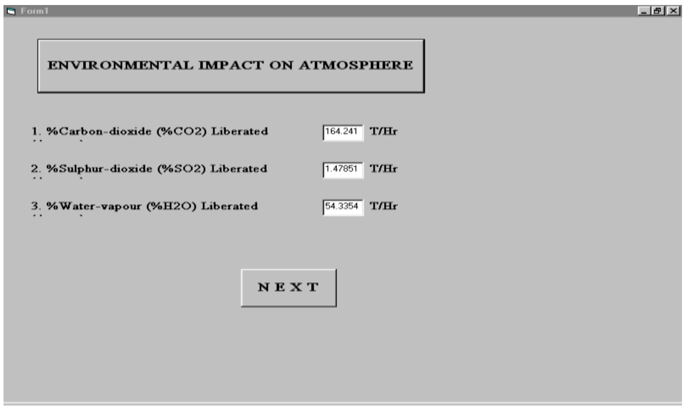

Fig.(11)

H. SEC V/s. GUHR (Graph)

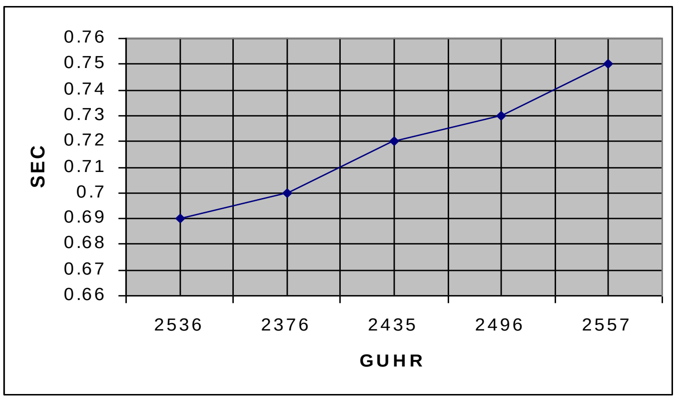

Fig.(12)

I. SEC V/s. GCV (Graph)

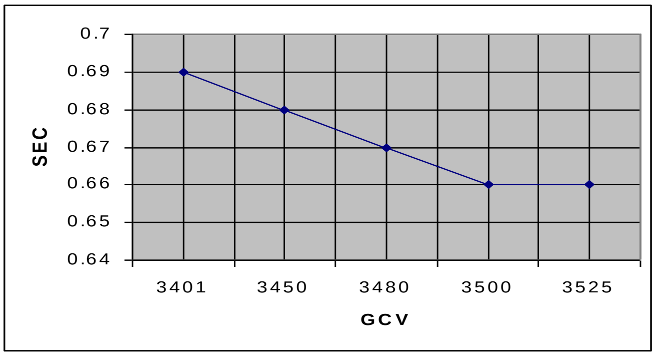

Fig.(13)

J. GUHR V/s. Generator Output (Graph)

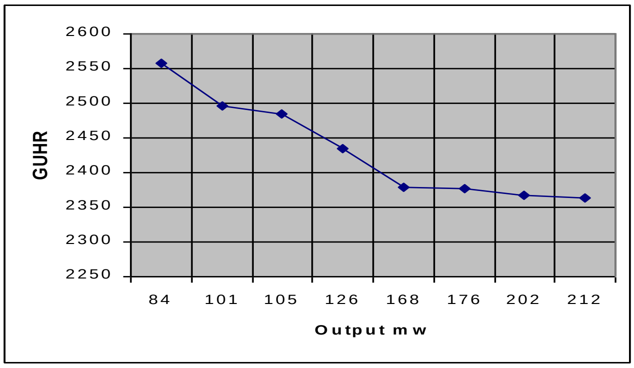

Fig.(14)

K. Load V/s. Coal required (Graph)

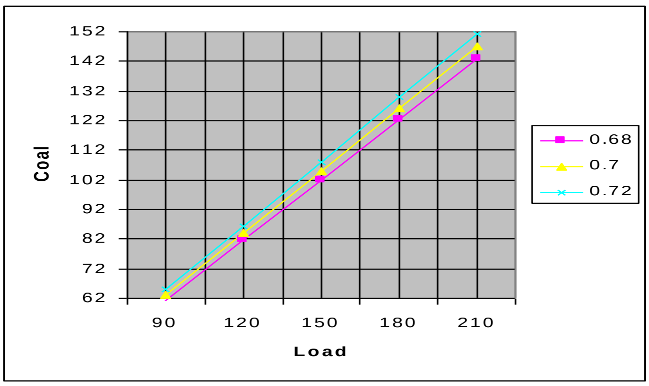

Fig.(15)

L. Load V/s. Air required (Graph)

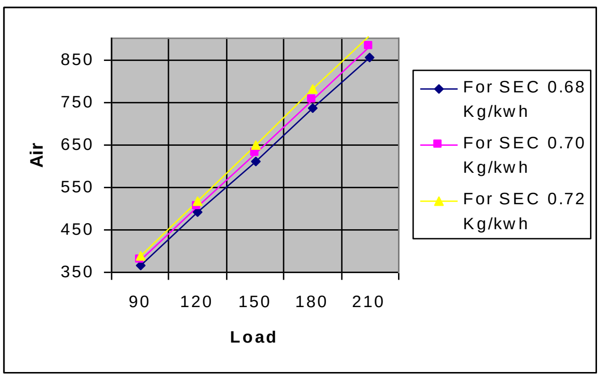

Fig.(16)

M. Oxygen V/s. Load in mw (Graph)

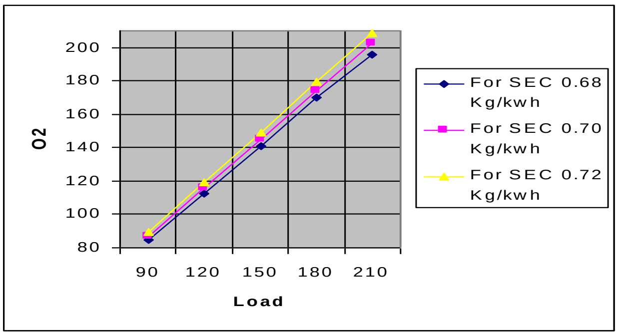

Fig.(17)

N. Load V/s. Co_2 liberated (Graph)

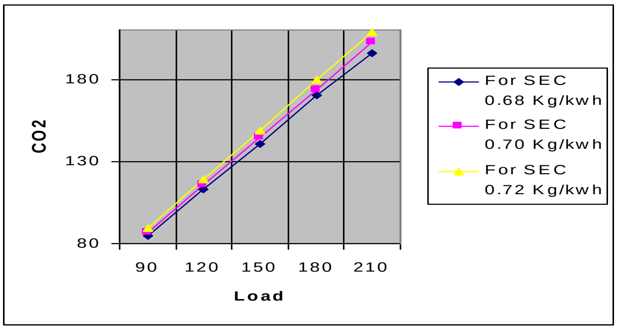

Fig.(18)

O. Load V/s. So_2 liberated(Graph)

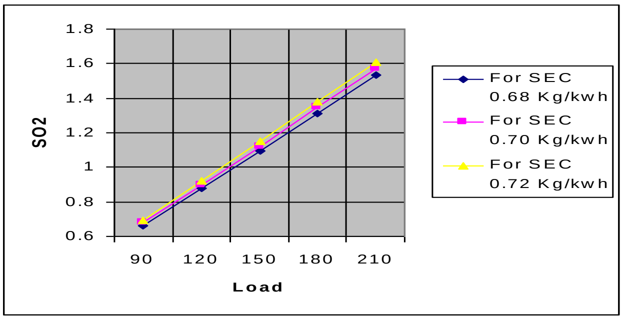

Fig.(19)

P. Load V/s. H_2O Vapour (Graph)

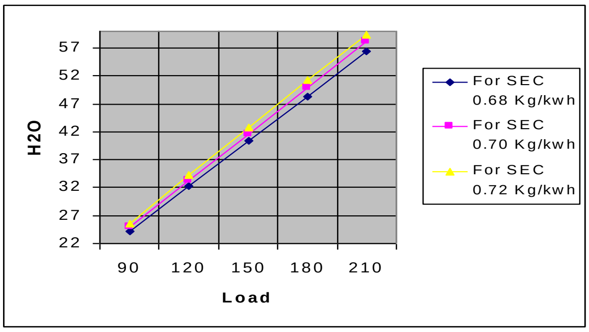

Fig.(20)

VII. COMMENT OF GRAPH.

A) Graph H. SEC V/s. GUHR - For higher value of GUHR coal consumption will be more for reducing coal consumption losses in Boiler, Turbine has to be reduced by means of adequate operational and maintenance practices.

B) Graph I. SEC V/s. GCV - higher value of GCV means more heating value for higher GCV coal requirement will be reduced.

C*) Graph J. GUHR V/s. Generator Output* - Generator offers more efficiency near to full load. Hence less coal is required per unit output.

D) Graph K. Load V/s. Coal - As load on generator increases, coal requirement increases. But for lower value of SEC comparatively less value of coal will be required.

E) Graph L & M. Load V/s. Air/ O2 required - lesser amount of air/O_2 is required for combustion if SEC is less.

F) Graph N, O & P. Load V/s. Co2 / So2 / H2o vapor - If the specific coal consumption is reduced by means of proper combustion & efficiency enhancement of Boiler, Turbine and Generator emission of Co_2 / So_2 / H_2o vapor will be definitely reduced from atmosphere.

One line monitoring of Co_2, O_2 & CO (in order to control the combustion quality) is essential. My above software will be definitely useful for studying the effect of various Boiler and Turbine related parameter on specific coal consumption.

VIII. REDUCTION IN NUHR & GUHR.

1) By reducing in house Auxiliary consumption.
2) Capacity utilization of induction motor used for various fan.
3) By reducing Air leakages/wastages.
4) Proper monitoring and targeting
5) Energy Audit / Water Audit / Proper housekeeping.
6) Energy efficiency of various subsystem used.
7) By means of fuel substitution.
8) WHR. (Waste heat recovery) performance.
9) By reducing Various Thermal/ Electrical Parameter.

In order to verify the possibility of using VFD for various in house auxiliary as well as above discussed parameter my developed software will be helpful.

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IX. CONCLUSION

A) Following some points can be studied wrto environment.

1) Effect of coal quality
2) Effect of Auxiliary consumption.
3) Effect of combustion quality.
4) Effect of operational excellence.
5) Effect of good maintenance practices.
6) Misc. Factor (External and Internal)
7) Effect of condenser vacuum.
8) Weather effect (Ambient Condition)
9) Effect of plant ageing effect.
10) Effects Overhaul (Capital/Annual).

B) Liberation of Co_2, So_2 & H_2o vapor in atmosphere is reduced by reducing SEC.

C) Cost /Kwh of generation is reduced.

D) Increased energy security by reducing imports.

E) Help to save globe by reducing green house gases

F) Exact integration of Energy/engg./economics/environment is possible.

X. FUTURE SCOPE

EC act issued by Government of India came into force in era of globalization energy, economics and environment is a key issue for captive plant. Software developed in my paper will be really helpful to developed a users friendly software for captive plant (Like RES based, DG based, Co-generation etc.) with the view to carry out detailed energy audit and detailed environmental audit.

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