iJRASET
International Journal For Research in
Applied Science and Engineering Technology

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY

Volume: 5 Issue: IX Month of publication: September 2017

DOI: http://doi.org/10.22214/ijraset.2017.9104

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue IX, September 2017- Available at www.ijraset.com

Super Critical Thermal Power Plant Boiler Efficiency Calculation Using Imported Coal

Ashish Kumar Rai[1], Dr. Mukesh Pandey[2], Dr. Prashant Baredar[3]
[1]*Ph.D. (Scholar) Department of Energy Technology RGPV Bhopal MP, India*
[2]*Professor Department of Energy Technology RGPV Bhopal MP, India*
[3]*Associate Professor Department of Energy Technology MANIT Bhopal MP, India*

Abstract: As a result of ever increasing demand for power and diminishing basic resources, the requirement of power plants with higher capacities and higher efficiencies have become the need of the day. In this context, Super Critical Technology is now being used for thermal power generation. In this technology, super critical boilers are used to convert the water into superheated steam. Due to using of super-critical boiler plant is called super-critical thermal power plant. Boiler is the most important part of thermal power plant. In super critical boilers water is splashed directly into steam, so called once through boiler. Initially imported coal was used, now Indian coal is also used for firing in super critical boiler to generate the steam. The point that needs to be addressed now is that how these advanced technology units perform in Indian conditions with imported coal. In this paper an attempt is made to calculate the efficiency of super critical boiler of capacity 660MW using imported coal by indirect method. In indirect method all heat losses of the system are included. This paper also presents a brief of various Boiler operation adjustments to enhance and optimize the supercritical boiler efficiency.
Keywords: Super critical, pulverized fuel, BFP, LHV, Rifled & CV, Separator, etc.

I. INTRODUCTION

The demand for electricity is rapidly increasing in India as economic growth continues. Coal remains the fuel of choice for electricity generation and much of the new demand is expected to come from coal-fired power plants. Fifty nine percent of the existing 230 GW power generated in the country comes from coal-fueled power plants. The next generation of coal plants is expected to have supercritical (SC) and ultra-supercritical (USC) units that have an efficiency of 38-45 percent depending on design, operating parameters, and ambient conditions [1].

The advantages associated with super-critical cycle includes a lower heat rate, low fuel burn rate, lower emission rate and improved load response [2]. On the basis of these factors super-critical technology is invariably adopted all over the world and India is no exception with most of upcoming plants being based on this technology.

The efficiency of the thermal power boiler is calculated by two methods, direct method and indirect method. Various parameters are required for efficiency calculation such as chemical analysis of coal, feed water analysis, coal feeding rate, steam generation rate, steam parameters and fuel consumption rate etc. These parameters are interrelated to each other and are required for efficiency calculation.

In this paper the sequence of steps is mention for the indirect method to calculate supercritical boiler efficiency. Efficiency calculation has been done on the basis of parameters available for 660 MW supercritical pulverized fuel boiler used for electrical power generation. Most of the supercritical power plants are using imported (Indonesian) bituminous coal with CV of 4200 kcal/kg to 4600 kcal/kg is used in furnace.

II. SUPERCRITICAL TECHNOLOGY

The term critical refers to the critical point of water, it is the maximum pressure that liquid and vapour can coexist in equilibrium. At this critical point the density of the steam and water are equal and there is no distinction between the two states, at the critical point the pressure and temperature being 22.1 MPa and 374ºC respectively [3] as shown in fig.2.1

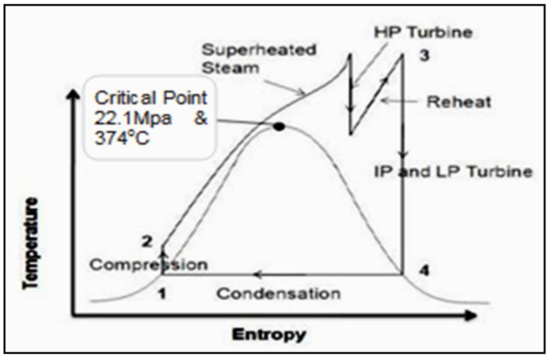


Fig.2.1 critical point

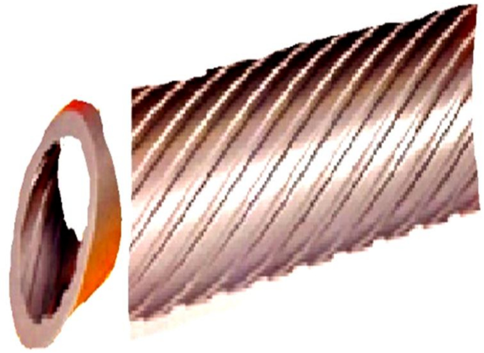


Fig.2.2 – Rifled tubes

When water is heated above the critical pressure, the temperature goes on increasing continuously. At critical point and above this the water will flash instantaneously into steam and super heating will commence [4]. There is no change of specific volume from the liquid to the dry state steam. This is called Super - Critical technology of steam generation.

A. Advantages of Supercritical Technology

Super critical technology has the following advantages

1) Highest achievable plant efficiency working on supercritical steam parameters is improve by 3% [5] on making the transition steam pressure from 16.7 MPa (e. g. drum boiler Sub - critical) to 25 MPa.
2) High plant efficiency even at part load ie. main steam temperatures in the supercritical boiler are independent of load. This results in higher process efficiency for the power plant over a wide load range. Minimum output in once-through operation at high main steam temperatures is 35 to 40% for furnace walls with smooth tubes and is as low as 20% if rifled tubes are used [6] as shown in fig.2.
3) Suitable for wide range of coal grades available on the world market. The transition from evaporation to superheating [7] is not fixed in location and can take place at any point in the upper section of the furnace. This enables dimensioning of the furnace without restrictions on the water/steam side.
4) The thermo-elastic construction and small thermal storage masses in the boiler enable flexible power plant operation [8] with short startup times and large load transients over a wide output range. The Benson boiler startup system consists of several separators, a collecting vessel and a flash tank as in fig.2.3 Installation of a circulation pump is cost-effective for frequent startup, as this further reduces startup losses.

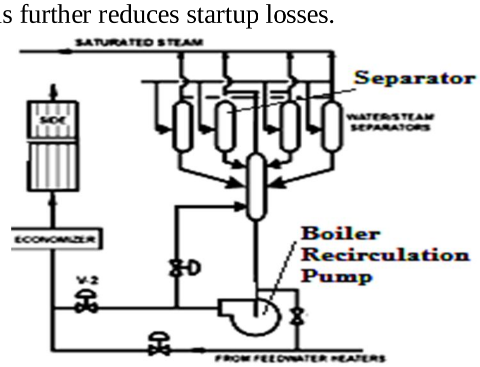


Fig.2.3 Start-up system & Separators connection.

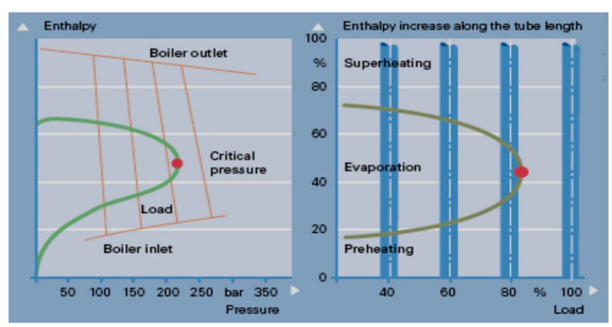


Fig. 2.4 Sliding-pressure operation

5) On high load transients, the temperature changes are in the evaporator section [9]. Due to its thermo-elastic design, Thermal power plants with Benson boilers are therefore especially well-suited to sliding-pressure operation. In sliding-pressure operation temperatures change in the boiler as shown in fig.2.4. The fig. shows, the advantage of the variable evaporation endpoint becomes especially clear in sliding-pressure operation. The enthalpy increase in the boiler for preheating, evaporation and superheating changes with pressure. However, pressure is proportional to output in sliding pressure operation. In a uniformly heated tube, the transitions from preheat to evaporation and from evaporation to superheat shift automatically with load such that the main steam temperature always remains constant.

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue IX, September 2017- Available at www.ijraset.com

III. PRESENCE OF SUPER CRITICAL POWER PLANTS IN INDIA

The first Super-Critical Coal fired power generation 660 MW unit is synchronized by Adani Power Limited in Mundra, Gujarat on 23rd of December 2011[10] and first 800 MW unit is synchronized by TATA Power Limited (Coastal Gujarat Power Limited) in Mundra [11], Gujarat. Some of the other Super-Critical power plant [12] units working in India are given in table1.

Table.1 Super-Critical power plant in India

Sr. no	Name of Power Plant	Location / State	Capacity	Coal
1.	Mundra Thermal Power Station, Adani Power	Mundra Gujarat	5 x 660 MW	Imported Indonesian Coal
2.	Sipat Thermal Power Plant NTPC	Sipat, CG	3 x 660 MW	Indian Coal
3.	Mundra Ultra Power Project, TATA Power, CGLL	Tunda, Kutch, Gujarat	4 x 800 MW	Imported Indonesian Coal
4.	Tirora thermal Power Project Adani Power	Tirora, MH	4 x 660 MW	Indian Coal
5.	Sasan Ultra Power Project, Reliance Infrastructure	Sasan , MP	6 x 660 MW	Indian Coal

IV. SUPER CRITICAL BOILER TECHNICAL DETAILS

A boiler operating at a pressure above critical point is called super - critical boiler. Super critical-boiler has no drum, instead of this it has one continuous path, hence called once through super-critical pressure boiler [13]. The water in boiler is pressurized by boiler feed pump (BFP), sensible heat is added in feed heaters, economizer and furnace tubes, until water attains saturation temperature and flashes instantaneously to dry saturated steam and super heating commences. In India, Supercritical boilers operate at typically main steam conditions of 24.7MPa and 571^{o} C with a single reheat stage at 571^{o} C with steam flow of around 2100 tons/hr [14].

The boiler is π type open-air arrangement supercritical with variable pressure operation, single intermediate reheat, single furnace, balanced draft, dry ash removal and total steel frame suspending structure. It has internal startup system of recirculation pump and adopts low NOx combustion technology, 24 burners are arranged in 6 layers, and tangential firing as in fig.4.1 is adopted. The boiler is equipped with 6 or 8 HP1203 medium-speed mills as in fig.4.2 with direct-fired system, 5 mills are in operation 1 mill is in standby.

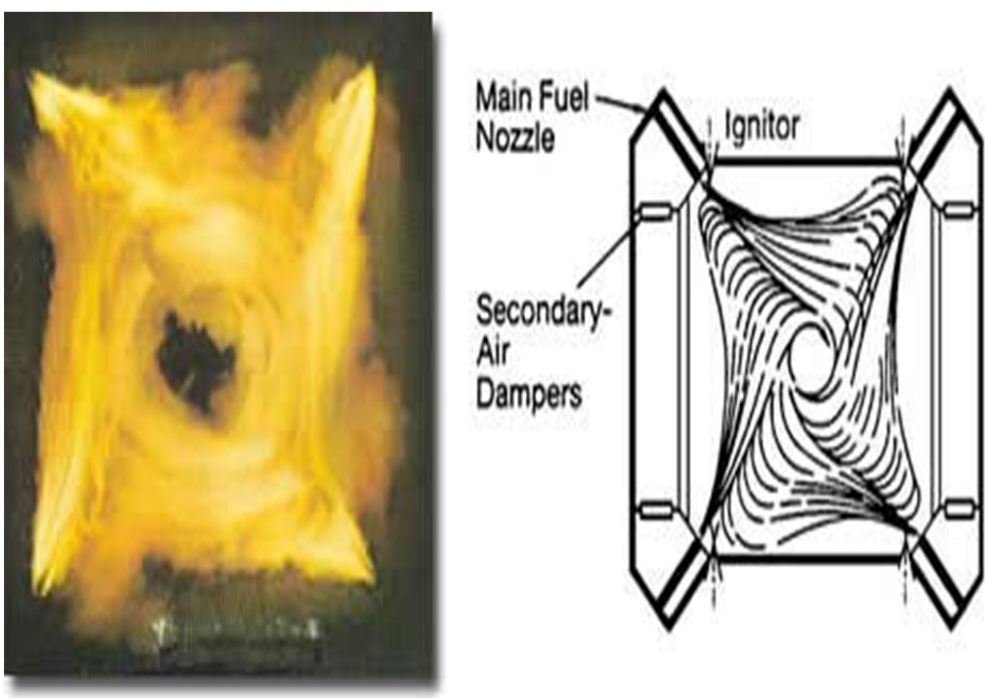


Fig.4.1-Tangential Firing

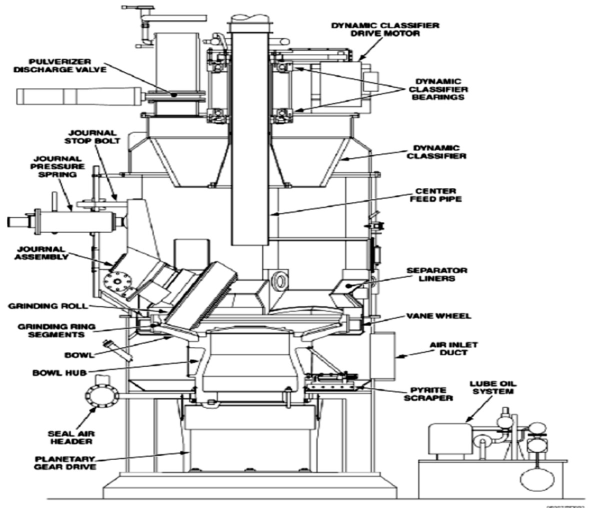


Fig.4.2 Mill (Where Coal is converted into pulverized form)

A. Technical Features

The lower furnace water wall and hopper adopt spiral coil and have enough cooling capacity under different loads, it can compensate the thermal deviation of furnace circumambience effectively, and the hydrodynamic force feature is stable. Four startup separators are adopted, the wall thickness is even and the thermal stress is small when temperature changing. It is fit for sliding pressure operation, increase the unit efficiency and extend the life-time of turbine. The system with recirculation pump is adopted.

The boiler has the capacity of quick startup which can shorten the startup time, and can recover heat and medium effectively during startup. The startup system is equipped with atmosphere type flash vessel and drain tank which has enough capacity.

Wall tangential combustion system which has stable firing and uniform temperature field Wall tangential combustion system can guarantee heat distribution along horizontal furnace is uniform. This reinforced single tangential is vertical to water wall because of the pulverized coal flow and big tangential makes the furnace flame fullness is good, and it is good for guarantee the stable combustion. Compare to corner arrangement burner, it has the advantages of short flame range and good condition for flame two-side blow down

V. SUPER - CRITICAL BOILER EFFICIENCY CALCULATION

In most large pulverized coal fired boilers, the boiler efficiency loss accounts for about 10 - 15 percentage points [15] of overall plant efficiency loss. If performance is not optimal, the controllable losses can result in an even greater degradation in boiler and overall plant performance.

The controllable losses [16] are often related to dry flue gas and carbon losses, which are in turn related to combustion. Since half of the losses are typically dependent on the fuel and ambient condition, the best efficiency can be achieved through optimal settings and tuning of a boiler and its auxiliary equipment.

Boiler efficiency is the ratio of energy output to the energy that is input into a system. Sometimes boiler efficiency is referred to as fuel-to-steam efficiency. It accounts for the effectiveness of the heat exchanger as well as the radiation and convection losses. The efficiency of a boiler is determined by two methods [17].

Input - Output Method or Direct method formula.

Heat - Loss Method or Indirect method formula.

Input - Output Method:

The Input - Output efficiency measurement method is based on the ratio of the output to input of the boiler [18]. The actual input and output of the boiler are determined through instrumentation and the data are used in calculations that result in the fuel-to-steam efficiency. To accomplish this, accurate scales, gravimetric coal feeders, and accountability for all fuels (quality of fuel) are essential. The boiler efficiency is calculated by below mention formula

Boiler efficiency % $\eta = \frac{\text{Heat Output}}{\text{Heat Input}} * 100$

A. Heat Loss Method

The Heat Loss efficiency measurement method is based on accounting for all the heat losses of the boiler. The actual measurement method consists of collecting representative samples of coal, flue gas, and ash for data compilation. Calculate all losses and then subtracting losses from 100. The resulting value is the boiler's fuel-to-steam efficiency [19]. The heat loss method accounts for stack losses, radiation and convection losses.

Boiler efficiency % η $= [100 - \text{Total Losses}]$ ------- (1)

$= [100 - \{L_1 + L_2 + L_3 + L_4 + L_5 + L_6 + L_7 + L_8\}]$

Where

L_1 - % Heat loss due to dry flue gas

L_2 - % Heat loss due to evaporation of water formed due to H_2 in fuel

L_3 - % Heat loss due to moisture present in fuel

L_4 - % Heat loss due to moisture present in air

L_5 - % Heat loss due to incomplete combustion

L_6 - % Heat loss due to radiation and convection

L_7 - % Heat loss due to unburnt in fly ash

L_8 - % Heat loss due to unburnt in bottom ash

B. Equation for calculating various losses

Initially air requirement is calculated for the combustion of fuel.

Step 1. Theoretical (stoichiometric) air requirement

Theoretical air requirement $= \frac{11.6C + 34.8\,[H_2 - \frac{O_2}{8}]}{100} \frac{\text{kg}}{\text{kg of fuel}}$

Step 2. % Excess air requirement (EA)

% Excess air requirement (EA) $= \frac{O_2\%}{21 - O_2} * 100$

Step 3. Actual air requirement

Actual air requirement (AAR) $= TA * \left[1 + \frac{EA}{100}\right]$ kg of $\frac{\text{air}}{\text{kg}}$ of fuel

C. Calculation of all heat losses

1) Percentage Heat loss due to dry flue gas

$$L_1 = \frac{[m * C_p * (T_f - T_a)]}{\text{GCV of Fuel}} * 100 \text{ -------------- (2)}$$

Where,

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

= 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 vapors in the flue gas should not be considered)

C_p = Specific heat of flue gas in kcal/kg °C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

2) Percentage Heat loss due to evaporation of water formed due to H_2 in fuel

$$L_2 = \frac{[9 * H_2 * \{584 + C_p(T_f - T_a)\}]}{\text{GCV of Fuel}} * 100 \text{ ------------ (3)}$$

Where

H_2 = kg of hydrogen present in fuel on 1 kg basis

C_p = Specific heat of superheated steam in kcal/kg °C

T_f = Flue gas temperature in °C

T_a = Ambient temperature in °C

584 = Latent heat corresponding to partial pressure of water vapour

3) Percentage Heat loss due to moisture present in fuel

$$L_3 = \frac{[M * \{584 + C_p(T_f - T_a)\}]}{\text{GCV of Fuel}} * 100 \text{ ------------- (4)}$$

International Journal for Research in Applied Science & Engineering Technology (IJRASET)
ISSN: 2321-9653; IC Value: 45.98; SJ Impact Factor:6.887
Volume 5 Issue IX, September 2017- Available at www.ijraset.com

Where
M = kg moisture in fuel on 1 kg basis
C_p = Specific heat of superheated steam in kcal/kg °C
T_f = Flue gas temperature in °C
T_a = Ambient temperature in °C
584 = Latent heat corresponding to partial pressure of water vapour.

4) Percentage Heat loss due to moisture present in air

$$L_4 = \frac{[AAS * \text{Humidity factor} * Cp(T_f - T_a)]}{\text{GCV of Fuel}} * 100 \text{ ----- } (5)$$

Where
AAS = Actual mass of air supplied per kg of fuel
Humidity factor = kg of water/kg of dry air
C_p = Specific heat of superheated steam in kcal/kg °C
T_f = Flue gas temperature in °C
T_a = Ambient temperature in °C (dry bulb)

5) Percentage Heat loss due to incomplete combustion

$$L_5 = \frac{\%CO * C * 5744}{(\%CO + CO_2) \text{ GCV of Fuel}} * 100 \text{ ---------- } (6)$$

CO = Volume of CO in flue gas leaving economizer (%)
CO_2 = Actual Volume of CO_2 in flue gas (%)
C = Carbon content kg / kg of fuel

6) Percentage Heat loss due to radiation and convection (L_6)

The actual radiation and convection losses are difficult to assess because of particular remissivity of various surfaces, its inclination, air flow pattern etc. In a relatively small boiler, with a capacity of 10 MW, the radiation and unaccounted losses could amount to between 1% and 2% of the gross calorific value of the fuel, while in a 500 MW& more than 500 MW boilers, values between 0.2% to 1% are typical. The loss may be assumed appropriately depending on the surface condition.

7) Percentage Heat loss due to unburnt in fly ash (%).

$$L_7 = \frac{(\text{Total ash collected per kg of fuel burnt} * \text{GCV of fly ash})}{\text{GCV of fuel}} * 100 \text{ -------- } (7)$$

8) Percentage Heat loss due to unburnt in bottom ash (%)

$$L_8 = \frac{(\text{Total ash collected per kg of fuel burnt} * \text{GCV of bottom ash})}{\text{GCV of fuel}} * 100 \text{------ } (8)$$

Now add all eight losses to find total heat losses and find out the boiler efficiency by using formula as in equation (1)
Boiler efficiency % η = [100 – Total Losses]

D. Data for Efficiency calculation

In a typical 660MW capacity super-critical thermal power plant using imported Indonesian coal [20] having boiler is from Harbin Boiler Company Ltd. China. The Boiler is Supercritical, circulating pump type starting, low NOx burner with corner fired combustion, once reheating, balanced ventilation, all steel frame and fully suspended structure.
Coal and other parameters are as mentioned in table 5.1 & 5.2

Table 5.1 Typical proximate Analysis

Item	Unit	Imported Coal*
Fixed Carbon	%	32.5
Volatile Matter	%	30.48
Moisture	%	33
Ash	%	4.02
Grindability Index	HGI	43
Lower Heating Value (LHV)	kcal/kg	4142

Table 5.2 Ultimate Analysis

Item	Unit	Imported Coal*
Carbon	%	47.64
Oxygen	%	10.06
Sulphur	%	0.64
Hydrogen	%	3.22
Nitrogen	%	1.42
Moisture	%	33.00
Ash	%	4.02

Coal consumption, ash production and ambient condition are as shown in table 5.3 & table 5.4

Table 5.3 Ash analysis

Item	Unit	Imported Coal*
Coal Consumption	tons/hr.	347
Ash production	tons/hr.	17.67
Bottom ash Unburnt Burnt Carbon	%	7.72
Fly ash Unburnt Burnt Carbon	%	0.59
Bottom ash to fly ash proportion	%	10 : 90

Table 5.4 Ambient Conditions

Item	Unit	Imported Coal*
Dry bulb temp.	℃	22
Moisture bulb temp	℃	15.78
Atmospheric pr.	kPa	100.2

E. Boiler operating parameters for calculating super critical boiler efficiency

The Boiler efficiency test is carried out on 660MW pulverized coal fuel boiler with imported coal. Operating parameters are shown in table 5.5

Table 5.5 Boiler operating parameters for 660MW capacity.

Item	Unit	Imported Coal*
Main steam flow	tons/hr	2115.5
Main steam outlet pressure	MPa	25.40
Main steam outlet temp	℃	571
Feed water pressure	MPa	28.87
Feed water temp	℃	292.6
Separator outlet pressure	MPa	27.36

Separator temp	℃	423
Reheat steam flow	tons/hr	1714.9
Reheat steam outlet pressure	MPa	4.60
Reheat steam outlet temp	℃	571
Reheat steam inlet pressure	MPa	4.79
Reheat steam inlet temp	℃	328.6
Flue gas exhaust temp	℃	146.3
O_2 content in flue gas	%	4.38
Flue gas temp in APH	℃	409
Total coal	tons/hr.	347

VI. RESULT FROM CALCULATION

Result derived from the above mentioned Equations in Heat Loss method, the boiler losses & Efficiency is shown in table 6.1.

Table 6.1 Boiler Losses& Efficiency.

Item	Unit	Imported Coal*
Losses due to unburnt carbon	%	0.1279
Dry gas loss	%	4.7
Moisture in fuel loss	%	0.268
Hydrogen in fuel loss	%	0.590
Loss due to carbon monoxide	%	0.00
Air moisture Loss	%	0.075
Other losses	%	0.3
Radiation losses	%	0.18
Total losses	%	6.24
Boiler efficiency	%	93.75

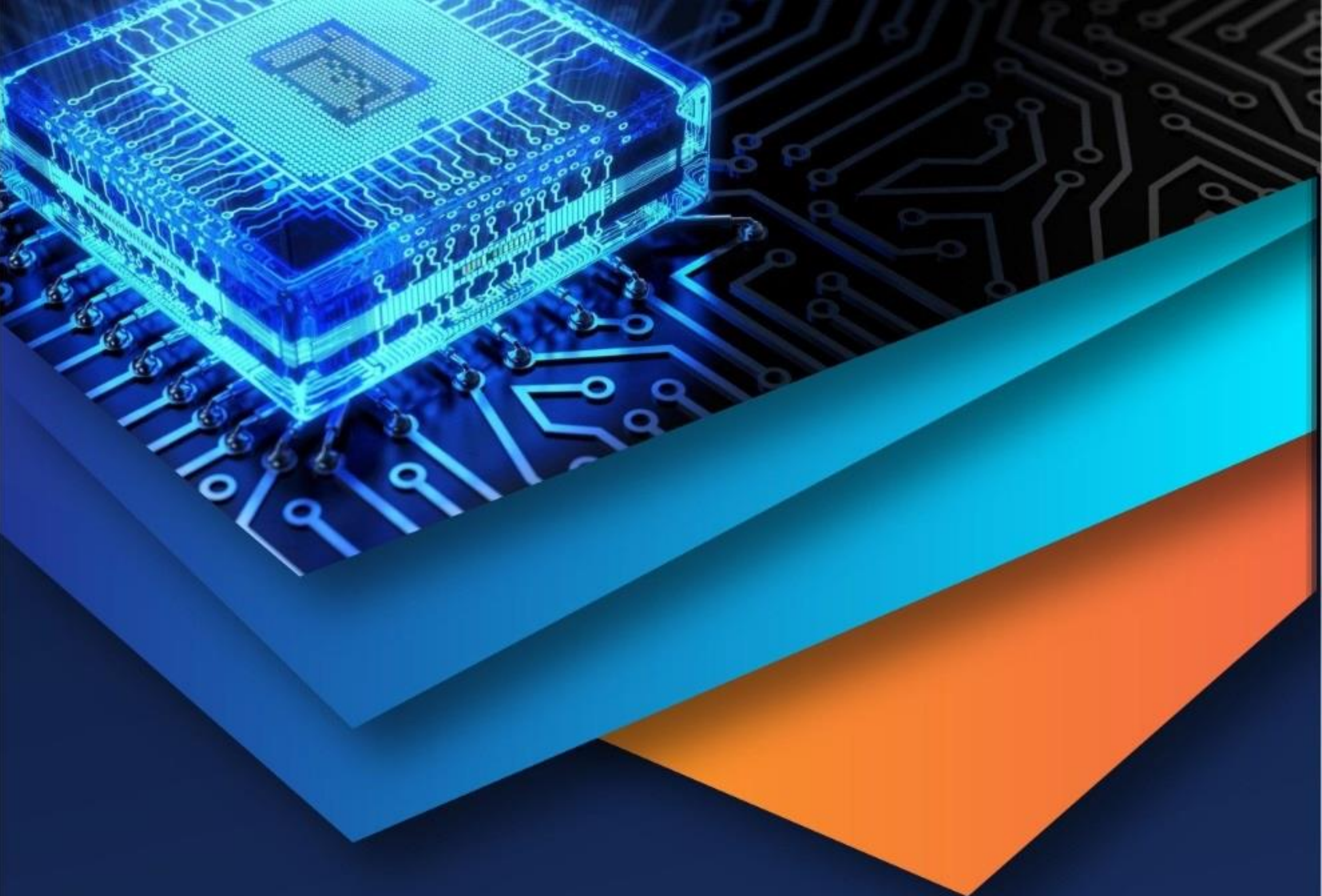
VI. CONCLUSION

This paper briefly focuses on the calculation of Super-critical boiler efficiency using imported coal. A comparatively high efficiency of 93.75% was obtained. Analysis shows that higher boiler efficiency can be obtained with high temperature steam at above the critical pressure. Super critical boiler with higher efficiency and low emission level also produces less percentage of ash. This type of boiler has been realized and will provide higher compatibility and reliability, using advanced technologies.

REFERENCES

[1] Data Collected by Survey of Super Critical Power Plants using Imported Coal in India.
[2] Balakrishnan T. and Balarathinam V., Introduction of supercritical / ultra-supercritical technology in India, Tiruchirapalli, India Energex (2008).
[3] Ralph E.H. Simsa, Hans-Holger Rognerb, Ken Gregoryc Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. Energy Policy 31 (2003):1315–1326

[4] Central Electricity Generation Board 1972. Modern Power Station Practice: Vol. 2: Mechanical Boilers, Fuel, and Ash Handling Plant Pergamon.
[5] British Electricity International 1991. "Modern Power Station Practice: Vol.B: Boilers and Ancillary Plant" Pergamon.
[6] Gupta A.V.S.S.K.S., Satyanarayana I., Srihari B., Reddy B.V., Govindarajulu K. and Nag P.K., Thermodynamic Analysis of Supercritical Cycle, Research Journal of Engineering Sciences ISSN 2278 – 9472 Vol. 2(1).
[7] Stephen J. Goidich, Richard J. Docherty, Kenneth P. Melzer, The world's first supercritical boiler FW-Benson vertical PC Boiler – The Long view power project, by – Power Gen Europe, Colonge, Germany, May (2009):26-28
[8] Steam, its Generation and Use, 41st Edition; J. B. Kitto, S. C. Stultz Eds., The Babcock & Wilcox Co. Barberton, OH, USA, 2005.
[9] Standard Technical Features of BTG system for supercritical 660/ 800 mw thermal units Government of India ministry of power central electricity authority new delhi july, 2013www.cea.nic.in
[10] Brian P. Vitalis, Constant and sliding pressure options for new supercritical plants, Riley Power Inc. Power – Jan/Feb2006
[11] www.adanipower.com
[12] http://www.tatapower.com
[13] www.cea.nic.in
[14] S Mahajan "Adaption of super critical technology an affirmative step by NTPC ltd".
[15] Installation of APL India's first 660MWSuper critical-unit at Mundra by S.Kavidass 2011.
[16] Energy conservationaspects in India thermal power stations by technological innovations: Experience and prospectives , I.P.S. Paul, S.C. Kaushik & S.P. Sabberwal, Pergamon Heat Recovery System & CHP Vol. 14,No.6 pp. 639-649, 1994
[17] Naterer GF, Regulagadda P, Dincer I. Exergy analysis of a thermal power plant with measured boiler and turbine losses. Applied Thermal Engineering 2010; 30:970–6.
[18] "Boiler Efficiency, Source: Cleaver Brooks", web site, 9/01 .www.cleaver-brooks.com.
[19] www.npti.in, Thermal Power Plant efficiencyand performance monitoring.
[20] Rao, K.R., (ed.), "Energy and Power Generation Handbook", ASME, New York, 2011.
[21] India Energy Report 2012, www.enerdata.net



10.22214/IJRASET

INDEX COPERNICUS 45.98

IMPACT FACTOR: 7.129

IMPACT FACTOR: 7.429

INTERNATIONAL JOURNAL FOR RESEARCH

IN APPLIED SCIENCE & ENGINEERING TECHNOLOGY