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Beneficiation of Coal with Biochemical Method and Effect of Treated Coal on Boiler Efficiency in Power Generatation

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ABSTRACT

In India it has become a major challenging task in majority of thermal power stations to maintain heat rate as per design norms due to problems associated with coal quality and constraints in operation and maintenance practices. Heat rate refers to the amount of heat required to generate one unit of power which mainly depends upon coal quality. Boiler efficiency and heat rate are mainly influenced by key quality parameters of the coal that is ash, moisture, volatile matter, net calorific value of coal, ratio of fixed carbon to volatile matter and grindability of coal. In this research study an effort is being made to improve coal quality by using bio-extracts derived from leaves of citrus limon in combination with lower concentrations of Ethylene Diamine Tetra Acetic Acid (EDTA) and compare boiler efficiency/heat rate with raw and beneficiated coals. Phyto extract derived from citrus limon is effective in demineralizing Aluminium and Pyrite minerals in coal and EDTA is successful for removal of Calcium and Magnesium mineral components of coal and hence calorific value of coal is increased. Results suggesting that usage beneficiated coals improving the boiler efficiency and reducing the heat rate of the thermal unit there by crores of rupee can be saved.

Keywords: Heat rate, Boiler efficiency, Quality of coal, Ash, Bio extract, Gross calorific value, IS (Indian Standard).

INTRODUCTION

Even after the bulk addition of renewable energy in the Indian energy sector, the contribution of energy generation from fossil fuels is very significant i.e., around 58% of the energy requirements are being met from these fuels[1]. The main advantage of the energy produced from these sources is the stability of the grids. In other words, these base load generators will supply uninterrupted and reliable power to various consumers viz. industrial, commercial, domestic, and agriculture etc. Coal being the major fossil fuel, it is very important to optimize the utilization of the available coal as the coal reserves in the country are depleting very fast. Every effort must be put forth to increase the subsistence of these coal reserves by optimizing consumption. In this context, beneficiation of low-grade coal is to be carried out and a comprehensive study on heat rate, the most important parameter related to thermal power, must be carried out and any improvement (reduction or maintaining as per design) in heat rate of a thermal station will be very useful.

Heat rate indicates the quantity of heat required to generate one unit of electricity. It is measured in Kcal/k watt.hr and is inversely related to the overall efficiency of the thermal unit[2]. In general, as the technology improves heat rate will be reduced. If heat rate is low, fuel cost of power generation will be low which helps to progress of the nation. In any thermal power generating unit, input design parameters (particularly coal quality) influence the heat rate. In most of the thermal stations located in south India designed heat rate will be 2100 to 2300 Kcal/Kwh approximately. Coal-fired power plants must adopt a strategy to reduce the heat rate and ensure economical generation of power. Coal is the primary fuel used in thermal power plants. Out of the total expenditure incurred in the thermal power generation, the landed cost of coal (that is coal cost plus transportation costs) alone accounts for about 70%. Any effort to reduce power plant's heat rate can lower coal consumption used to generate one unit of power and thereby expenditure to generate power will be reduced, directly benefiting the entire nation. As per detailed calculations of efficiency and planning departments of the thermal power stations, in a generating unit of capacity 800-MW with plant load factor of 80%, using 8500MT of coal per day, if heat rate is reduced by 1% it results in the savings of forty crore rupees. Heat rate improvement has environmental benefits also. Reduction in the heat rate results in reducing Carbon dioxide and Sulphur dioxide emissions and hence controlling global warming and acid rains. As per the available data, reduction in the heat rate by 1% will reduce CO_2 emissions by more than 1% which approximately amounts to CO_2 quantity of about 40,000 tons/year[3].

One of the major contributory factor for heat rate improvement is improving the chemical characteristics of the coal which is known as beneficiation of the coal. Regarding coal quality, the most important parameters which influence the boiler efficiency and in turn heat rate are, percentage of ash content, moisture, fixed carbon/volatile matter (FC/VM) ratio and graindability characteristics of the coal.

The power generating plants located in South India are receiving coals with more than 50% ash in majority of occasions whereas units of 210MW are designed for the coal with ash content less than 45%. Hence, at least 10% reduction in the ash is required for maximum power generation. Besides, the reduction in ash will significantly improve the boiler efficiency and heat rate. This obviously results in huge financial savings. Moisture present in the coal matrix which is inherent in nature, reduce the net calorific value of the coal during combustion process hence reducing the inherent moisture will also enhance the coal quality and in turn improves the boiler efficiency. The Fixed carbon/Volatile matter (FC/VM) ratio of the coal is another key parameter that play an important role in combustion process and improvement in this ratio has more than one advantage. The improvement in the ratio will not only reduce the unburnt carbon but also avoid incomplete combustion thereby formation of Carbon monoxide (CO) is avoided. As per the available literature, the recommended FC/VM ratio shall be in the range of 1.0 to 1.3 sub-bituminous/bituminous coal[4]. The improvement in FC/VM ratio will also have a positive influence in 3Ts (temperature, turbulence, time of retention of coal particle in flame zone) in the process of combustion. Hard grove index (HGI, unit less parameter) of the coal is a measure of the softness of the coal that is if HGI is more softness will be more coal can be powdered easily. The recommended HGI value shall lie between 45 to 55 and coal sample with HGI of 55 is more suitable for ideal grinding. The lesser the value, difficult will be the grinding. Hence, beneficiation attempted in this research investigation to improve all these coal characteristics that is to increase HGI, reduce ash and inherent moisture and to increase FC/VM ratio, gross calorific value to meet the design parameters of the boiler.

At present the quality of coal supplied to thermal stations in south India, is of lower gross calorific value, high ash and inherent moisture content and undesirable FC/VM ration which implies the need for beneficiation of coal. Proximate analysis results of some of the raw coal rakes received at power station located in near Kadapa, India are presented in the Table 1.

Table 1: Quality of some of the coal rakes received at RTPP

S. No	Date	Source	Eq. Moisture%	Eq. Ash%	VM(volatile matter)%	FC (Fixed carbon)%	Calorific value Kcal/Kg	Grade of the coal
1	30.04.23	JVRB-Sattupally	4.86	54.04	18.89	22.21	2760	G16
2	01.05.23	RUSG-Rudrampur	5.22	51.18	20.05	23.55	2975	G15
3	04.05.23	CSPS-Manugur	4.40	49.83	20.17	25.60	3188	G14
4	07.05.23	JVRB-Sattupally	3.88	59.61	17.16	19.35	2388	G17
5	07.05.23	JVRB-Sattupally	4.24	55.01	19.08	21.68	2729	G16
6	07.05.23	JVRB-Sattupally	4.32	54.68	19.00	22.01	2763	G17
7	09.05.23	JVRB-Sattupally	4.21	53.55	19.47	22.77	2899	G15

Above quality clearly indicates the low-grade coal hence beneficiation of coal is essential. With regard to the beneficiation of coal various physical and chemical methods are in practice, physical methods include Jig washing, froth flotation and magnetite cyclonic wash which are mainly density-based separation of impurities from the coal[5-14]. whereas pure chemical methods used acids, bases and their combinations[15-25]. Chemical methods cannot be used on a large scale for beneficiation of coal due to corrosive nature of chemicals. In recent times bio methods for beneficiation of coal are attracting the researchers as they are ecofriendly and two such successful efforts are published recently[26-27]. It is proposed to use bio-extracts of Citrus limon in combination with lower concentrations of Ethylene Diammine Tetra Acetic Acid (EDTA) for enhancement of coal quality in this research investigation. The main objective of this research study is to enrich the quality of coal receiving at power generating station located near Kadapa, India (Rayalaseema thermal power project) and an intensive study of effect of treated coals on boiler efficiency /Heat rate.

METHODS AND MATERIALS

Rayalaseema Thermal Power Project (RTPP), Kadapa, India

This project is located in the close proximity of Penna River near Kadapa, India and it has 1650MW total installed capacity (5 number 210 MW units and one unit of 600 MW). At present RTPP is receiving coal with poor quality as represented by the monthly weighted average of gross calorific value of coal is approximately 3000 Kcal/Kg with 52 to 54% ash whereas 210 MW units are designed for 3686 Kcal/Kg with 45% ash. Hence an effort is made in this research investigation to improve the quality of coal, by reacting the low-grade coal with the mixture of bio-extract derived from leaves of citrus limon in combination with lower concentrations of Ethylene Diamine Tetra Acetic Acid (EDTA) and in addition all calculations pertaining to advantage of using treated coals for improving boiler efficiency/heat rate are presented in this research study.

Collection of coal samples: As per the fundamentals of sample collection and preparation procedure presented in IS 436: 2020, accurate coal sample which is representative of the entire train rake was collected.

Procedure of sample collection and preparation: Train rake of raw coal generally contains 58 or 59 boxes(wagons) with total of approximately 3600Mt of coal. As per IS procedure 15 boxes are selected by following IS random table. From each wagon approximately 25 Kg sample is collected. 350 Kg sample collected in this manner is thoroughly mixed and further reduced in quantity by coning and quartering method. Finally, one kg of 212 micron powdered coal sample is prepared by using pulverisers and taken to laboratory for treatment with mixure of bioextract and EDTA.

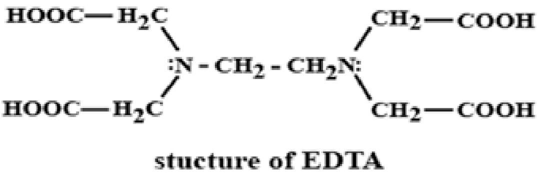
Phyto extract & EDTA

Extracts derived from plant leaves of Citrus limon, is weakly acidic in nature with Potential Hydrogen ion concentration that is PH (measure of acidity) of approximately 2.8 that is with acidic nature and this phyto-extract contains 6% of citric acid. It is useful to act as good complexing agent having ability to leach out metal ions (particularly Aluminum and Iron) present in the coal. Ethelene Di ammine Tetra Acetic acid (EDTA) is an hexadentate ligand having good coordinating ability to remove Calcium and Magnesium present in the coal is employed as second leaching agent in this investigation. The mixture of bio-extract and EDTA solution is used for treatment of coal. The effort made in this research investigation resulted in effective leaching of mineral components from coal in addition to reducing the Sulphur and inherent moisture present in the coal.

The bio-extract

For preparing required citrus extract, the collected green leaves of the plant (Citrus limon) were thoroughly cleansed with demineralized water. The leaves which are cleansed and dried were crushed properly and made of 200 g of paste. This paste is mixed with 1000 mL of demineralized water and uniform heating is arranged to this mixture for a span of one hour at 80^{0}C. Then the temperature of mixture was reduced to 28^{o}C and then filtered. The filtrate so collected is the bio extract, mixed with EDTA and employed as leaching agent in this research investigation.

EDTA It is an hexadentate ligand having good ability to chelate with the Calcium and Magnesium ions present in the coal. However, as coal contains lower proportions of Calcium and Magnesium only low concentration of EDTA (1 N) solution is employed in this investigation.



Scheme 1. Structure of EDTA

Is the structure of EDTA is a very important chelating ligand in chemical sciences which has the ability to form complexes with Calcium and Magnesium ions present in the coal.

Treatment of 212 microns powdered form of coal with the mixture of bio-extract and EDTA

Initially 500 mL mixture of bio-extract and 1Normal solution of EDTA in 50:50 proportion was prepared. This mixture is used as leaching agent for treatment with the coal .10.0 g of 212 micron size coal sample collected as per the standard procedure was taken in a round bottom flask (250 mL capacity) and 25 mL of leaching agent is added and thoroughly mixed. This reaction vessel was fitted with condenser arrangement. To carry out the reaction between coal particles with leaching agent more effectively following precautions are taken;

a) Very less particle size of the coal (212 microns).
b) High temperature (80^{o}C) to increase the rate of reaction.
c) Uniform heating for a span of 1 h to carry effective leaching of impurities (minerals and other impurities in the coal).

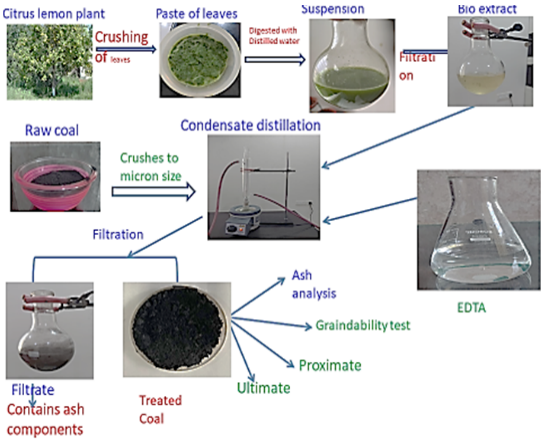


Fig. 1. Pictorial representation of experimental steps

After heating the reaction vessel for a span of one hour, then heating was stopped, and the reaction vessel was brought to room temperature conditions. Filtration was carried out, precipitate is separated and then dried. This dried precipitate is the treated coal (beneficiated coal).This beneficiated coal was analyzed for various quality parameters such as ash, gross calorific value, inherent moisture, carbon content etc., to ensure the enhancement of coal quality. To confirm the effective leaching capacity of bio extract and EDTA and enhancement of quality, ash composition test is also carried. The experiment was repeated with different volumes of leaching agent(50, 75, 100 mL). Calculations pertaining to boiler efficiency are carried out by using raw and enriched coal.

Characterization

Grindability test, proximate analysis, ash composition test and ultimate analysis were carried for both for raw(untreated) and beneficiated coals.

Grindability test (Hard groove Index): This test is carried by using Hard groove apparatus. Higher HGI indicatesa soft and easily grindable coal.50 g of air-dried coal sample of size 16+30 mesh is subjected to 60 revolutions in HG apparatus. After grinding coal is screened through a 200mm sieve.

HGI=6.93W+13

W=weight of the coal sample (came out of HG Apparatus) passing through 200 mesh sieve.

HGI represents hard groove grindability index that has no unit. Coal with approximately 50% HGI is used in thermal power generation. HGI values of untreated (raw) and beneficiated coals are tabulated in (Table 2).

Proximate analysis

This analysis gives the percentage of inherent mineral matter that is ash, inherent moisture, volatile material and fixed carbon present in the coal.

Ash

Ash content in both raw and enriched coal is measured through a standardized methodology mentioned in IS 1350 Part 1. To accomplish this, a specialized instrument known as a muffle furnace is employed. The method entails placing precisely 1 g of air-dried, finely powdered coal, with a particle size of 212 microns, into a Silica crucible. The Silica crucible, containing the coal sample, is then subjected to controlled heating within the muffle furnace, where it reaches a temperature of 815°C and is maintained at this level for a duration of one hour. After the heating phase, the furnace is powered down, allowing the crucible to naturally cool to a temperature of approximately 28°C. During this cooling process, any residual unburnt rock material that remains within the crucible is quantified as a percentage, representing the mineral content, commonly referred to as ash.

This meticulous analysis of ash content is carried out for both raw and treated coal samples, employing the muffle furnace as the primary analytical tool. The resulting data is methodically recorded and compiled into tabular form in Table 3 for further analysis.

Inherent Moisture

Inherent moisture, is the moisture present within the pores of coal matrix that is left after the removal of external moisture. Its determination adheres to the methodology outlined in Part 1 of IS 1350: 2020. The procedure entails dispersing 1 g of fine powdered 212 microns coal sample, evenly distributed within a Silica crucible, placed inside an oven maintained at 108°C for one hour. As boiling point of water is 100°C, inherent moisture in coal is completely removed at 108°C there by mass of coal sample is reduced.

The percentage reduction in the coal sample's mass gives the inherent moisture content. This analysis is conducted for both untreated and enriched coal samples, and the resulting data is systematically tabulated in Table 3 for reference and for further analysis.

Volatile Matter

The hydrocarbon content within coal is a pivotal determinant of its volatile matter. The quantification of this volatile matter is conducted in accordance with the comprehensive methodology outlined in the IS 1350: 2019.The process initiates with the placement of precisely 1 g of fine powdered coal sample, featuring particles of 212 microns in size, within a Silica crucible. This crucible, with the coal sample securely enclosed, is then introduced into a Muffle furnace, where it is subjected to a controlled environment at an operating temperature of 900°C for a period of 7 minutes. During this time, stringent precautions are taken to prevent the ingress of external air. Following this controlled heating, the sample's temperature is gradually brought to room temperature and the mass of the coal sample is meticulously recorded. By considering the reduction in mass and after giving the correction for the inherent moisture content, volatile matter expressed in percentage.

This analysis of volatile matter is executed for both untreated and enriched coal samples, and the resulting data is presented in Table 3 for reference and analysis.

Fixed Carbon (FC)

The calculation of the fixed carbon content in both raw coal and treated coals is a critical step in coal analysis. This value is computed using the following formula:

FC=100−(A+IM+VM)

Where FC is fixed carbon; ‘A” represents ash content; VM is volatile matter and IM is inherent moisture.

This calculation provides an essential insight into the composition of coal, particularly the portion that is relatively stable and non-volatile. The results of these calculations for both raw and the beneficiated coals are systematically tabulated (Table 3). This table offers a comprehensive overview of the fixed carbon content, allowing for a detailed comparison and analysis of the coal samples, which is invaluable for various industrial and research applications.

Gross Calorific Value

It quantifies the energy content of the coal. The GCV represents the heat (expressed in Kcal) generated after the efficient combustion of a unit quantity (1 Kg) of coal. Unit of GCV is Kcal/Kg.

To determine the GCV of coal, the methodology prescribed in IS 1350: Part II; 2020, is followed. The instrument used for this purpose is a bomb calorimeter, specifically designed for accurate calorific value measurements.

The procedure involves taking 1 g of air-dried, fine powdered (212 micron size), coal sample in the form of pellet, placing it in the bomb calorimeter. Oxygen is used to facilitate the firing of the coal sample, and the resulting value of the GCV is recorded using the Leco Bomb Calorimeter.

The GCV values for both untreated and enriched coals are systematically tabulated in Table 3. These values provide critical information about the energy potential of the coal samples and are essential for various industrial and research applications.

Ash composition test

This test is carried out to find out the percentage composition of various mineral oxides, present in ash for both treated and untreated coal received at RTPP and the results are tabulated (Table 4).

Ultimate analysis was carried out to know the elemental composition of coal before and after treatment and presented in Table 5.

Boiler efficiency and heat rate of thermal power station: Boiler efficiency can be evaluated in two methods viz. direct method and indirect method. In this investigation, an indirect method was chosen since the heat losses can be accounted for more accurately. These heat losses include dry gas loss, loss due to combustibles in ash, loss due to moisture and hydrogen in fuel, loss due to sensible heat in ash, air moisture loss and radiation loss. These losses are evaluated for both raw and beneficiated coals and improvement in the boiler efficiency is presented in Table 6 of results and discussion section. Heat rate depends upon many parameters which may be controllable or uncontrollable. However, the parameters used in evaluating boiler efficiency are very useful to calculate the heat rate and in turn financial benefits are also presented in the boiler efficiency section.

RESULTS AND DISCUSSION

Coal quality assessment

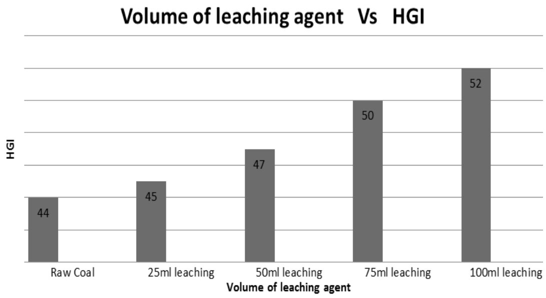
Hard groove index (Grindability of coal)

This is a measure of ease with which coal may be crushed to fine particle size. Hard grove index (HGI) is a measure of softness of the coal, higher the index number represents it is easy to crush the coal. Harder the coal, the lower is the index number. The higher the HGI, the softer and more grindable is the coal. In general, it has values of 40, 50, 60, 70 …. etc., with no unit. The higher the HGI, the higher is the mill loading in the thermal power station.

HGI values of determined in the experiment and tabulated in Table 2 infers that as the concentration of leaching agent increased HGI value also increased. In the present investigation HGI values of untreated and enriched coal is 45 and in the final treated coal is 52%.Same is presented in the graphical study also. Analysis of ash composition reveals that ash is mainly composed of major components Silica and Alumina (80%) and minor components of FeO, CaO, MgO etc., As leaching agent employed in this investigation is successful in removing Aluminium, Calcium, Magnesium and Iron components in coal, the hardness of coal is decreased and hence HGI increased. Increase in HGI is an advantageous outcome of the treatment as softness of coal is increased there by mill performance in the thermal power generating unit is better (as shown in Fig. 2 graph) there by unburnt carbon after combustion will be low.

Table 2: HGI data of raw and treated coal

	Volume of the leaching agent in mL				
Parameter	0 (raw coal)	25	50	75	100
HGI	44	45	47	50	52



Graph Corresponding to data presented in Table 2

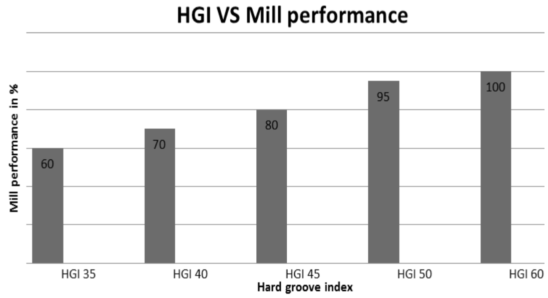


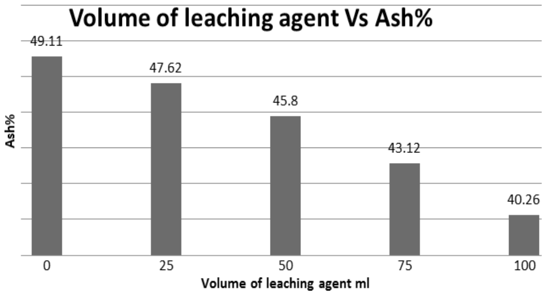
Fig. 2. HGI Vs mill performance

Proximate Analysis

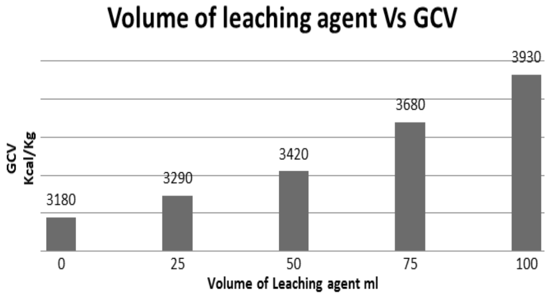
Table 3: Analysis of raw and enriched coals (Proximate analysis)

	Before digestion Raw Coal	Digestion with 25 mL leaching agent	Digestion with 50 mL leaching agent	Digestionwith 75mL leaching agent	Digestionwith 100 mL leaching agent
Ash content	49.11	47.62	45.80	43.12	40.26
GCV	3180	3290	3420	3680	3930
Inherent Moisture	5.1	4.7	4.0	3.8	3.5
Volatile Matter	26.4	26.5	26.4	26.2	26.3
Fixed Carbon	19.39	21.18	23.80	26.88	29.94

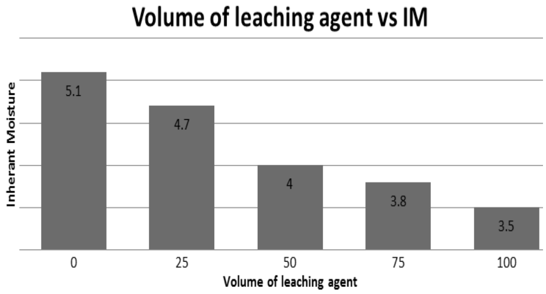
*The values presented here are the average of 5 experimental results: Standard Deviation =/-0.01



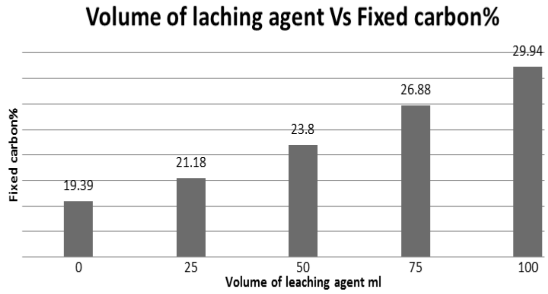
Graph of ash variation corresponding to data presented in Table 3



Graph of GCV variation corresponding to data presented in Table 3



Graph of IM variation corresponding to data presented in Table 3



Graph of Fixed carbon variation corresponding to data presented in Table 3

The per the proximate analysis data mentioned in the Table 3 and in turn represented by graphs clearly illustrates a notable reduction in the ash content, transitioning from 49.11% to 40.26%. Furthermore, with an increase in the concentration of the leaching agent, this reduction becomes even more significant. It's important to recognize that ash is essentially comprised of unburnt mineral matter found within the coal, mainly consisting of a mixture of oxides of Silicon, Aluminium, Iron, Titanium and alkali, and alkaline earth metals.

The effectiveness of the leaching agent which is a mixture of bio-extract and EDTA lies in its ability to leach out certain ash components, leading to a decrease in the percentage of ash. This, in turn, results in an increase in the fixed carbon content and subsequently elevates the gross calorific value (GCV) of the coal. It's interesting to note that the slight reduction in inherent moisture may be attributed to the removal of water molecules associated with ash components, such as $Al_2O_3.2H_2O$ (water of hydration within the crystal structure of alumina). This reduction in inherent moisture also contributes to the enhanced GCV of coal.

Interestingly, no significant change is observed in the volatile matter content, as it primarily consists of hydrocarbons, and the leaching agent texhibits non reactivity towards hydrocarbons. Notably, the units designed for 210MW are engineered for a GCV of 3686, and this research study successfully achieves the designed boiler value, highlighting the practical implications of these findings.

Ash Analysis

The components present in the of ash were analyzed by using IS 1355:2019 to understand the quantitative and qualitative nature of mineral matter present in the coal. Ash composition data of both untreated and enriched coals is presented in the Table 4.

When coal is fired in the furnace, carbon based components undergo combustion but mineral based (rocks) components remains as un burnt as the melting points of these mineral components is more than the furnace temperature. These unburnt mineral residue is termed as ash, that is ash is a mixture of mineral components.

Table 4: The composition of Ash obtained from Coal received at RTPP

Sources	Silica	Alumina	Calcium oxide	Magnesium oxide	Iron oxide	Titania	Na_2O	K_2O
Before treatment	60.6	25.8	3.6	2.1	1.60	3.21	0.41	0.11
After Treatment	72.98	21.3	0.8	0.7	0.75	3.19	0.20	0.08

On comparison of ash composition of untreated and enriched coals, it infers that the contribution of Al_2O_3, CaO, MgO, FeO and Oxides of Sodium and Potassium are decreased in treated coal. Bio-extract having citric acid is effective in demineralizing Aluminium, Iron, Sodium and Potassium compounds and EDTA is a good complexing ligand thereby Calcium and Magnesium components of the coal are reduced. As analysis is based on percentages, decrease in above components reflected in the increased percentage of Silica.

Following chemical reactions are suggested.

$C_6H_8O_7(C_6H_5O7)^{3-}+3H^+$

$(C_6H_5O_7)^{3-}+Al^{3+} \longrightarrow Al\ (C6H5O7)$
(Aluminium citrate)

$(C_6H_5O_7)^{3-}+Fe^{2+} \longrightarrow Fe(C_6H_5O_7)$

$2(C_6H_8O_7) \longrightarrow 2(C_6H_5O_7)^{6-}+6H^+$

$2(C_6H_5O_7)^{6-}+ 3Ca^{2+} \longrightarrow Ca3\ (C_6H_8O_7)^2$
(Calcium citrate)

$EDTA^{4-}+2Ca^{2+} \longrightarrow Ca_2EDTA$

$EDTA^{4-}+2Mg^{2+} \longrightarrow Mg_2EDTA$

When coal with high ash content is treated with leaching agent which is a mixture of bio-extract and EDTA, then coordinating agents present in the leaching agent are forming complex compounds with ions of Aluminium, Iron, Calcium and Magnesium present in the coal and converting into soluble form hence filtrate contains leached out mineral components of the coal and enriched coal is in the precipitate form (as mineral component is reduced).

Elemental Analysis

By following the concept of IS 1350:2020 with the use of advanced CHNS analyser equipment, detailed elemental presence is analysed for both raw and enriched coals and tabulated the results (Table 5). This gives the percentages of key elements present in the coal that is Carbon, Oxygen, Nitrogen, Sulphur and Hydrogen.

The data presented in Table 5 clearly demonstrates that as the concentration of leaching agent increases (mixture of bio-extract and EDTA), the carbon percentage in the coal also increases. Due to increase in the carbon content, during combustion of coal calorific value also experiences an increase, thereby amount of coal required to generate one unit of power decreases.

In addition to the rise in carbon content, the treatment process leads to slight decreases in the percentages of hydrogen and oxygen. This reduction is attributed to the decrease in inherent moisture in the coal, a phenomenon elaborated upon in the proximate analysis section.

Table 5: Elemental composition of raw and enriched coal samples:

	For raw coal	Treated coal (25 mL leaching agent)	Treated coal (50 mL leaching agent)	Treated coal (75mL leaching agent)	Treated coal (100 mL leaching agent)
Carbon%	33.20	35.62	37.85	39.99	42.26
Hydrogen%	3.12	3.11	3.06	2,98	2.91
Nitrogen%	0.80	0.81	0.80	0.82	0.83
Sulpher%	0.44	0.42	0.39	0.37	0.36
Oxygen%	12.00	11.21	9.98	9.70	8.70

*The tabulated values are the average of 5 experimental results: Standard deviation: +/-0.10

One significant benefit of this investigation is the decrease in the Sulphur content observed in all the enriched coals. An important ore of Iron that is Iron pyrites contains Sulphur, is often found in the crystal structure of coal and serves as the primary source of SO_2 emissions during firing of coal. The citric acid present in the phyto extract of citrus limon leaves, is a weak organic acid have the capability to form complexes with Fe^{2+} ions present in the coal and Iron citrate is water soluble. As a result, a decrease in the concentration of iron sulfide (FeS) is noticed, leading to a reduction in Sulphur in treated coals.

Coal with minimal or zero sulfur content is highly recommended for use in power generating stations. This is because, during coal combustion, sulphur is converted into Sulphur oxides, such as SO_2 and SO_3, which are acidic and contribute to acid rain formation. Therefore, this process of upgrading low rank coals has two major advantages, one is preparing the coal with design calorific value and other is reduction in the Sulphur, a significant step in environmental safety by reducing the risk of acid rain formation.

Comparative study of boiler efficiency with untreated and treated coals

The boiler efficiency is calculated using heat loss method where in all the losses in boiler are accurately assessed, the efficiency is obtained by deducting the % losses from 100.

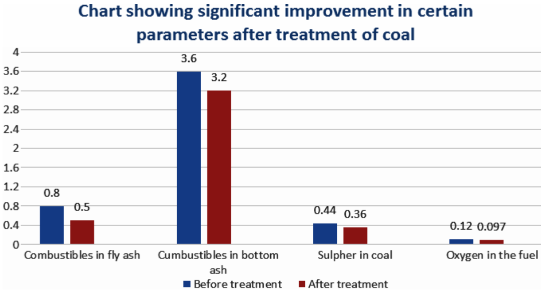
Table 6: Parameters of boiler efficiency

S. No	Parameter	Before Treatment	After treatment with 75 mL sample of leaching agent
1	% Ash in COAL	49.11	43.12
2	% Ash appearing at ESP	0.8	0.5
3	% Combustibles in Fly Ash	0.8	0.5
4	% Ash appearing at Furnace bottom	0.2	0.2
5	% Combustibles in Bottom Ash	3.6	3.2
6	% CO_2 in FG After APH	14	14
7	% Carbon in COAL	33.2	39.99
8	% Sulphur in COAL	0.44	0.36
9	Specific heat of GAS	30.6	30.6
10	FG Temp after APH	144	144
11	Dry Bulb Temperature	42.5	42.5
12	CV of COAL	3180	3680
13	CV of Carbon	8077	8077
14	% Moisture in COAL	5.1	3.5
15	% Hydrogen in COAL	3.12	2.98
16	Specific heat of MOISTURE	1.88	1.88
17	Minimum gas temperature	25	25
18	Enthalpy of vapour in the process of combustion	2442	2442
19	Specific heat of ash	0.2	0.2
20	Bottom ash temperature	620	620
21	Radiation Loss	0.2	0.2
22	O_2 required for Kg of Carbon	2.666	2.666
23	O_2 required for Kg of Hydrogen	7.937	7.937
24	O_2 required per Kg of Sulphur	0.996	0.996
25	O_2 in the fuel (COAL)	0.12	0.097
26	O_2 from ORSAT analysis after APH	5.6875	5.6875
27	%Excess Air	1.37	1.37
28	Moisture in air	0.01	0.01
29	%O_2 in atmosphere by weight	23.2	23.2

The generation of heat within the boiler relies on the process of combustion. To ensure efficient combustion, it is imperative to address factors that lead to incomplete combustion. Adding more air than necessary to the combustion process increases the oxygen available for burning the fuel. When there is an ideal equilibrium between the fuel and the oxygen from the air, it is referred as a stoichiometric combustion. Enhancing the combustion efficiency is achievable by introducing more excess air, but only up to the point where the heat loss due to the surplus air surpasses the benefits of improved combustion.

Various factors and operating conditions influence the boiler efficiency are studied in detail on 210MW unit RTPP boiler by managing the ingress of unwanted air into the furnace, maintaining the optimal ratio of coal, air, and water, sustaining the requisite velocity of secondary air, achieving a well-balanced distribution of the air mixture across burner levels. Prevention of slag buildup on the boiler's heating surfaces is also crucial as deposits on these surfaces hinder heat exchange and result in varying steam temperatures within the boiler, and this unequal distribution of temperature reduces the boiler's operating capacity and overall efficiency. Many other factors that influence the boiler efficiency has been studied with two different coals i.e., before treatment and after treatment of coal, and the results are tabulated in Table 6. for further analysis.

Above mentioned boiler efficiency is calculated by considering all losses pertaining to Percentage of dry gas, combustionables in ash, Hydrogen and moisture in the coal, sensible heat in ash, radiation and air moisture.



Above data of Table 6 indicates that usage of enriched coal increases the efficiency of boiler by 2.22% which results in the annual savings of about 62 Crores per annum per every unit with 210 MW capacity. The RTPP station consists of 5 such units and about 300 Cr per annum is very significant. In addition, there are several intangible benefits such as environmental, operation & maintenance related, reduced specific water consumption, reduced auxiliary power consumption etc.

CONCLUSION

In this investigation mixture of bio-extract of Citrus limon in combination with Ethylene Diamine Tetra Acetic Acid (EDTA) is found to be successful in improving the quality of the coal and thereby increase in boiler efficiency and maintaining the heat rate in thermal power generation. The phyto extract of citrus limon is useful to leach out Aluminium and Iron components in the coal whereas EDTA works effectively for complexing with Calcium and Magnesium components of the coal, which results in the significant decrease in mineral matter (ash) of the coal. Results of proximate analysis suggest that ash content, inherent moisture are decreased and fixed carbon was increased to the desired level to improve boiler efficiency in the thermal power generating units. Consequently, heat rate that is heat required to generate one unit of power also maintained in the safe limits. HGI index is a measure of grindability of coal,also improved in this investigation there by mill performance will be enhanced due to usage of these treated coal. Sulphur present in the coal also decreased in this research study as leaching agent is successful in removing Iron Sulphide mineral in the coal which is an added advantage as Sulphur is responsible for acid rains. All these significant facts are proved in measurement of caloric value, grindability test, ash analysis, proximate and ultimate studies. The significant outcome of the present research study is that phyto-extract of leaves of Citrus limon plant (contains citric acid) in combination with EDTA is proved to be useful for successful demineralisation of coal there by quality of coal is enhanced and improvement of boiler efficiency is noticed. Hence by using these treated enriched coals it is possible to generate maximum power at less variable cost there by savings of huge money to the nation.The developed procedure of coal beneficiation is ecofriendly as only lower concentration of EDTA is mixed with bio-extract.

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Conflict of interest

The author declare that we have no conflict of interest.

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