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Low cost treatment of acid mine drainage

Gorbi mine belonging to Northern Coalfields Limited (A subsidiary of Coal India Limited) has been abandoned and mine void is filled with water acidic, which is due to presence of pyrite in the coal measure, strata containing sulphur varying from 0.5 to 1.0 per cent. Pyrite (FeS2) is oxidized when exposed to oxygen and water, resulting in hydrogen ions, sulfate ions and metal cations. This problem also persists in coalfields of North East India. The problem of acid mine drainage pollutes the surface and ground water making it unsuitable for plants and animals and need to be neutralize with the removal of trace and major metal before its supply. Acid mine drainage (AMD) is characterized by low pH value 2-4 and often contains high concentrations of chemical species such as Fe, Mn and anionic species such as SO_4, *apart from heavy metals such as Zn, Co, Pb, Cr, and Cu in trace concentrations.*

This paper describes the results of a study conducted to determine the ability of coal fly ash (CFA) and rice husk biochar (RHB), which are available locally and do not cost much to neutralize inorganic trace and major elements from acid mine drainage in different conditions. In this study optimum doses of CFA and RHB have been determined for the neutralization.

Keywords: *AMD, CFA, RHB*

1. Introduction

Acid mine drainage (AMD) is a major pollutant in the mining areas of the world attracting attention of environmental engineers. In the presence of water and oxygen, oxidative decomposition of sulphide minerals (mainly pyrite, FeS_2) gives this acidic, metal-filled water. High acidity of AMD and large amounts of dissolved heavy metals, such as copper, zinc, manganese, iron, arsenic, lead etc., generally make AMD very toxic for most organisms (Pentreath, 1994) [1].

Mining activities highlight a significant amount of pyrite mineral deposited in layers of rock beneath the surface of the earth, where there is no oxygen. Mining activities bring these deposits to the surface where they are crushed to leave precious minerals like copper, zinc, gold, nickel etc. while tail is left at the mine site. Thus, in large quantities, the pyrite comes in contact with surface conditions, i.e. air and water, which will help in the oxidation of pyrite for the production of AMD (Jenkins et al., 2000) [2]. Due to abundance in the environment, pyrite is recognized as the major source of AMD (Evangelou, 1998) [3].

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As discussed above, sulphide minerals are oxidized in the presence of oxygen (dissolved in air or in water) and water (in the form of vapor or liquid) to produce sulfide acid. Primary responses to pyrite formation of AMD are presented below (Singer and Strumm, 1970) [4]:

Pyrite initially oxidizes sulfuric acid and ferrous iron (Fe^{2+}) by atmospheric oxygen according to the following reaction:

$$FeS_2 + 7/2\ O_2 + H_2O \rightarrow Fe^{2+} + 2SO_4^{2-} + 2H^+ \quad ...\ (1)$$

$$Fe^{2+} + 1/4\ O_2 + H^+ \rightarrow Fe^{3+} + 1/2\ H_2O \quad ...\ (2)$$

Ferrous ion can be further oxidized by oxygen, which releases more acid in the environment and precipitates ferric hydroxide:

$$Fe^{2+} + 1/4\ O_2 + 5/2\ H_2O \rightarrow Fe(OH)_3 + 2H^+ \quad ...\ (3)$$

With the increase in acid production, the pH of the solution decreases, which results in oxidation of pyrite by Fe^{3+}, resulting in more acid formation:

$$FeS_2 + 14\ Fe^{3+} + 8H_2O \rightarrow 15\ Fe^{2+} + 2SO_4^{2-} + 16H^+ \quad ...\ (4)$$

Reaction (4) is catalyzed by bacteria, especially Thiobacillus feroxidas. The overall response to the formation of AMD is as follows:

$$4FeS_2 + 15O_2 + 14H_2O \rightarrow 4Fe(OH)_3 + 16H^+ + 8SO_4^{2-} \quad ...\ (5)$$

The rate of AMD formation depends on many factors, such as presence and type of microbes, sulfide and non-sulfide minerals present, rock particle size, solution pH, temperature and oxygen, nutrient and water (Evangelou, 19983; Valenzuela et al., 2005) [5].

AMD can be treated by active or passive techniques, of which passive treatment is more common. Most AMD treatment systems involve the use of neutralizing agents to increase pH and promote metallic precipitation. AMD can

Fig.1 Maps showing study area

also be treated in many other methods, such as reverse osmosis, adsorption, ion exchange, electromechanical technique etc. However, here it is experimented with locally available low cost CFA and RHB to treat acidic water accumulated in abandoned opencast mine void of Gorbi mine of NCL (CIL). The mine is situated in Singrauli district of Madhya Pradesh about 200 km from Varanasi in Moher basin of Singrauli coalfields. It was worked by opencast method and abandoned in the year 2000 after reserves were exhausted. The mine void has been filled with water which is acidic in nature (pH of 2-4). There are no aquatic or plant life in this type of water.

Coal fly ash (CFA) is waste produced after the coal is burnt in thermal power plants, which is also one of the main source of environmental pollution. CFA has been used in many ways such as an alternative material for Portland cement, due to its physical (self-hard) properties in structural filler (usually for road construction), soil stabilization and mineral filler asphalt concrete, and in recent years, due to its chemical (high degree of alkalinity) properties it is used to neutralize the AMD. To mitigate AMD, the reuse of this waste product can be a successful alternative and a proper method of disposal, thereby reducing the need for storage of coal fly ash in large amounts.

Due to being cheap in the country, rice husk biochar has received a lot of attention recently. In addition, the use of biochar is widely used in environmental aspects in the world to improve soil fertility and water quality (A. Nurul Farhana et al., 2018) [6]. Therefore, the objective of this study is to evaluate CFA and RHB as low cost alternative neutralizing agent of AMD compared to any active or passive treatment methods.

2. Material and methods

2.1. Study area

The Indian coal area covering more than 15,000 km^2 is usually under the Miocene era, from the lower Gondwana group of the Permian era and the tertiary group of Eocene (Saxena, 1991) [7]. Block B project was chosen for the present study which is located in Singrauli district of Madhya Pradesh, India. Block-B project covers Gorbi-B, Gorbi-C and Vindhya Sub-Block. Gorbi-B & Gorbi-C are located on the north of Vindhya Sub-Block and Moher Block is on the south of Block-B. Its elevation is about 375 meters to 512 meters above the MSL. It is located between the latitude 23° 47' and 24° 12' north and longitude 81°48' and 82°52' east.

2.2. Sample Collection

Acid mine drainage water samples were collected from abandoned Gorbi mine (Block B project) located in NCL, Singrauli district of Madhya Pradesh, India. This abandoned mine site contains the massive quantity of mine water. The earlier proposals to utilize this abandoned mine void for backfilling of CFA generated at NTPC pit head thermal power plants at Singrauli did not materialize due to apprehension of environmental pollution due to overflow of AMD (pH 2-4). The study will also establish suitability of CFA of STPP at Singrauli. The raw water sample was collected in 10 l clean plastic jars, which were carefully washed with raw water sample before starting water sampling (acid mine drainage) from mine sites.

2.3 Preparation of Adsorbents

(a) Fly ash adsorbents

Low cost adsorbents were prepared from collected fly ash samples and used for the treatment of acid mine drainage for an effective reduction of trace and major metal during the adsorption technique. Ash samples were kept into oven at 110ºC for drying and adsorbent activation purpose nearly for 3 hours. Fly ash samples are collected from NTPC's Vindhyachal super thermal power project which is located in the Singrauli district of Madhya Pradesh. This project is in Singrauli area, on the interstate border of Madhya Pradesh and Uttar Pradesh, approximately 225 kilometers south of Varanasi city. Vindhyachal is a pithead power station of installed capacity 1260 MW (6×210 MW) under Stage-I, 1000 MW (2×500 MW) of Stage-II), 1000 MW (2 × 500 MW) under Stage-III and 500 MW under Stage-IV. Presently the total capacity of this project is 4260 MW and 500 MW of Stage-IV is under construction. This makes it as one of the largest power projects of NTPC consuming approximately 18 MT of coal every year and generation of high amount fly ash.

(b) Rice husk biochar adsorbents

The rice husk used in this work was obtained from nearby rice mill. Rice milling generates a byproduct as husk. It surrounds the grain of paddy. Due to local availability, cost-effectiveness rice husk was used for production of biochar. After collection of rice husk from rice mill, it was initially washed thoroughly with tap water to remove the dust and other impurities. Then the material was washed with distilled water. After washing it was dried in an oven at 105ºC for 24 hours. To avoid further adsorption of moisture, samples were preserved in desiccators. Dried rice husk sample was taken in a porcelain crucible and covered with lid and kept in proportional integral-derived (PID) control muffle furnace at 650ºC for one hour. Carbonated husk samples were cooled and preserved to be used for the next stage of the process.

2.4. Characterization of AMD

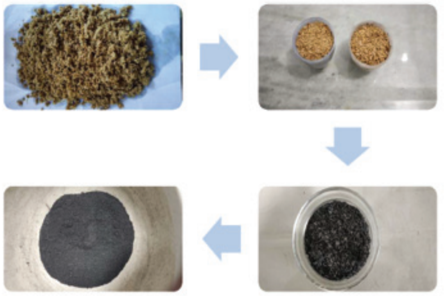

Fig.2 Process showing preparation of rice husk biochar

Typically, AMD has low pH values, high sulfate content, high total dissolved solid content and high levels of heavy metals dissolved in the form of ions. With decreasing pH, the dynamics of trace elements increases. It produces high concentrations of acidity, sulfate and high concentrations of metals such as Fe, Cu, Zn, Co, Cr, Mn, Pb, Cd and other elements. Chemical characteristics of AMD in the study area are given in Table 1.

Table 1

	Substance	Value
1.	pH	2.58
2.	Acidity as $CaCO_3$(mg/L)	1120
3.	Alkalinity as $CaCO_3$(mg/L)	0
4.	TDS (mg/l)	1408
5.	EC (µS/cm)	2200
6.	$SO4^{2-}$ (mg/L)	5.235
7.	Cl^{-} (mg/l)	179.9442
8.	Ca (mg/L)	18.3
9.	Na (mg/L)	25.7
10.	K (mg/L)	4.9
11.	Mn (mg/L)	8.88
12.	Fe (mg/L)	18.12
13.	Cu (mg/L)	0.008
14.	Ni (mg/L)	2.854
15.	Zn (mg/L)	12.94
16.	Cd (mg/L)	0.034
17.	Pb (mg/L)	0.453
18.	Co (mg/L)	1.182
19.	Cr (mg/L)	0

2.5. Treatment of AMD

(a) With fly ash

The fly ash sample was collected from NTPC power plant of Singrauli district, Madhya Pradesh, India. Ash samples were kept into oven at 110ºC for drying and adsorbent activation purpose nearly 3 hours. The sample dosage was fixed as per the literature study. Different dosages were selected to test the efficiency of fly ash in adsorbing the metals concentration. The dosages were 0.25gm/100ml, 0.5gm/100ml, 1gm/100ml, 1.5gm/100ml, 2gm/100ml, 2.5gm/100ml, 3mg/100ml, 3.5gm/100ml, 4mg/100ml, 4.5mg/100ml, 5mg/100ml, 5.5mg/100ml, 6mg/100ml, 6.5mg/100ml and 7mg/100ml. The flasks with different dosages were run on an open pan shaker machine at room temperature at 150 rpm. Shaking was done for total 24 hours. After shaking, the samples were filtered with membrane filter paper. Filtered sample were analyzed for different water quality parameters like pH, acidity, alkalinity, sodium, potassium, sulphate and heavy metals etc.

(b) With rice husk biochar

The biochar sample was derived from the charring of rice husk collected from nearby rice mill. The charred sample was crushed with mortar and pestle and it was grinded into fine powder. The powder was fine enough to pass through the minus 72 BSS sieve. The sample dosage was fixed as per the literature study. Different dosages were selected to test the efficiency of biochar in adsorbing the metals concentration. The dosages were 0.25gm/100ml, 0.5gm/100ml, 1gm/100ml, 1.5gm/100ml, 2gm/100ml, 2.5gm/100ml,3mg/100ml, 3.5gm/100ml and 4mg/100ml. The flasks with different dosages were run on an open pan shaker machine at room temperature at 150 rpm. Shaking was done for total 24hours. After shaking, the samples were filtered with membrane filter paper. Filtered sample were analyzed for different water quality parameters like pH, acidity, alkalinity, Sodium, potassium, sulphate and heavy metals etc.

3. Results and discussion

In order to carry out the adsorption studies, different doses of fly ash (dose range from 0.25 gm to 7.0 gm) and rice husk biochar (dose range from 0.25 gm to 4.0 gm) were mixed with 100 ml AMD solution at the initial pH level and heavy metals concentration and shaked for 24 hours. The results of studies are presented and discussed in this section.

(a) Effect on pH (Table 2)

It is clear from the graph (Fig.3) that pH is increasing with the increase in amount of fly ash and rice husk biochar in AMD. Here one can see that rice husk biochar is more effective for increasing the pH value of AMD as compared to fly ash.

(b) Effect on chloride (Table 3)

From the graph (Fig.4) it is clear that with the increase in doses of fly ash and rice husk biochar material in AMD the chloride content is decreasing.

Table 2

Doses of Adsorbent	pH Value (CFA)	pH Value (RHB)
AMD (Pure)	2.58	2.58
0.25gm/100ml	2.73	2.81
0.50gm/100ml	2.82	2.96
1.00gm/100ml	2.98	3.19
1.50gm/100ml	3.20	3.60
2.00gm/100ml	3.39	4.25
2.50gm/100ml	3.69	5.91
3.00gm/100ml	4.06	6.61
3.50gm/100ml	4.38	6.96
4.00gm/100ml	4.78	7.38
4.50gm/100ml	5.18	
5.00gm/100ml	5.66	
5.50gm/100ml	6.08	
6.00gm/100ml	6.39	
6.50gm/100ml	6.80	
7.00gm/100ml	7.02	

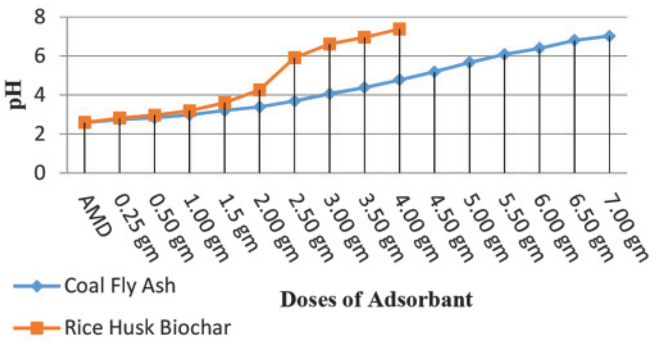

Fig.3

Table 3

Doses of Adsorbent	Chloride(mg/l) (CFA)	Chloride(mg/l) (RHB)
AMD (Pure)	179.9442	179.9442
0.25gm/100ml	159.9504	219.9318
0.50gm/100ml	139.9566	239.9256
1.00gm/100ml	119.9628	219.9318
1.50gm/100ml	119.9628	279.9132
2.00gm/100ml	119.9628	219.9318
2.50gm/100ml	99.969	179.9442
3.00gm/100ml	99.969	199.938
3.50gm/100ml	99.969	179.9442
4.00gm/100ml	79.9752	179.9442
4.50gm/100ml	79.9752	
5.00gm/100ml	79.9752	
5.50gm/100ml	79.9752	
6.00gm/100ml	59.9814	
6.50gm/100ml	59.9814	
7.00gm/100ml	59.9814	

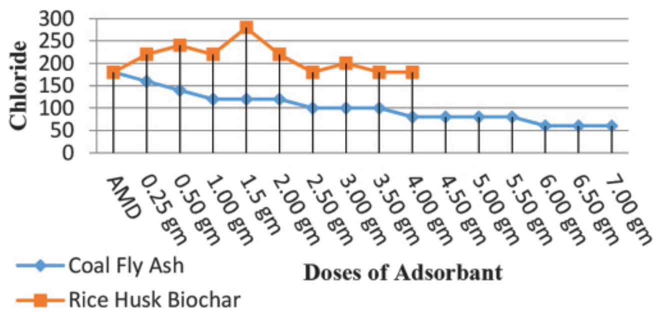

Fig.4

(c) Effect on sodium (Table 4)

From the graph (Fig.5) it is clear that with the increase in doses of fly ash and rice husk biochar material in AMD the sodium content is decreasing.

TABLE 4

Doses of Adsorbent	Na+(mg/l) (CFA)	Na+(mg/l) (RHB)
AMD (Pure)	25.7	25.7
0.25gm/100ml	19.7	24.9
0.50gm/100ml	19.6	23.5
1.00gm/100ml	19.4	22.6
1.50gm/100ml	18.4	22.2
2.00gm/100ml	17.7	21.1
2.50gm/100ml	17.5	19.7
3.00gm/100ml	17.5	18.7
3.50gm/100ml	17.5	16.5
4.00gm/100ml	17.3	15.6
4.50gm/100ml	17.2	
5.00gm/100ml	16.8	
5.50gm/100ml	16.5	
6.00gm/100ml	16.3	
6.50gm/100ml	16.2	
7.00gm/100ml	15.9	

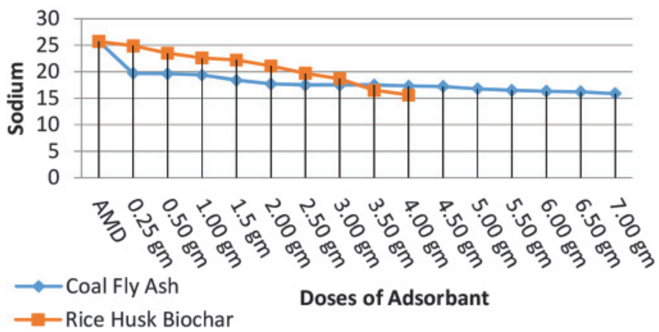

Fig.4

(d) Effect on potassium (Table 5)

As biochar material already contains some amount of potassium, the concentrations of the element have increased and hence the graph (Fig.6) is showing an increasing trend. And here one can see with increasing doses of fly ash the amount of potassium is showing decreasing trends.

TABLE 5

Doses of Adsorbent	K+(mg/l) (CFA)	K+(mg/l) (RHB)
AMD (Pure)	4.9	4.9
0.25gm/100ml	3.5	17.3
0.50gm/100ml	3.5	19.3
1.00gm/100ml	3.4	25.1
1.50gm/100ml	3.2	46.9
2.00gm/100ml	2.9	47.5
2.50gm/100ml	2.7	47.8
3.00gm/100ml	2.6	59.6
3.50gm/100ml	2.1	81.2
4.00gm/100ml	2.1	87.8
4.50gm/100ml	2.0	
5.00gm/100ml	2.0	
5.50gm/100ml	1.95	
6.00gm/100ml	1.95	
6.50gm/100ml	1.85	
7.00gm/100ml	1.85	

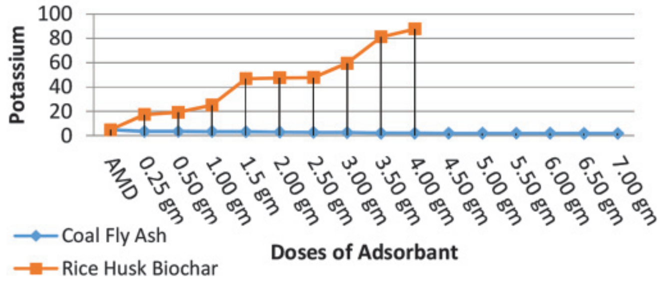

Fig.6

(e) Effect on calcium (Table 6)

It is clear from the graph (Fig.7) that calcium content is increasing with the increase in amount of fly ash and rice husk biochar in AMD.

TABLE 6

Doses of adsorbent	Ca^{+}(mg/l) (CFA) (RHB)	Ca^{+}(mg/l)
AMD (Pure)	18.3	18.3
0.25gm/100ml	21.2	20.4
0.50gm/100ml	24.5	22.2
1.00gm/100ml	24.5	52
1.50gm/100ml	25.4	52
2.00gm/100ml	28.3	61.5
2.50gm/100ml	29.2	64
3.00gm/100ml	29.2	69.5
3.50gm/100ml	29.7	75
4.00gm/100ml	30.6	87.1
4.50gm/100ml	34.4	
5.00gm/100ml	38.6	
5.50gm/100ml	38.6	
6.00gm/100ml	41.9	
6.50gm/100ml	44.3	
7.00gm/100ml	47.1	

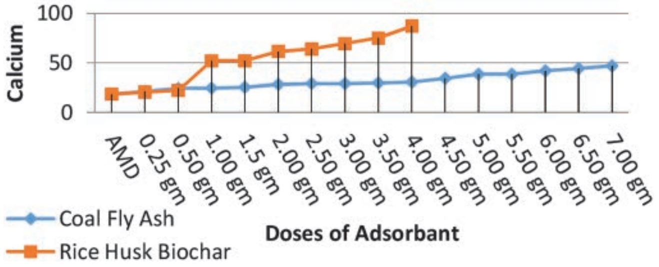

Fig.7

(f) Effect on acidity (Table 7)

It is clear from the graph (Fig.8) that acidity is decreasing with the increase in amount of fly ash and rice husk biochar in AMD. Here one can see that rice husk biochar and fly ash both adsorbents are effective for decreasing the acidity of AMD.

TABLE 7

Doses of adsorbent	Acidity (mg/l) (CFA)	Acidity (mg/l) (RHB)
AMD (Pure)	1120	1120
0.25gm/100ml	776	752
0.50gm/100ml	712	668
1.00gm/100ml	672	656
1.50gm/100ml	656	612
2.00gm/100ml	628	584
2.50gm/100ml	600	544
3.00gm/100ml	588	528
3.50gm/100ml	548	508
4.00gm/100ml	544	432
4.50gm/100ml	504	
5.00gm/100ml	492	
5.50gm/100ml	472	
6.00gm/100ml	452	
6.50gm/100ml	392	
7.00gm/100ml	356	

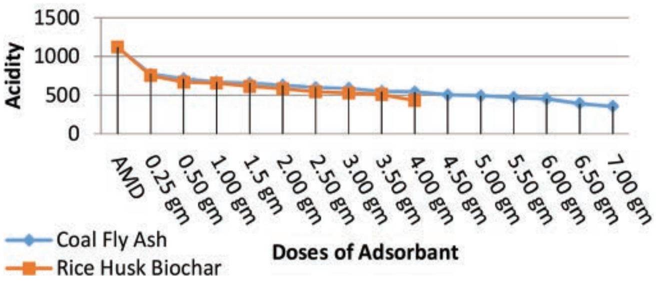

Fig.8

(g) Effect on alkalinity (Table 8)

It is clear from the graph (Fig.9) that alkalinity of water is increasing with the increase in amount of fly ash and rice husk biochar in AMD.

TABLE 8

Doses of adsorbent	Alkalinity (mg/l) (CFA)	Alkalinity (mg/l) (RHB)
AMD (Pure)	0	0
0.25gm/100ml	152	204
0.50gm/100ml	204	204
1.00gm/100ml	212	252
1.50gm/100ml	216	300
2.00gm/100ml	232	324
2.50gm/100ml	252	416
3.00gm/100ml	300	456
3.50gm/100ml	324	480
4.00gm/100ml	416	480
4.50gm/100ml	456	
5.00gm/100ml	456	
5.50gm/100ml	468	
6.00gm/100ml	480	
6.50gm/100ml	496	
7.00gm/100ml	512	

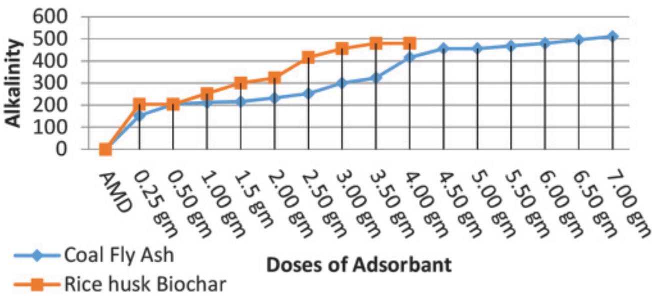

Fig.9

(h) Effect on electrical conductivity (Table 9)

It is clear from the graph (Fig.10) that electrical conductivity is decreasing with the increase in amount of fly ash and rice husk biochar in AMD.

TABLE 9

Doses of adsorbent	EC(µS/cm) (CFA)	EC(µS/cm) (RHB)
AMD (pure)	2200	2200
0.25gm/100ml	2180	2200
0.50gm/100ml	2150	2180
1.00gm/100ml	2150	2170
1.50gm/100ml	2120	2150
2.00gm/100ml	2080	2130
2.50gm/100ml	2060	2100
3.00gm/100ml	2050	1970
3.50gm/100ml	2030	1950
4.00gm/100ml	2030	1910
4.50gm/100ml	2010	
5.00gm/100ml	1980	
5.50gm/100ml	1930	
6.00gm/100ml	1920	
6.50gm/100ml	1890	
7.00gm/100ml	1880	

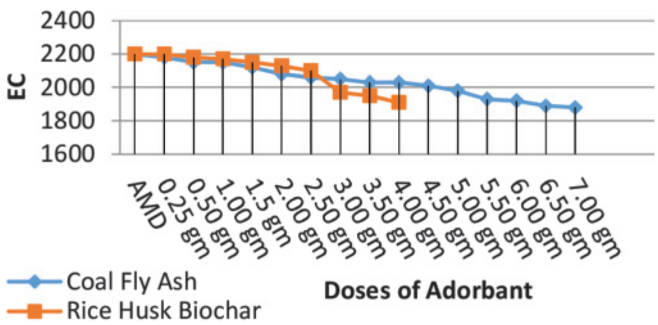

Fig.10

(i) Effect on total dissolved solids (Table 10)

It is clear from the graph (Fig.11) that electrical conductivity is decreasing with the increase in amount of fly ash and rice husk biochar in AMD.

TABLE 10

Doses of Adsorbent	TDS(mg/l) (CFA)	TDS(mg/l) (RHB)
AMD (Pure)	1408	1408
0.25gm/100ml	1395.2	1408
0.50gm/100ml	1376	1395.2
1.00gm/100ml	1376	1388.8
1.50gm/100ml	1356.8	1376
2.00gm/100ml	1331.2	1363.2
2.50gm/100ml	1318.4	1344
3.00gm/100ml	1312	1260.8
3.50gm/100ml	1299.2	1248
4.00gm/100ml	1299.2	1222.4
4.50gm/100ml	1286.4	
5.00gm/100ml	1267.2	
5.50gm/100ml	1235.2	
6.00gm/100ml	1228.8	
6.50gm/100ml	1209.6	
7.00gm/100ml	1203.2	

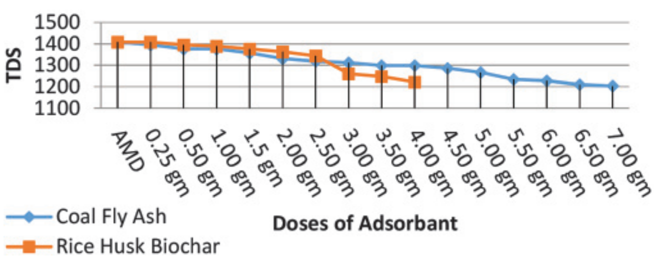

Fig.11

(j) Effect on sulphate (Table 11)

It is clear from the graph (Fig.12) that sulphate content is showing both increasing and decreasing trend with the increase in amount of fly ash and rice husk biochar in AMD. Both the adsorbents are not effective for sulphate.

TABLE 11

Doses of adsorbent	Sulphate (mg/l)(CFA)	Sulphate (mg/l)(RHB)
AMD (pure)	5.235	5.235
0.25gm/100ml	2.3031	2.5249
0.50gm/100ml	2.5249	2.3045
1.00gm/100ml	2.5249	2.5263
1.50gm/100ml	2.5249	2.5249
2.00gm/100ml	2.5249	2.5249
2.50gm/100ml	2.5249	2.5249
3.00gm/100ml	2.5249	2.0478
3.50gm/100ml	2.5249	2.0478
4.00gm/100ml	2.5249	2.0478
4.50gm/100ml	2.5249	
5.00gm/100ml	2.5249	
5.50gm/100ml	2.5249	
6.00gm/100ml	2.5249	
6.50gm/100ml	2.5249	
7.00gm/100ml	2.5249	

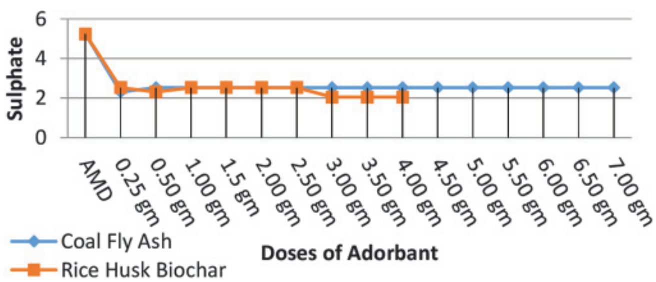

Fig.12

(k) Effect on geavy metals

(i) Coal fly ash (Table 12 and Fig.13)

With the increase in doses of biochar material and fly ash the heavy metal concentrations are showing decreasing trend.

(ii) Rice husk biochar (Table 13 and Fig.14)

With the increase in dose of biochar material all heavy metal concentrations are showing decreasing trend except manganese, it shows increasing trend.

4. Conclusion

Fly ash and rice husk obtained from the local power plants and rice mill respectively were found to be useful for the treatment of acid mine drainage. The pH value of the AMD water sample improved from 2.58 to 7.02 and 7.38 respectively. The study results show that fly ash and rice husk biochar can be used as an economical material for the uptake of other heavy metals from mine water. Study establish that AMD water of Gorbi abandoned mine may be backfilled with coal fly ash of NTPC plants without risk of acidic water overflow.

TABLE 12

Doses of Adsorbent	Cu	Cd	Cr	Pb	Fe	Mn	Ni	Zn	Co
AMD (Pure)	0.008	0.034	0	0.453	18.12	8.88	2.854	12.94	1.182
0.25gm/100ml	0.007	0.032	0	0.173	16.72	10.68	2.836	10.88	1.162
0.50gm/100ml	0.006	0.031	0	0.12	16.7	10.68	2.812	10.72	1.158
1.00gm/100ml	0.006	0.031	0	0.12	16.12	10.28	2.806	10.68	1.139
1.50gm/100ml	0.005	0.031	0	0.119	15.74	10.04	2.789	10.32	1.127
2.00gm/100ml	0.005	0.031	0	0.119	14.96	9.88	2.748	9.68	1.119
2.50gm/100ml	0.003	0.03	0	0.093	12.8	9.6	2.739	9.56	1.111
3.00gm/100ml	0	0.03	0	0.093	12.74	9.44	2.726	9.36	1.109
3.50gm/100ml	0	0.03	0	0.087	12.58	9.2	2.705	8.92	1.106
4.00gm/100ml	0	0.03	0	0.079	12.4	8.92	2.688	8.56	1.105
4.50gm/100ml	0	0.029	0	0.066	12.26	8.76	2.669	7.92	1.098
5.00gm/100ml	0	0.028	0	0.065	12.02	8.48	2.647	7.88	1.057
5.50gm/100ml	0	0.028	0	0.05	11.88	8.36	2.632	7.68	1.007
6.00gm/100ml	0	0.025	0	0.044	11.64	8.28	2.613	7.52	0.987
6.50gm/100ml	0	0.025	0	0.037	11.54	8.28	2.593	7.16	0.975
7.00gm/100ml	0	0.023	0	0.033	11.28	8.04	2.579	7.16	0.952

TABLE 13

Doses of adsorbent	Cu	Cd	Cr	Pb	Fe	Mn	Ni	Zn	Co
AMD (Pure)	0.008	0.034	0	0.453	18.12	8.88	2.854	12.94	1.182
0.25gm/100ml	0.007	0.032	0	0.2	8.434	9.66	2.705	11.4	1.131
0.50gm/100ml	0.006	0.032	0	0.153	6.892	10.28	2.661	11.2	1.09
1.00gm/100ml	0.006	0.031	0	0.141	5.546	10.96	2.529	10.74	1.073
1.50gm/100ml	0.005	0.029	0	0.131	3.783	11.18	2.369	10.56	1.032
2.00gm/100ml	0	0.029	0	0.102	2.337	11.92	2.174	10.36	1.03
2.50gm/100ml	0	0.028	0	0.087	2.097	12.06	2.103	10.32	1.012
3.00gm/100ml	0	0.026	0	0.07	1.776	12.98	2.027	10.06	1.003
3.50gm/100ml	0	0.026	0	0.061	1.379	14.96	1.901	10.02	0.965
4.00gm/100ml	0	0.026	0	0.055	0.947	19.08	1.822	9.86	0.926

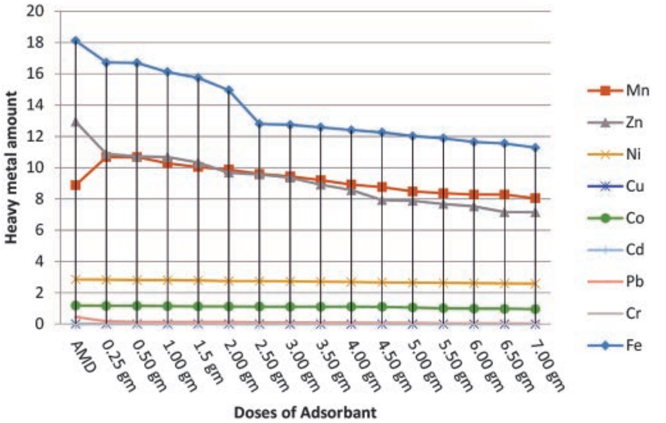

Fig.13

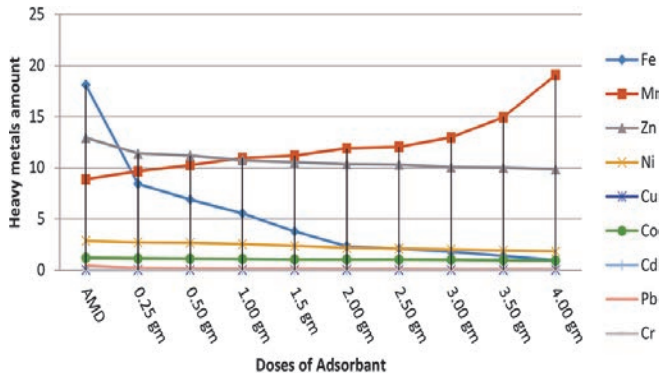

Fig.14

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